HANDBOOK

ON

ENVIRONMENT STATISTICS

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Foreword

The rapid pace of economic growth in the Asian and Pacific region has been accompanied by resource depletion and environmental degradation. Air and water pollution, water scarcity, desertification, and the depletion of natural resources are beginning to have an adverse impact on almost all forms of economic activity by causing frequent disasters such as floods and landslides, and generally diminishing the quality of life in the region. To address those problems, a broad-based program of environmental policies and regulations is needed. Such programs require that countries collect and compile authentic environment data for use by government officials and other decision makers. Data relating to existing environmental conditions is crucial for environmental planning and decision making. The developing countries of the region will therefore need to vigorously collect and collate environment statistics on an urgent basis.

In 1995, the Asian Development Bank (ADB) initiated the Regional Technical Assistance (RETA) for Institutional Strengthening and Collection of Environment Statistics in 11 selected developing member countries (DMCs) of the Asian and Pacific region. The objective of the RETA was to assist the countries in improving the collection of environment statistics. In 1999, ADB extended the RETA to five Central Asian DMCs, including Mongolia.

In the process of implementing the RETAs, it was felt that methodologies in the field of environment statistics were relatively new and not adequately developed. New concepts are emerging and many definitions remain ambiguous or otherwise lack broad agreement. Moreover, environment statistics is a new subject for statisticians working in a national statistical office (NSO), who have been traditionally involved in collecting and disseminating economic and social statistics. Thus, a handbook on environment statistics is needed to assist NSOs in collecting and compiling environment statistics.

By drawing on the experiences of the 16 countries in the Asian and Pacific region as well as on the works of the OECD, UN, World Bank, and some industrialized countries, the authors developed a series of statistical tools to monitor air and water pollution and to measure environment conditions relating to human settlements. The Handbook also gives a detailed discussion of certain methodological issues relating to the measurement of environmental pollution and environment quality. It contains a number of recommendations that should help in planning and designing a system of environment statistics. The discussion in the Handbook is aimed primarily at practitioners in countries that either have recently begun to collect environment statistics or are still at an early stage of the program.

The publication of the Handbook is the first attempt to address some of the existing methodological gaps in the field of environment statistics. It should be a useful guide to statisticians, environment experts, and government policy makers in their effort to develop a system for collecting environment statistics in the developing countries.

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Contents

List of Tables

List of Figures

Abbreviations

AAS	atomic absorption spectrometer
ADB	Asian Development Bank
BOD	biochemical oxygen demand
CES	compendium of environment statistics
CFC	chlorofluorocarbons
CO	carbon monoxide
CO_2	carbon dioxide
COD	chemical oxygen demand
DO	dissolved oxygen
ECE	Economic Commission for Europe
EI	environmental indicator
ESCAP	Economic and Social Commission for Asia and the Pacific
EU	European Union
FAS	ferrous ammonium sulfate
FDES	framework for development of environment statistics
FID	flame ionization detector
GDP	gross domestic product
GEMS	Global Environment Monitoring System
GHG	greenhouse gases
H_2S	hydrogen sulfide
ISIC	International Standard Industrial Classification
MPN	most probable number test
N	nitrogen
NDIR	nondispersive infrared technique (for monitoring carbon monoxide)
NGO	nongovernment organization
NH_3	ammonia
NO	nitric oxide

NO_2	nitrogen dioxide
NO_x	oxides of nitrogen
NSO	national statistical office
O&G	oil and grease
OECD	Organisation for Economic Co-operation and Development
P	phosphorus
Pb	lead
POC	persistent organic compounds
ppm/C	parts per million by carbon
ppm/V	parts per million by volume
PSR	pressure-state-response framework
QA/QC	quality assurance and quality control
RETA	regional technical assistance
SNA	system of national accounts
SO_2	sulfur dioxide
SO_4	sulfate
SO_x	oxides of sulfur
SOE	state-of-the-environment report
SPM	suspended particulate matter
TDS	total dissolved solids
TEOM	tapered element oscillating microbalance
TFE	tetrafluoroethylene
TKN	total Kjeldahl nitrogen
TSS	total suspended solids
UN	United Nations
UNCHS	United Nations Conference on Human Settlements
UNEP	United Nations Environment Programme
UN-FDES	United Nations Framework for Development of Environment Statistics
USEPA	United States Environmental Protection Agency
UVF	ultraviolet fluorescence
VOC	volatile organic compound
WHO	World Health Organization
WMO	World Meteorological Organization

1

Summary and Highlights

Environment data ranks alongside economic and sociodemographic data as one of the three major branches in most national statistical systems. The environment is the newest of the three subjects, but it has quickly become a sprawling field of loosely related topics and no single publication can effectively address all aspects. This Handbook therefore adopts a pragmatic approach. The discussion is primarily aimed at practitioners in countries that have recently begun to collect environment statistics or are still at an early stage of the program.

The Handbook has six chapters. The discussion in this chapter singles out some of the more important recommendations and highlights several critical features of environment statistics. Chapter 2 deals mainly with organizational matters such as the choice of a framework for planning and guiding the development of a program of environment statistics and the preparation of supporting publications. Chapter 3 considers two versions of a statistical framework and describes the rationale for each. In Chapter 4, the design and operation of networks to monitor air quality are discussed, along with the most common parameters included in this exercise. Methods of identifying emission sources and estimating emissions are also surveyed. Chapter 5 addresses the quality and availability of water. Various types of networks and parameters to monitor water quality are discussed, along with methods of gathering data on the discharge of effluents from different sources. Statistics on human settlements are summarized in Chapter 6.

The challenges posed by environment statistics are generally greater than for most other types of statistics. Several reasons for this complexity are discussed in Chapter 2 of the Handbook. Most significant perhaps is the fact that a national statistical office (NSO) must rely heavily on other agencies to collect and supply the bulk of the primary data. Such a high degree of interdependence between different government bodies demands close cooperation and collaboration. Lacking these attributes, any program of environment statistics is likely to fail. Other salient characteristics of environment statistics are the unique methods of collecting data, the distinguishing characteristics of the primary data, limitations of the statistical classifications and systems used, and the dynamic nature of the users' information requirements.

A number of recommendations should help in planning and designing a system of environment statistics. One of the most crucial steps, which is described in Chapter 2, is the creation of a steering committee to oversee all phases of the work. This body should be established before the program of environment statistics is launched. Its main purpose is to promote cooperation, prevent interagency disputes, and encourage the smooth flow of information. Another important function is to monitor the changing data requirements of policy makers and ensure that these needs are consistently met. The committee could be cochaired by the environment ministry and the NSO, and should also include several high-ranking officials representing the users of environment statistics.

A second critical decision is the choice of a framework that will help to determine the division of labor and organization of the work. Several versions are discussed in Chapter 3 of the Handbook, with particular attention to those developed by the Organisation for Economic

Co-operation and Development (OECD) and the United Nations. In practice, countries do not adopt one particular framework and discard all others. Different versions can be used in the same country, sometimes simultaneously.

An appropriate framework is a powerful tool that should guide decisions on the processes of collecting, estimating, and interpreting data; determining efficient ways to organize the data around key issues and topics; and identifying topics to be addressed. No single framework can adequately depict the intricate and constantly changing network of relationships that are found in the environment. Any version necessarily introduces some simplifications, indicating that certain aspects of reality are not accurately represented.

When a program of environment statistics is at an early stage, a relatively simple but flexible framework is necessary. As the program matures and becomes more comprehensive, a more sophisticated framework can be adopted. The United Nations Framework for Development of Environment Statistics (UN-FDES) is the framework recommended for newcomers to this field. It draws on some concepts developed by OECD, but depends on no particular scheme of statistical classification or particular methods of data collection. A step-by-step account of the construction of an FDES is found in Chapter 3. Statisticians can use this material as a starting point, but will have to introduce additional variables or otherwise modify the sample tables to ensure that the environmental concerns of their country are accurately depicted.

All too often, countries that are new to the field of environment statistics treat the issue of data dissemination as an afterthought or assign it a low priority. Such an approach can have serious consequences. Public officials must be able to track environmental changes before they can develop an effective set of policies. They will require additional information to monitor compliance and enforcement. Even in industrialized countries, there is a tendency for each agency to focus on its own information requirements and give little thought to the needs of the larger data-using community. A computerized inventory of environmental data, sources, and publications can encourage cooperation, provided that such inventory is accessible to all potential users.

An aggressive program of data dissemination may seem to be a particularly radical step in transition economies where, historically, the State controls much of the economy. In the past, officials in many centrally planned economies were reluctant to allow the circulation of many types of statistics. Today, however, information systems must satisfy new functions in which the State monitors and regulates market-based economic activities. The widespread dissemination of data is essential if information systems are to contribute to environmental improvements and sustainable development.

Nor can the public be excluded from these information flows. Access to environmental information should extend beyond government ministries and agencies to include non-government organizations (NGOs) and the general public. Two publications are discussed in Chapter 2 and recommended for recurrent distribution. These are the state-of-the-environment report (SOER) and the compendium of environment statistics (CES). The SOER is designed for a wide audience, including the general public, while the CES is aimed primarily at users of the data.

Once the collection of environmental data has begun, a huge amount of data can be generated in a surprisingly brief period of time. This problem, too, must be anticipated. Statisticians need some ready means of accurately summarizing the underlying trends in the raw data. A number of environmental indicators, many of them developed by OECD, are used for this purpose. These indicators, which are described at some length in Chapter 3, are intended to reduce the volume of data required to obtain an accurate picture of a situation and to facilitate communication between statisticians and data users.

Most likely, only a few of the indicators discussed can be easily and readily incorporated into a new program of environment statistics. The distinction between different indicators can quickly become blurred, owing to conceptual difficulties and ambiguities in interpretation. Data gaps and inaccuracies are other problems that can force statisticians to find proxies for several of their preferred indicators. Officials in the NSO will have to work closely with data suppliers in other agencies to develop an informative set of environmental indicators. At the same time, the collection effort must be gradually expanded to produce more accurate proxies and, eventually, the preferred indicators themselves.

Once a statistical framework and an overall plan for the program are in place, attention turns to more detailed matters such as methods of collection and sampling. The tasks of gathering and interpreting data on the quality of air and water are two of the most important topics in any environmental program and are discussed at some detail in Chapters 4 and 5. Marked differences between the two media influence the strategies and procedures for collecting raw data. Air is a continuous medium, but water consists of various submedia–for example, watercourses (ranging from brooks and streams to large rivers), lakes, groundwater resources such as aquifers, and saltwater bodies. Each of these submedia has its own particular set of attributes and the appropriate methods of gathering data vary from one to the next.

The design of networks to monitor the quality of air and water is a critical feature of the overall program, and considerable attention is devoted to this subject. The available financial resources and human skills are the major constraints, but a host of other factors must also be taken into account. When monitoring air quality, officials must choose from a wide range of options involving anything from a "minimum network" to a flexible approach, or a rather dense network of monitoring stations. The number of possibilities is even greater in planning a network to monitor the quality of water, since the design must be tailor-made to accommodate the characteristics of specific submedia (for example, groundwater, river systems, lakes, and so on). Moreover, any network, however well designed, is unlikely to yield sufficient data to produce the types of representative indicators that public officials require. The information will have to be supplemented with the use of estimation procedures and, perhaps, special surveys to fill in the data gaps.

Among the many factors that must be taken into account in the design of a network, the most important are the parameters to be monitored and the sampling frequencies. The most common parameters for both air and water are described in detail. Statisticians may have to augment this list, but most parameters that would be included in a regular monitoring program are considered in the Handbook. Methods for collecting and estimating data are recommended and descriptions of the types of equipment required and the laboratory procedures are provided.

Finally, the networks to monitor the quality of air and water will have to be supplemented by a variety of other tools and procedures. Public officials, for example, cannot assemble an effective set of policies to improve the quality of air or water without a clear idea of the types of emissions being released into the atmosphere and the major sources of these emissions. Emission inventories will have to be constructed, and several options are outlined in the Handbook.

In conclusion, the primary objective of this Handbook is to improve and expand the exchange of information between statisticians and the many other specialists who contribute to a program of environment statistics. Recent experience suggests that misunderstandings and breakdowns in communication between these groups are a major source of difficulty, restricting the flow of information and undermining the quality of data. The problem seems to be especially serious for countries at an early stage in the development of environment statistics. Accordingly, the material in this Handbook is designed to help bridge the gap between different groups of contributors. Statisticians, for example, need a basic understanding of the procedures and methods for collecting data, and of problems encountered by the engineers and technicians who supply much of the raw data. The latter groups must also have an appreciation of statistical procedures and classifications.

2

Organizing a Program of Environment Statistics

International work on environment statistics has a comparatively brief history, dating back only three decades. Because environment statistics is relatively new, there are frequent requirements in methodologies, measurement techniques, and other procedures. Meanwhile, the rapid emergence of new concerns and environmental threats is expanding the field's boundaries. Statisticians must therefore deal with a constantly changing set of demands while incorporating new and often more complex procedures into their normal routine.

Countries that have just begun to develop their own programs of environment statistics will encounter both advantages and disadvantages relative to those that have gone ahead of them. The former can draw on the experience of their predecessors by adopting classifications, methodologies, and techniques that have already been tested elsewhere. However, the dynamic nature of environment statistics means that the start-up is a more complicated undertaking today than it was only a decade ago. The range of skills needed goes far beyond conventional areas of statistical expertise, while much of the information must be obtained from groups outside the NSO. The collection of environment statistics therefore requires an unprecedented degree of interagency cooperation and collaboration between the NSO and data suppliers in other government bodies (federal, regional, and local) and research institutes.

This chapter describes some of the unique characteristics that distinguish environment statistics from other statistical fields. The complexities of this data and the huge amounts of information that may soon be generated or sought by policy makers require that the work be organized according to some simple principles at a very early stage. Several types of framework for organization are briefly described. Methods for disseminating data are also discussed in this chapter, and the broad outlines for two recurrent publications are summarized.

Distinguishing Features of Environment Statistics

The official statistics of most countries consist of three major branches or fields. These are economic statistics, social and demographic statistics, and environment statistics. The three fields overlap to some extent. For example, a portion of the country's economic and social statistics can be used in developing an official set of environment statistics. Adjustments, recalculations and reestimations will be required, however. The extent of overlap varies from country to country, but is unlikely to be substantial in any case. Generally, the addition of environment statistics will significantly expand the scope of official statistical activities.

Environment statistics is also proving to be a especially challenging field because of its unique nature. One crucial distinction is found in the procedures for collecting data. Economic and social statisticians collect the data they require by making use of official registers of firms and relying on censuses and field surveys of enterprises and households. The same tools are not available in the environmental field. Instead, much of the raw data is obtained from networks of monitoring stations that depend on instrument readings and from other collection activities conducted by sources outside the NSO.

This distinction has two important consequences. First, the NSO faces the relatively unfamiliar task of developing channels of communication and data exchange with other national agencies. This dependence on outsiders is typically greatest in the first years after the launch of an environment program. Even in developed countries, a sizeable portion of the data is not generated by the NSO. Second, national statisticians must have a clear understanding of the collection techniques and procedures used when the data is first gathered. Outside agencies collect information to fulfil their own mandates and the results rarely (if ever) coincide with the requirements of the NSO. The raw data must almost always be reorganized or adjusted so as to meet accepted standards and classification schemes. Such tasks are not possible without a thorough knowledge of the original concepts and methods of data capture employed by each external supplier. Thus, the supply of raw data to the NSO must be accompanied by a great deal of supplementary information (generally known as "meta-data") regarding concepts, definitions, procedures, and related operations. This requirement is a continuous one, but difficulties can be minimized if a high level of cooperation can be maintained and if external suppliers have a good understanding of the standards followed by the NSO.

A second distinguishing characteristic is the lack of a precise system to compile and record environmental data. The contrast is perhaps sharpest when environment statistics are compared with the System of National Accounts (SNA). The SNA is an intricate system founded on a generally accepted model of economic exchanges and flows and is supported by a standard set of concepts and definitions. Relationships between different parts of the SNA are clearly specified in terms of accounting identities, and parts of the systems can easily be aggregated or disaggregated. No equivalent system exists for environment statistics.

The types of information sought in environment statistics, the definitions, and the concepts are too diverse to allow the construction of a formal system such as the SNA.

In addition to lack of a true statistical system, data on the environment exhibit a number of properties that pose unique problems for the NSO. Most of these properties can also be found in other statistical fields, but are more pronounced in this case. They include the following:

(i) The amount of data screened by the NSO may be voluminous owing to the use of satellite imagery or the capture of raw data from continuous monitoring equipment.

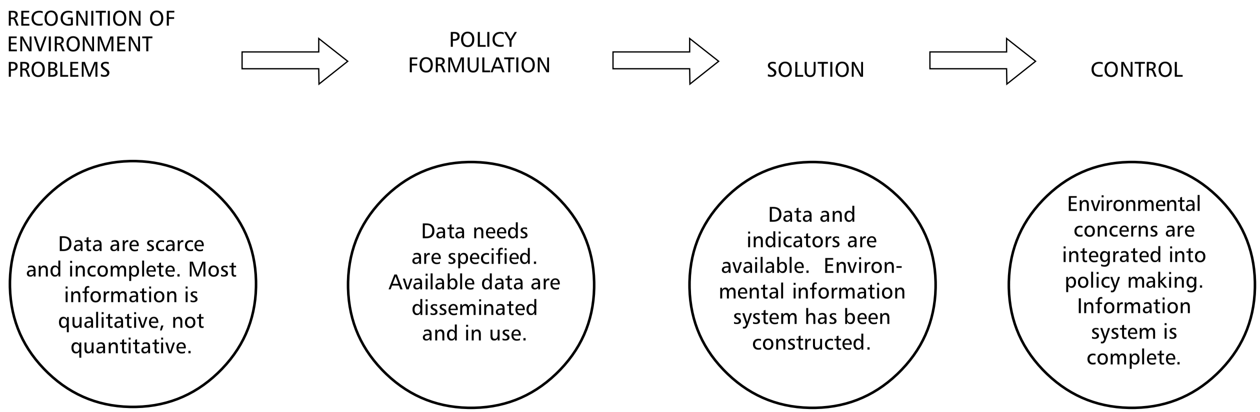
(ii) The data obtained from sources outside the NSO may give rise to conflicts involving computer hardware and software, and methods for selecting and organizing data.

(iii) Environmental data can be very specific with regard to location (the point of collection) and the precise time when the observation was made. A complicating factor is that natural spatial units seldom coincide with administrative boundaries. The interpretation and significance of such data can be problematic and will require a large amount of supporting information.

(iv) To detect significant environmental changes, the data must typically span longer time intervals than those for socioeconomic statistics.

Finally, the data needs of policy makers change markedly over time and the operations of the NSO will have to adapt as a country's network of environmental policies and regulations evolves. The driving force behind these changes is sometimes described as an environmental policy cycle (Figure 2.1). In the "recognition stage," problems are identified and begin to appear on the political agenda. Data, however, is scarce and little, if any, is collected solely for the purpose of monitoring environmental

Figure 2.1: The Policy Cycle and the Changing Role of the NSO



NSO = national statistical office.
Source: Adapted from UN Statistical Division (1999).

changes. In fact, most of the available information will be qualitative rather than quantitative. At this early stage in the program, the NSO will need to make an inventory of the available data, assess their quality, and compile supporting information (meta-data). The outcome of this exercise may take the form of a compendium of environment statistics (CES), which is discussed later in this chapter.

In the second stage, a plan for the development of environment statistics is formulated. The plan, which is based on conditions within the country, should specify several tasks. These include (i) methods of using existing data, whether collected by the NSO or external bodies; (ii) strategies to produce additional data in a timely and cost-effective manner; and (iii) plans to promote the harmonization and integration of data. Once the country has entered the third or "solution stage," environmental policies and an environmental information system will be in place and various types of statistics will be available. In the fourth and final stage, the program becomes part of the day-to-day routine of the NSO. Direct and immediate problems are under control. The focus can then shift to more detailed matters, although issues such as data compatibility and integration will continue to demand attention.

Today, most countries that are members of the OECD are thought to have reached the third (solution) stage in the policy cycle. Environmental pollution in general is regarded as being contained, but specific concerns are not fully integrated into the policy-making apparatus and various issues relating to the use of resources and other economic or societal concerns have not yet been resolved. In contrast, the majority of developing countries are still in stage one or two and are unlikely to reach stage three for a number of years.

In conclusion, environment statistics depend on a rather elaborate network for data collection that involves several agencies and institutions. The statistics being collected are unique in many ways and the information requirements of policy makers change over time. Coordination is essential if such a program is to succeed. The creation of a steering committee should therefore be one of the first steps taken once a decision is made to launch or expand the program of environment statistics. The committee could be cochaired by the environment ministry and the NSO, but should also include several high-ranking officials who have no direct affiliation with the function of collecting data but represent the community of data users. The committee's main purpose is to promote cooperation, avoid interagency disputes, and ensure that information flows smoothly.[1] As the program matures, the committee will also need to monitor the changing data requirements of policy makers to ensure that they are being met.

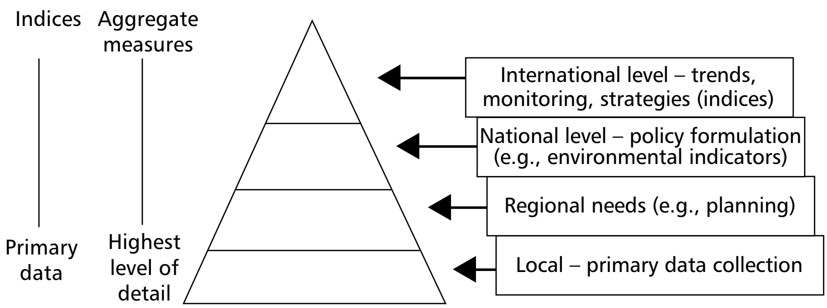
The Environmental Framework and Environmental Indicators

The complexities of environment statistics pose immediate challenges for countries new to the field. An urgent task is to introduce some order out of this chaos by organizing the work according to some simple principles. One of the first decisions to be made is the choice of a framework for organizing the statistics by type of data, level of aggregation, environmental issue, and so on. In practice, countries do not adopt one particular framework and exclude all others. Different versions can be used in the same country, some of them simultaneously. Several alternatives are described in this section.

The information pyramid. Environment statistics can be organized into several layers, as in a pyramid with a very wide base. At the base of the pyramid is all the primary data, and the apex represents the most aggregate or summary measures such as environmental indices. The arrangement in Figure 2.2 shows a pyramid with four layers of data distinguished according to the level of aggregation. Policy makers are the main users of all these statistics, but they have different requirements, depending on the scope of their responsibilities. The four layers in the

[1] The committee will need to establish working groups to deal with specific issues of a relatively technical or detailed nature. Examples might be working groups for statistical information and methodologies (possibly chaired by a senior statistical official), for access to environmental information, and for technical issues such as meteorology and information technology.

Figure 2.2: Statistical Categories and Users' Needs



pyramid correspond to users' information needs at the local, regional, national, and international levels. The statistics at each level are interrelated. Information at the lower layers of the pyramid can be used to construct measures for national or international comparisons. The primary data forming the base of the pyramid is not only the most voluminous set, but also the most detailed. For example, primary data for water could include daily measured concentrations of key pollutants taken from a river sampling station. Other primary data for the river might include the volume and rate of flow, water temperature, dissolved oxygen, suspended solids, and so on. Such information would be relevant to local officials, but is likely to be of limited use to those with broader responsibilities.

The second layer of the pyramid consists of analytical data, which has been generated by consolidating the primary data. Analytical data for the river referred to may include annual averages, measures of variance, and totals for each water parameter. Primary data can also be combined to obtain information on the pollution load of the river (for example, by combining data on pollutant concentration with the volume and rate of flow). Thus, two elements of analysis are likely to be found in this layer: (i) data aggregation (that is, averages obtained from individual measurements or other representations of patterns in time and space), and (ii) data combinations (combining two or more parameters to create a new measure).

At the third and fourth levels of aggregation, environmental indicators and indices are constructed from the underlying primary and analytical data. For example, emissions of carbon dioxide (CO_2) from an individual source may be of interest to local authorities, but this statistic is of little use at the national level. Instead, national policy makers may require an estimate of CO_2 emissions per unit of gross domestic product (GDP) so as to determine the appropriate regulatory measure. The primary and analytical data found in the first and second layers of the pyramid must be reformulated and aggregated to serve the needs of national authorities.

The work of constructing these aggregate measures can be difficult, since the results must be analytically sound and comprehensive, yet easily understood. One complicating factor is that the building blocks used to derive these measures are disproportionately large compared with the small number of key indicators and even smaller number of indices desired. Another is that it is often unclear who or which agency is in charge of consolidating the huge amounts of separately collected primary and analytical data to come up with the aggregate measures represented by the two top layers of the pyramid.

A framework based on environmental media. One of the simplest types of available frameworks makes use of the notion of environmental media. Data are collected and organized to describe conditions in each of several environmental media such as air, water, land, and soil. This method of organization is popular because it coincides with traditional scientific disciplines and because many government institutions are organized along similar lines. Another advantage is that statisticians can make use of any existing data, which have already been compiled according to environmental media.

However, a media-based approach has drawbacks. First, the framework only describes existing conditions or problems in a specific medium. It provides no information on the forces responsible for these conditions or how the problems may be addressed. Nor does the framework promote the development of statistics that shed light on the linkages between different media–for example, pollution of the air or soil that eventually finds its way into the country's water system. Most researchers are specialized in just one medium. They tend to ignore relationships between their own field of specialization and other media, and a media-based framework reinforces this bias. Despite these drawbacks, the popularity of a media-based framework has been sustained. The practical reason for its success is that environmental condition and consequences are usually best examined in terms of specific media.

A resource accounting framework. This approach relies on methods of resource accounting to track the life cycle of a resource. Data is organized so that users can monitor the stocks and flows of a particular resource, the commodities into which the resource is converted, the waste generated as a result of resource/commodity conversion, any recycling procedures that may be used, and the deposition of waste in the environment. In principle, a resource accounting framework should allow analysts to determine the optimum use of resources with minimum environmental degradation. Such a framework is useful, but it requires large amounts of data from many sources and a high level of coordination between a large number of government agencies.[2]

A pressure-state-response framework. A number of different approaches fall into this category. A pressure-state-response (PSR) framework is intended to help identify human activities that inflict damage on the environment or place it under significant stress. The precise meaning given to each of the three stages (that is, pressure, state, and response) can vary, depending on the particular version of the framework in use. The general line of reasoning, however, is that human activities exert pressures on the environment. These pressures, in turn, change the state (or quality) of the environment and alter the quantity of natural resources. Ultimately, changes in the state of the environment prompt responses by society. Responses are intended to rectify specific environmental problems and may include the imposition of new public

[2] For a comprehensive discussion of the resource accounting framework, see UN (1993).

policies and regulations, or changes in the overall pattern of economic activity that are introduced by the government, households, or businesses.

Statisticians employing this approach frequently assume that the three stages represent an identifiable sequence of events or line of causation. Each human activity creates a pressure which, in turn, alters the state of the environment and leads to a specific response by some part of society. This line of reasoning has been criticized by some who argue that it is an oversimplification of the real world. A PSR framework implies the existence of a one-to-one relationship between each of the three stages. In reality, however, these relationships are more complicated.

The United Nations framework. The UN framework, known as the UN-FDES, combines the PSR approach with a list of environmental concerns that closely correspond with the media approach. The UN-FDES does not specify statistical parameters or indicators. Nor does it depend on a specific classification or on particular methods of collecting data.

Rather than attempt to construct a very specific or detailed set of procedures, developers sought to create a framework that allows countries to focus on their own specific set of environmental problems without overtaxing a partially developed statistical system. The UN-FDES is sufficiently flexible to permit statisticians to monitor all unique features of their country, while still providing a basis for international comparison. However, this concession to flexibility is not without costs. There is a loss of precision in the specification of linkages between pressure, state, and response; in the ability to aggregate primary data; and in the underlying accounting relationships. Once countries reach an intermediate stage in the development of their program of environment statistics, they may opt for a more elaborate approach than that of the UN-FDES.

An ecological approach. An ecological approach to data organization also draws on the notion of pressures, state, and response (PSR), but applies these concepts to ecological zones within the country. This practice distinguishes the ecological framework from the traditional PSR model, since the latter usually identifies the effects of human activities according to their impact on environmental media such as air or water. The attraction of the approach is that ecological zones offer a natural way of classifying issues and problems. The classification, however, is both complex and unique to specific regions within the country. The boundaries of an ecological zone will rarely, if ever, coincide with provincial borders or other forms of geographic breakdown that have legal or governmental status. The use of ecological zones to classify data also makes comparisons between countries difficult.

This list of alternative frameworks is by no means exhaustive. Other options include methods of environmental accounting, geographic information systems that present data in a spatial context, frameworks that make use of various types of economic models, and so on. These options are not discussed in this Handbook, primarily because they are relatively complex or are meant to fulfil specific purposes. Such complex frameworks are usually employed in countries that have been collecting environment statistics for several years. The reader who is interested in learning more about other types of frameworks not discussed here can consult the list of readings at the end of this Handbook.[3]

Planning Forms of Disseminating Data

Environmental data will generally be of interest to several types of readers. Policy makers are perhaps the most important users, but researchers, the general public, and international institutions also have need of this information. Over time, various publication forms have been developed to meet these needs, and a decision on methods of disseminating data should be made at an early stage in the statistical program.

One of the publications that will typically be a cornerstone of any new program of dissemination is the compendium of environment statistics. A CES typically contains analyzed data (such as time-series statistics, computed averages, and aggregates) rather than primary or raw data. Thus, CES focuses on presenting a holistic picture of the overall environmental status of a country without going into elaborate narrative

[3] For additional description and sources, see UN Statistical Division (1999), Chapter 1.

explanation or interpretation of the impacts of every natural event and economic activity on various environmental components. There is no fixed or rigid format for the CES. Most compendiums, however, are intended to serve as a reference or source of information. They present basic data that has been organized according to topics determined when the choice of a framework was made (for example, environmental media, or pressures, state, and responses). No attempt is made to integrate data across subjects or to construct higher level measures such as environmental indicators.

The compendium is usually prepared by the NSO and is intended to be a faithful, but passive presentation of the data available. In other words, the publication is strictly objective; no specific conclusions or judgments are made since such observations are not the responsibility of the NSO. The bulk of the publication will consist of data. Explanatory text accounts for less than half the publication and serves limited purposes such as a description of the phenomena behind the data, cross-references between different statistical items, and indication of the data limitations.

A typical CES may be composed of three chapters. The first chapter generally contains information on the country's physiography, biodiversity, and socioeconomic conditions, as well as an overview of environment statistics. Also included in the first chapter would be a description of each major subject appearing in the framework adopted by the NSO. For example, if the framework is based on environmental media, the chapter will have a brief description of each of the six media (atmosphere, water, land/soil, flora, fauna, and human settlements). The second chapter will consist of detailed tables to support the text in the first chapter. The contents of the second chapter could readily serve as a database. The third chapter will contain several appendices indicating the sources of information, the methodologies employed to collect data, and the relevant environmental legislation. Appendix 1 of this Handbook gives the outline of a CES as described here. For a more elaborate version, the reader may consult the international compendium published by OECD (1999a).

A second publication known as the state-of-the-environment report (SOER) is usually less data-intensive than the CES and tends to focus more on environmental problems or concerns that capture the attention of policy makers and the general public. Often, publication of the SOER begins before the preparation of the CES, but both publications are recurrent and represent major components of any dissemination program. The goal of the SOER is to raise awareness of environmental problems, rather than to provide the sort of general and neutral information found in the CES. Emphasis is on the presentation of trends and the use of graphs rather than tables. The SOER should have ample discussion of problems and the underlying trends, in part to compensate for the lack of information that usually persists at the early stages in the development of the program. The SOER is usually published by an environmental agency in the government. Over time, the contents of both the CES and the SOER tend to become more sophisticated as the underlying database improves and as attention focuses on specific concerns and problems.[4]

[4] In addition to consulting the general outline for a CES in Appendix 1, readers may refer to some of the many published versions of a CES prepared at the national level. Another useful publication that deals with several Central Asian countries is ADB (1997).

3

A Framework for Environment Statistics

The choice of a framework on which to base a program of environment statistics is a pivotal decision that will influence all subsequent phases of the work. This chapter begins with a discussion of the pressure-state-response (PSR) approach, which is the inspiration for several different frameworks. The UN-FDES is recommended as a starting point for countries that have recently embarked on a program of environment statistics. The various components of this framework are examined in some detail. At a later stage, countries may wish to adopt a more elaborate type of framework. The OECD's version of an environment statistics framework is also discussed in this chapter. Finally, statisticians must find ways to summarize the huge amounts of primary data that can be generated even at the early stages of the program. Environmental indicators are used for this purpose and a number of these measures are presented in this chapter.

Purpose of the Framework

No framework can adequately depict the intricate and constantly changing network of relationships that exists in the environment. Each version necessarily introduces simplifications, meaning that some aspects of reality are not accurately represented. The benefits, however, will usually outweigh the costs. Policy makers and analysts can still make rational decisions even though their information about any particular environmental problem or chain of events is incomplete. In fact, most of the decisions reached by government officials, whether dealing with the environment or other matters, must be made without complete information. In the case of the environment, the degree of uncertainty will vary, being greatest for broad issues such as global warming and climate change. Uncertainty will be less when attention turns to specific national issues and declines even further when the focus is on regional or local concerns.

A framework will be especially useful in the process of assigning priorities to various environmental issues. The severity of environmental problems varies widely from country to country and the adoption of a framework should help statisticians identify the issues of greatest importance for their country. Pollution, for example, is a concern everywhere, but it usually receives a higher priority in rich countries than in poor ones. In countries where the economy is dominated by agriculture or natural resources, issues relating to land conservation and resource depletion may loom large. In arid climates, water quality and availability are prominent issues. The significance of particular environmental problems also changes over time and this, too, must be reflected in the statistical program.

A framework can also be of help in reaching decisions on a number of organizational matters, such as

(i) agreement on the overall process of data collection, estimation, and interpretation;

(ii) determination of logical ways to organize the data around key issues and topics;

(iii) identification of important issues for which data is lacking;

(iv) clarification of the responsibilities for collection and reporting on specific topics, and agreement on the division of work between the NSO and other data suppliers.

When a program of environment statistics is first launched, statisticians usually choose a relatively simple type of framework as the basis for their program. However, the selection of any specific framework does not mean that all other versions are automatically excluded. Over time, the scope and detail of environment statistics expands and another framework may eventually be more suitable. Sometimes, a country may even use different versions simultaneously. Even within a particular publication, the framework can change from chapter to chapter.

The OECD Framework

The OECD has developed a framework based on the PSR approach, which was cited in Chapter 2. This approach is used in all OECD member countries, and parts of the framework are also being applied in other countries in East Europe and Central Asia. The OECD framework is based on two key assumptions. The first is that there is a direct line of causation, running from environmental pressure to state of the environment to societal response. Second, there is a one-to-one relationship linking each environmental pressure to a particular change in the state of the environment and to a response by society.

As with many other types of economic analysis, these assumptions oversimplify conditions in the real world. Simple, clear-cut, one-to-one relationships between cause and effect are rare. A new pressure on the environment may damage the quality of the air, water, or soil in numerous ways. Likewise, several distinctly different types of environmental pressures can have a concentrated effect on one environmental medium. Multiple relationships of this sort are also common among the responses of society. For example, a number of policies and/or regulations may be required to address a particular environmental problem, while in other cases a single policy will be an appropriate remedy for a multitude of pressures. The list of examples could be extended, but the underlying point is clear. Frequently, the cause-and-effect relationships that prevail in the real world are not one-to-one but many-to-many, and are sometimes too complicated to depict in any framework.

An overview of the OECD version is given in Figure 3.1. Human activities make use of environmental resources (air, water, land, and natural resources) and generate environmental pressures, which can be observed in various economic sectors such as energy, industry, or agriculture. Responses to environmental pressures come from "economic agents," which may include government (national, provincial, or local), households, and business enterprises. Links between the three stages depend on information flows. Economic agents receive information on the types of pressures being generated as well as on the state of the environment. The agents then formulate responses that may be directed at a particular economic sector or environmental medium.

A critical feature of the OECD framework is the information flows pictured in Figure 3.2. Different sets of environmental indicators have been developed to measure pressures, assess the state of the environment, and gauge society's responses. Other indicators are used to report on the state of the environment and to evaluate environmental performance. A core set of indicators has also been specified for regular data collection, together with environment-related indicators for each of several economic sectors (agriculture, transport, industry, and so on). Finally, the OECD has developed an extensive set of definitions and supporting examples for each type of indicator.[5]

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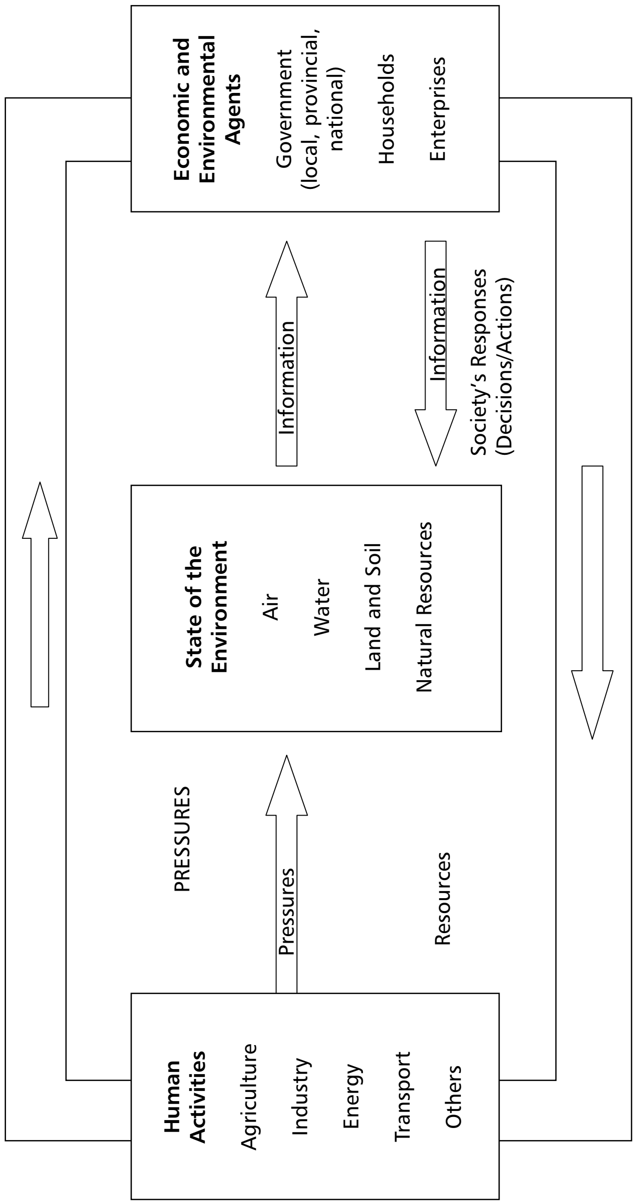
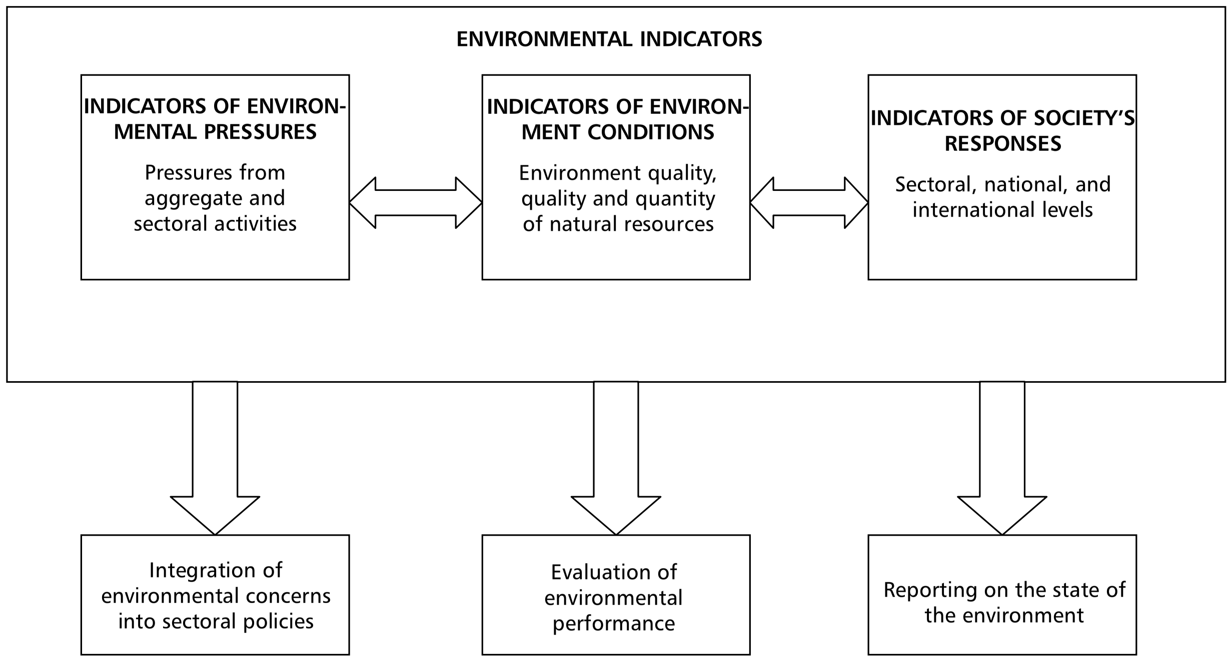
[5] For more information on the PSR framework, see OECD (1993).

Figure 3.1: OECD's Pressure-State-Response Framework



Source: OECD (1993).

Figure 3.2: Environmental Indicators in the OECD Framework



Source: Adapted from OECD (1993).

Clearly, a great deal of thought has been given to the formulation and interpretation of all these environmental indicators. The OECD program has made much progress, but it also demands much in the way of data collection and manipulation (that is, construction of indicators, indices, and related measures). Because these requirements can be extremely challenging for a country just entering the field, a simpler alternative, the UN-FDES is recommended as a starting point.

The UN Framework for Development of Environment Statistics

The framework developed by the UN combines the PSR approach with a list of environmental concerns that closely correspond with the environmental media approach mentioned in Chapter 1. The UN-FDES does not require a specific set of statistical parameters or indicators. Nor does it depend on a specific classification scheme or a particular method of collecting data. Instead, the framework is designed to be sufficiently flexible to permit statisticians to monitor all unique features of their country's environment while still providing a basis for international comparison. However, this concession to flexibility is not without costs. There is, for example, a loss of precision in the specification of linkages between pressure, state, and response; in the ability to aggregate primary data; and in the underlying accounting relationships. Once countries reach an intermediate stage in the development of their program of environment statistics, they may require a more elaborate approach.

Structure of the FDES

The FDES follows a building-block approach that allows the user considerable leeway in selecting the topics and variables. Table 3.1 shows the overall structure of the framework. In this particular example, six environmental media or components (flora, fauna, atmosphere, water, land/soil, and human settlements) are singled out for attention. The table also identifies four information categories, which are associated with each component.

Environmental components. The six environmental components shown in Table 3.1 are only illustrations. Statisticians may expand, modify, or rearrange the list to better reflect conditions in their own country. Another option is to single out various submedia. For example, water can be broken down into freshwater, marine water, or groundwater, while environmental issues relating to land and soil can be distinguished as surface or subsurface.

Farming, animal husbandry, forestry, and mining are all activities that are likely to have a significant impact on both flora and fauna. They may affect certain animal species, reduce or improve the quality of land, contribute to erosion or have other consequences. Industry, human settlements, and transportation can have an indirect negative impact on these components as a result of emissions and discharges into the air and water.

In the case of the atmosphere, the statistician may choose to distinguish between pollution at the global level and urban air quality at local levels. If this breakdown is followed, urban air quality can be included as a component of human settlements because of its local impact, while general atmospheric or "background pollution" is a key element of air quality. Atmosphere as a component could also be broadened to include air quality and climate. Obviously, the way the statistician chooses to describe the component and the submedia will determine the activities, impacts, and responses that will be included in the FDES.

A major concern arising from atmospheric pollution is the impact of acid deposition on biota and their habitat, resulting in the acidification of lakes, soils, and forests. Eventually, atmospheric pollution will affect the quality of inland water, soils, biota, and ecosystems. These issues have local, national, or transnational consequences, while other atmospheric concerns are of international significance. The latter include emissions of chlorofluorocarbons (CFCs) and their effect on the ozone layer and the dispersion of human-caused radiation in the case of nuclear accidents and weapons testing.

Water quality is a more complex issue than air quality since much depends on its uses. For example, nutrient-rich water may be beneficial to certain kinds of biotic life, but unacceptable for recreational and drinking purposes. A distinction is usually made between fresh and marine water and the problems will vary accordingly. Seacoasts and shorelines of large lakes are favored locations for highly polluting industries because they offer an "easy" solution for waste disposal. Finally, the contaminants of major concern are toxins such as heavy metals and pesticides, organic matter, nutrient loadings such as fertilizer runoff, deposits from acid precipitation, and pathogens such as coliform. The list is still growing with each discovery of new contaminants and their associated stress effects on human health and aquatic ecosystems. Only a fraction of contaminants are monitored on a regular basis.

If land and soil are distinguished according to surface and subsurface problems, the relationships between each component and the related activities, events, and responses are often more easily identified. A wide range of activities may affect surface soil, while mining and energy extraction usually have the most impact on subsurface conditions. Waste and wastewater discharges may alter conditions for both these submedia and the responses will vary accordingly.

Human settlements can impact on the environment in a multitude of ways. Population concentrations will often contribute to the pollution of water and land resources. Lack of basic services such as water treatment plants, garbage collection, and other essential amenities may be a serious problem. Rapid population growth, migration, and urbanization can exacerbate all these problems. Local air pollution, often due to the concentration of motor vehicles, is yet another prominent aspect of this component. Finally, the FDES in some countries takes into account the quality of housing as measured in terms of the existence of slums and dependence on substandard housing.[6]

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6 For more information on the role of human settlements, see Chapter 6.

Table 3.1: Example of a Framework for Development of Environment Statistics

	Information Categories			
Environmental Component	**Social and Economic Activities**	**Environmental Impact of Activity**	**Response to Impact**	**Inventories, Stocks, Background Conditions**
1. Flora	Agricultural and livestock production[a]	Proliferation, depletion, extinction of species	Protection of endangered species	Inventory of species and genetic resources
	Forestry and logging	Depletion/growth of forests and woodlands	Forest management, including afforestation	Inventory of vegetation cover
	Emissions hazardous to flora	Impact of pollution on vegetation cover (e.g., acidic precipitation)	Pollution monitoring and control	Inventory of emissions hazardous to flora
2. Fauna	Competing land uses[b]	Change of habitats/ ecosystems	Protection of habitat[c]	Inventory of land uses and characteristics
	Emissions hazardous to fauna	Human health and welfare impact[d]	Pollution monitoring and control	Inventory of emissions hazardous to fauna
3. Atmosphere	Land use affecting climate[e]	Biological and ecological impacts[f]	Promotion of alternative land uses and production processes	Emission inventory (types, sources of air pollution)

Table 3.1: Example of a Framework for Development of Environment Statistics (continued)

Environmental Component	Information Categories: Social and Economic Activities	Environmental Impact of Activity	Response to Impact	Inventories, Stocks, Background Conditions
	Emission of air pollutants from stationary and mobile sources[g]	Impact on health and welfare[h]	Health protection, monitoring and control	Socioeconomic factors affecting air quality[i]
4. Water				
a. Freshwater	Water withdrawal[j]	Water quantity, water levels, flow and supply	Conservation, development of water resources	Inventory of water resources
	Water use for industrial, municipal, agricultural purposes	Water quality[k]	Water treatment (primary, secondary, tertiary)	Land use, types of vegetation cover, soil types, vulnerability
	Wastewater and discharges	Biological and ecological impacts[l]	Pollution monitoring and water quality control	Emission inventory (types, sources of discharges, pollutants)
b. Marine water	Water withdrawal and use (desalination, consumption)	Biological and ecological impacts[m]	Pollution monitoring and control, conservation	Inventory of ecosystems
	Emissions from coasts, rivers, seadumping, oil spills	Human health and welfare impacts[n]	Health protection	Coastal land use and characteristics

Table 3.1: Example of a Framework for Development of Environment Statistics (continued)

Environmental Component	Information Categories: Social and Economic Activities	Environmental Impact of Activity	Response to Impact	Inventories, Stocks, Background Conditions
5. Land/soil				
a. Surface	Land use for agriculture, forestry, mining, settlements	Soil gain or loss, loss of agricultural land, erosion	Land use regulation, zoning	Inventory of land use, tenure, characteristics, topography
	Waste and wastewater discharges	Health and welfare impacts[o]	Waste disposal, pollution monitoring and control	Emission inventory for solid and liquid wastes
b. Subsurface	Mining and treatment of minerals	Depletion of reserves, open pits, waste disposal	Reclamation and rehabilitation of land	Inventory of mineral resources
6. Human settlements	Construction (residen-tial, non-residential) Emissions and waste discharges	Housing shortages, slum and squatter settlements Ambient concentration of waste and pollutants	Zoning, resettlement, community development Conservation of energy and water	Inventory of buildings, facilities Emission inventory (sources, types of pollutants)

[a] For example, land clearing, irrigation, grazing, use of fertilizers and pesticides.
[b] Agriculture, ranching, settlements, wildlife, recreation.
[c] Land-use regulations, zoning, national parks.
[d] Nutrition-related effects, changes in productivity and costs of livestock production, etc.
[e] Deforestation, desertification, drainage urban sprawl, infrastructure.
[f] Contamination, destruction of species, disruption of ecosystems by acidic precipitation, etc.
[g] For example, from industry, households, agriculture, transportation.
[h] Morbidity and mortality associated with air pollution, changes in productivity and costs.
[i] For example, population growth and density, urbanization, industrialization, patterns of production and consumption.
[j] Surface water, groundwater, other sources.
[k] Ambient concentrations of biological contaminants, chemical substances,and suspended solids.
[l] Eutrophication, contamination, destruction of biota.
[m] Depletion, extinction or contamination of marine biota, disruption of habitats/ecosystems.
[n] Waterborne diseases, impact on tourism and recreation, etc.
[o] Soilborne diseases, impact on productivity, and costs for agriculture, tourism, recreation.

Information categories. The four information categories in Table 3.1 imply some linkage between environmental problems and human activities or natural events. In general terms, the first three categories (columns 2, 3, and 4) represent a sequence of events involving action, impact, and reaction. The fourth category–inventories, stocks, and background conditions–gives supplementary background information.

Together, the four categories suggest–but do not assume–the existence of certain cause-and-effect relationships. The FDES does not insist on a one-to-one relationship between a pressure, the resultant stress, and the response of government or society. Its purpose is primarily organizational, rather than explanatory. The focus is on identifying and presenting data variables that should be useful in tracing and verifying interrelationships. In fact, several activities may be the cause of each impact. Agricultural activities, for example, may contribute to deforestation and soil erosion, but mining and forestry operations can also aggravate the impact on forests and soil. The implied sequence of pressure-state-response is not treated as an established fact, but rather as a challenge for statistical verification. A fundamental objective of the framework is to identify and organize various types of information that may be useful for tracing and verifying actual cause-and-effect relationships.

Socioeconomic activities represent the first of the four information categories in the framework. Human activities falling into this information category consist mostly of the production and consumption of goods and services, but can also include activities in pursuit of noneconomic goals. The environmental impact of all these activities results from the direct use or misuse of natural resources, or the generation of waste and emissions in production and consumption processes. Natural events may also be considered part of this category, although statisticians sometimes have chosen to treat such occurrences as a separate environmental component. In any case, natural events such as droughts, floods, earthquakes, and cyclones place a severe stress on the environment.

The environmental impact of economic activities or natural events includes the depletion or discovery of natural resources, changes in ambient concentrations of pollutants, and deteriorating or improving living standards in human settlements. These impacts can be harmful or beneficial. Responses to environmental impacts can be initiated by individuals, social groups, nongovernment organizations, and public authorities. The responses are meant to prevent or reverse negative impacts and to generate positive ones.

Finally, stocks, inventories, and background conditions provide benchmark data and illustrate links with other subject areas for possible analysis of these relationships. This information category includes stocks of natural resources and the capital assets of human settlements, as well as environmental inventories and economic, meteorological, or geographic background conditions.

Statistical topics and variables. Once the environmental components have been selected, attention turns to the statistical variables that appear in the body of the table. To ensure completeness and consistency, the selection of variables is a two-step process. The first step is to determine the aspects of general environmental concern that can–at least in theory–be subjected to statistical assessment. These items, which are referred to as statistical topics, should be identified for each environmental component and information category. Some examples of possible topics are already supplied in Table 3.1. Table 3.2 presents more examples referring to the natural environment. Topics are grouped together according to common characteristics (bold and italics). The reader should bear in mind that these examples are simply broad guidelines. Statisticians will need to make their own list of statistical topics that represent the specific environmental problems in their respective countries.

Once the list of statistical topics has been agreed upon, the statistician must prepare a corresponding list of statistical variables that will allow the quantitative assessment of each topic. One or more variables may be chosen for each topic. Some may be readily available from existing data collections. Others will not exist at present and their absence indicates a gap in collection procedures. The properties and related characteristics of these variables are likely to differ significantly from the more familiar types of data that statisticians usually work with.

The following are some of the distinguishing characteristics of the biophysical data that may be included in the framework:

(i) data variables based on scientific readings from instruments or laboratory analysis;

(ii) analytic or synthetic data produced from ground surveys and remote-sensing imagery, frequently recorded in mapped form;

(iii) sampling frameworks that are based on spatial rather than population distribution;

(iv) longer time intervals than are common in socioeconomic systems so as to detect significant environmental changes;

(v) natural spatial units, which are rarely as well-defined as administrative boundaries;

(vi) data based on physical measuring units (weight, volume, and area); and

(vii) lack of well-developed methods and techniques for aggregation of common denominators.

More generally, social, economic, and demographic statistics are collected using methods that are familiar to statisticians such as questionnaire surveys and administrative records. There is ample documentation on procedures of data collection and the information is readily available since all operations are conducted by the NSO itself. In contrast, the collection of environment statistics is still at an "immature" stage of development. Biophysical data may be obtained from monitoring programs, natural resource inventories, mapping and survey activities, or the interpretation of remote-sensing imagery. Procedures for collecting data from such sources are not always well-documented and can change over time.

Examples of completed framework tables are in Appendix 2. Neither the list of components nor the statistical variables in the appendix tables are meant to be exhaustive. Statisticians can use these examples as a

Table 3.2: Examples of Statistical Topics: Statistics of the Natural Environment

(A) Social and Economic Activities	(B) Environmental Impact of Activities	(C) Responses to Environmental Impacts	(D) Stocks and Inventories
1. Use of natural resources and related activities	**1. Resource depletion and increase**	**1. Resource management and rehabilitation**	**1. Biological resources**
Agriculture	Biological resources	Protection and conservation of nature	Agricultural stocks
Forestry	Cyclical and nonrenewable resources	Management and conservation of natural resources	Forestry stocks
Hunting and trapping	**2. Environmental quality**	Rehabilitation of degraded environments	Fishery stocks
Fisheries	Atmospheric pollution	**2. Pollution monitoring and control**	Fauna and flora inventories
Minerals, mining, and quarrying	Water quality	Pollution research and surveillance	**2. Cyclical and nonrenewable resources**

Table 3.2: Examples of Statistical Topics: Statistics of the Natural Environment (continued)

(A) Social and Economic Activities	(B) Environmental Impact of Activities	(C) Responses to Environmental Impacts	(D) Stocks and Inventories
Water use for human activities	Soil and land quality	Standards, control and enforcement	Hydrological systems
Land use and environmental restructuring	Quality of biota and ecosystems	Environmental cleanup and rehabilitation	Climate
2. Emissions, waste loadings and application of biochemicals		Pollution control facilities	Lithosphere
Emissions and waste loading in environmental media			Mineral resources
Application of bio-chemicals			

Source: United Nations (1991).

starting point and will probably have to introduce additional variables or otherwise modify the sample tables to ensure that the environmental concerns of their country are accurately depicted.

Environmental Indicators

An environmental indicator (EI) can be broadly defined as a parameter, or a value derived from a parameter, which provides information about a phenomenon.[7] The EI, however, has a significance that extends beyond its association with a specific parameter. First, the use of EIs should reduce the volume of information required to obtain an accurate picture of a situation. A huge amount of primary data can be generated even during the early stages of a program, and statisticians must have some way of summarizing the underlying trends. A decision on the appropriate number of indicators is itself a difficult one. Use of a great many indicators may only confuse the situation by introducing an unnecessary amount of detail. Conversely, reliance on one or a very few indicators may not be sufficient to convey all the information needed. Second, EIs are meant to facilitate the communication process between the statistician and the data user. To accomplish this goal, indicators are often simplified and tailored to meet users' needs. Because of these adaptations, EIs do not always meet strict scientific standards. Nevertheless, they can be regarded as an expression of the "best knowledge available."

OECD has carried out much of the methodological work on Els. The organization has developed indicators to serve various purposes, but the ones most relevant to the present discussion are those intended for application in a PSR framework.[8] The UN-FDES is not so rigorous in its

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7 This definition and the following discussion draw heavily on OECD (1993).

8 Some OECD indicators refer to specific economic sectors such as energy, transport, industry, or agriculture. Others apply to particular issues or policy matters. For more information, the reader is referred to the OECD references in the bibliography. Other organizations that have also published material on environmental indicators include ADB and the United States Environmental Protection Agency. Their publications are noted in the bibliography.

specification of the relationships between pressure, state and response, but it does make use of ideas on which the PSR framework is based. Thus, the work of OECD can provide some useful insights for those using the UN approach.

The OECD framework relies on three types of EIs. Indicators of environmental pressure describe pressures on the environment resulting from human activities. These measures can be subdivided further into indicators of proximate pressure–that is, pressures exerted directly on the environment–and indicators of indirect pressure, which are known as "background indicators." Indicators of environmental conditions refer to the quality of the environment. They provide information on the state of the environment and its development over time. Finally, indicators of society's responses reflect the result of individual or collective actions to mitigate or prevent the negative impact of human actions on the environment, or efforts to halt or reverse damage already inflicted.

The distinctions between the three sets of indicators may seem clear-cut, but these boundaries can quickly become blurred when the ideas are put into practice. Some indicators of environmental conditions are sensitive to environmental pressures and this fact creates uncertainty about what is actually being measured. The development of a precise set of indicators to monitor environmental conditions can also be difficult and relatively expensive. As a result, statisticians frequently use measures of environmental pressures as a substitute for measures of environmental conditions.

The situation is even more ambiguous when attention turns to the indicators of societal response. The history of these Els is shorter than that of others used in the PSR framework. These Els are at an earlier stage of development, both conceptually and in terms of data availability. The "immature" status of societal indicators increases the likelihood of misinterpretation.

Indicators of societal response are also subject to conceptual weaknesses. First, the distinction between these measures and those designed to gauge environmental pressure is blurred when response indicators capture the results of society's efforts to mitigate pressures. For example, a reduction in greenhouse gas emissions or an improvement in energy efficiency can be regarded as either a change in environmental pressure or as a societal response. Second, all EIs are quantitative in nature, but some of society's responses can be judged only in qualitative terms. In other instances, society's responses are either too numerous or too specific to be measured without great difficulty. This problem arises frequently in the case of technology-related regulations and standards involving a comprehensive and detailed set of rules. The effects of such policies are usually too diffuse and detailed to be measured in any concise manner.

A few examples of indicators proposed by OECD, shown in Table 3.3, serve to illustrate some general characteristics.[9] They address two issues: eutrophication and acidification. Eutrophication is the enrichment of water by nutrients (especially nitrogen [N] and phosphorus [P] compounds). The result is an accelerated growth of algae and higher forms of plant life that upset the balance of organisms present in the water and jeopardize the quality of the water. The preferred indicator of environmental pressure from eutrophication takes into account the emissions of N and P compounds from manure, fertilizer, domestic and industrial wastewater, and various other sources. Because few OECD countries compile data on all these sources, proxies are commonly used. Examples of proxies include the apparent consumption of fertilizers and general information on wastewater discharges. Livestock density is regarded as a rough but measurable proxy for potential eutrophication from manure.

Similar compromises are necessary when choosing indicators of environmental conditions. Ideally, these indicators would take into account the amount of excess nutrients in both soil and water. Because the measurement of nutrients in soil is rather complicated, the preferred alternative focuses only on inland and marine waters. At present, data is available only for biological oxygen demand (BOD), phosphate, and nitrate concentrations for selected rivers in OECD countries.

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9 OECD has developed a number of other indicators referring to various environmental issues. For more information, see OECD (1993).

Finally, indicators of societal responses should represent the country's efforts to reduce eutrophication and the amount of excess nutrients. The percentage of the population connected to sewage treatment with biological and/or chemical treatment is the preferred indicator, but few OECD countries have enough data to construct this measure. Nor do all countries collect information on waste charges. Instead, proxies such as the percentage of people connected to wastewater treatment are commonly used.

The situation is similar in the second example in Table 3.3. Sulfur (S) and N compounds are responsible for most acidification, and emissions of SO_x, NO_x, and NH_3 are useful indicators of environmental pressures. However, few countries are able to construct an index based on all three compounds since little information is available on emissions of NH_3. Emissions of the two other compounds are used instead. The most common indicator of environmental conditions is also a proxy–the concentration of acid precipitations (pH, SO_4, and NO_3). Data on depositions and measurements of pH values in surface waters and soil is available in some OECD countries and serves as another alternative. Finally, the preferred indicator of societal response is the capacity of SO_x and NO_x abatement equipment, but little information on this subject is being compiled at present. Most of the data refers to expenditures on pollution abatement equipment as a whole, including expenses for installing and running non-acidifying air emission equipment.

The examples given here are hardly exhaustive, but they serve to illustrate an important point. In addition to the conceptual difficulties and ambiguities in interpretation mentioned at the outset of this section, lack of data forces statisticians in developed countries to find proxies for many preferred indicators. For statisticians in developing countries–and particularly in those where the program of environment statistics is new–the scarcity of data will be even more acute. Although the FDES makes use of the pressure-state-response approach, its requirements are not so stringent as those outlined above. Statisticians will nevertheless encounter many data gaps. They will have to use their imagination and work closely with the suppliers of primary data in other agencies to devise meaningful proxies. At the same time, the collection effort must be gradually broadened to

Table 3.3: Examples of Indicators for Eutrophication and Acidification

Suggested Indicator	Preferred Indicator	Proxy Indicators
	Eutrophication	
1. Environmental pressure	Emissions of N and P into water and soil (L)	Apparent consumption of fertilizers, measured in N and P[a] (S) Wastewater discharges (M) Livestock density (S/M)
2. Environmental conditions	BOD/DO concentration of N and P in inland and marine waters (S/M)	None
3. Societal responses	% of population connected to sewage treatment with biological and/or chemical treatment (M/L)	% of population connected to wastewater treatment (S) User charges for waste-water treatment (M)
	Acidification	
1. Environmental pressures	Index of acidifying substances (M/L)	Emissions of SO_x and NO_x (S)
2. Environmental conditions	Exceedance of critical loads of potential acid in water and soil (S/M)	Concentration in acid precipitations - pH, SO_4, NO_3 (S) Total depositions of acidifying substances (M)
3. Societal responses	Capacity of SO_x and NO_x abatement equipment of stationary sources (M/L)	Equipment for abatement of air pollution (S)

S = Data is generally available in countries of the Organisation for Economic Co-operation and Development (OECD) or will be available in the short term; M = Additional empirical work and data collection efforts are necessary and the indicator will only be available in OECD countries in the medium term; L = Significant work on data development is needed and use of the indicator in OECD countries will only be possible in the long term; BOD = biochemical oxygen demand, DO = dissolved oxygen, N = nitrogen, NO_x = oxides of nitrogen, P = phosphorus, SO_x = oxides of sulfur.

[a] Apparent consumption is defined as production plus imports minus exports.

Source: OECD (1993), pp.23-25.

acquire the information that will enable them to produce more accurate proxies and, eventually, the preferred indicators themselves.

Some of the characteristics of EIs that should be kept in mind during the early stages of the environmental program are the following:[10]

(i) The values of an indicator should be measurable or at least observable.

(ii) An indicator must be empirically linked to the phenomenon under study. In other words, when the values of supporting data on which the EI is based move up and down, the indicator should behave similarly and in a proportional manner.

(iii) Data should be readily available or obtainable through special projects, surveys, or monitoring activities.

(iv) The methodology for gathering and processing data and for constructing indicators should be clear, transparent, and standardized.

(v) The resources necessary for building and monitoring the indicators should be in place. They include the financial, human, and technical requirements.

(vi) The process of collecting data, processing data, and developing the indicators should always be cost-effective.

(vii) The "political acceptability" of the indicators, whether at the local, national, or international level, is crucial. The most distinctive feature of indicators is their relevance to policy and decision making. Indicators that are not acceptable to policy makers are unlikely to influence decisions.

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[10] The list of characteristics is based on Gallopin (1997) and the UN Statistical Division (1999).

Table 3.4: OECD/UNEP Matrix of Issue-Based Environmental Indicators

Issue	Pressure	State	Response
Climate change	Emissions (GHG)	Concentrations	Energy intensity, environmental measures
Ozone depletion	Emissions; production (halocarbon)	Concentrations (chlorine)	Protocol signed, CFC recovery, fund contribution
Eutrophication	Discharges (N, P, water, soil)	Concentrations (N, P, BOD)	Treatment connection, investments, costs
Acidification	Emissions (SO_x, NO_x, NH_3)	Deposition; concentrations	Recovery of hazardous waste, investments/cost
Toxic contamination	Emissions (POC, heavy metals)	Concentrations (POC, heavy metals)	Investments, signed agreements
Urban environmental quality	Emissions (VOC, NO_x, SO_x)	Concentrations (VOC, NO_x, SO_x)	Expenditures, transportation policy

continued next page

Close attention to these characteristics should help to simplify the statistician's job, but the task of specifying relevant EIs clearly remains more of an art than a science. Table 3.4 concludes this discussion with a listing of issue-based indicators developed jointly by OECD and the United Nations Environment Programme (UNEP).

Table 3.4: OECD/UNEP Matrix of Issue-Based Environmental Indicators (continued)

Issue	Pressure	State	Response
Waste	Waste generation (municipal, industrial, agricultural)	Soil/groundwater quality	Collection rate, recycling investments/cost
Water resources	Demand/use intensity in residences, industry, agriculture	Demand-supply ratio, quality	Expenditures, water pricing, savings policies
Forest resources	Use intensity	Area of degraded forest, sustain-able growth ratio	Protected forest area, sustainable logging
Fish resources	Fish catches	Sustainable stocks	Quotas
Soil degradation	Land use changes	Topsoil loss	Rehabilitation/ protection
Oceans/coastal zones	Discharges, oil spills, depositions	Water quality	Coastal zone management, ocean protection

BOD= biological oxygen demand, CFC= chlorofluorocarbons, GHG= greenhouse gases, N= nitrogen, NH_3= ammonia, NO_x= oxides of nitrogen, P= phosphorus, POC= persistent organic compounds, SO_x= oxides of sulfur, VOC= volatile organic compounds.
Source: Adapted from ADB (1999), pp. 61-62.

4

Air Pollution and Air Quality

Air pollution has been rising in most parts of the world for over a century. Among the reasons for this upward trend are rapid industrialization, the increasing concentration of population in urban areas, and a growing dependence on fossil fuels. Today, the amount of human-caused emissions released into the earth's atmosphere is a ubiquitous and complex problem. Evidence can be found everywhere—from city streets to lakes, streams, and soil, to the stratosphere. The consequences and costs are also mounting, whether measured in terms of deteriorating levels of human health, higher levels of acidity in water and soils, or by other standards.

Chapter 4 begins with a discussion of the monitoring system: its objectives, the location of monitoring stations, procedures for handling data, and related issues. Some of the most common parameters included in a program to monitor air quality are considered in the section Air Parameters. Brief descriptions of the methods of collecting and estimating data and the apparatus used are provided. Sources of emission and procedures for constructing emission inventories are considered in the section Emission Sources and Inventories. The section Estimating Air Emissions describes the methods of estimating air emissions.

Overview of a Monitoring Program

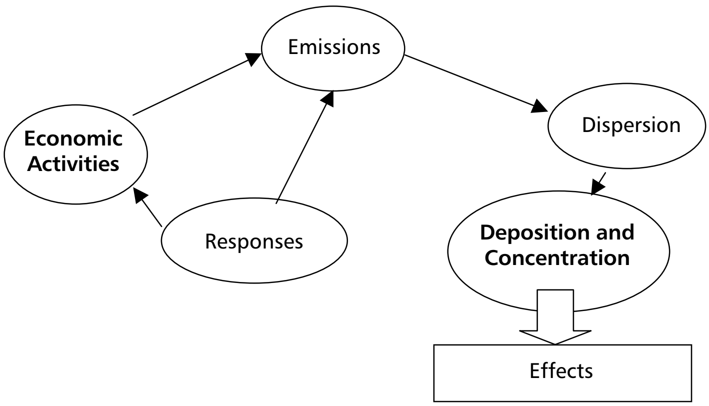
Figure 4.1 depicts the process of air pollution. Economic activities generate emissions (discharges from a source) which are then dispersed.[11] Wind is the main agent of dispersion. The physical character of the substances emitted may change or undergo a chemical reaction after release into the atmosphere. Substances can also adhere to suspended particulate matter (SPM). The process of deposition of an airborne pollutant can be either wet or dry. Substances that are dissolved or enclosed in water drops eventually fall to earth. In the case of dry deposition, substances are deposited on land or water through gravitation or are intercepted by some parts of the earth's surface such as mountains or forests.

Differences in a nation's priorities and environmental circumstances influence various aspects of a monitoring system. The availability of financial resources and human skills are other factors that are taken into account. Even industrialized countries find it necessary to limit their monitoring efforts. Decisions regarding the pollutants to be monitored, and the scope and quality of the data collected are all subject to these constraints.

Monitoring objectives. The design of any monitoring program—whether dealing with air, water, or other environmental media—starts with the identification of objectives. The explicit purpose is to collect data on specific parameters, but the ultimate objectives will be much broader. These goals need to be clearly defined to ensure that resources

[11] Emissions can result from natural events as well as human activities. Examples of natural emissions include volcanic eruptions, forest fires, and radioactive decay. Pollution resulting from natural events can be substantial. This subject is included in the FDES, but is not discussed extensively here.

Figure 4.1: Stages in the Process of Air Pollution



are used efficiently and that acceptable results are obtained. Some examples of objectives that may be incorporated in any environmental program follow:

(i) Assess the quality of the environment and enhance public awareness.

(ii) Determine compliance with national or international standards.

(iii) Assess population exposure and the impact on health.

(iv) Identify threats to natural ecosystems and develop early-warning systems.

(v) Identify sources of pollution and estimate pollutant loads.

(vi) Evaluate the effectiveness of pollution control measures.

(vii) Provide inputs for environmental management, traffic management, and land-use planning.

(viii) Support the development of policies, the determination of environmental priorities, and other managerial decisions.

(ix) Support the development and validation of managerial tools (for example, models and geographic information systems).

The choice of monitoring objectives will determine the degree of precision or quality of the data to be collected. Data of the highest quality is not always necessary, but it must be sufficient to satisfy the objectives. Statistical methods can be employed to help planners match issues of sampling frequency, data detail, and periodicity of monitoring with budget constraints.

Once the objectives have been fixed, a series of decisions need to be taken with regard to (i) the parameters to be monitored; (ii) the location and number of monitoring sites; (iii) sampling frequencies; (iv) the choice of monitoring equipment and sampling apparatus; (v) sampling methods and analytical techniques; and (vi) methods for data storage, retrieval, analysis, and interpretation.

Air quality parameters. One of the most distinctive features of any program is the list of parameters to be monitored. Variations in national practices are great. Indeed, at the international level comparable data are available for just two parameters: SO_2 and SPM. As the number of motor vehicles has risen, more countries have begun to monitor traffic-related pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), and lead (Pb). Ultimately, the selection of parameters must take into account the cost and complexity of gathering data for a specific pollutant and its relative significance for public health.

Whatever the initial combination of parameters, the list will certainly change over time. As the economy grows, the composition of human activities is altered and so, too, is the impact on the environment. New industries emerge and the fortunes of existing ones rise and fall. Additional investment brings new technologies while rising standards of living alter patterns of consumption. The interaction between these macroeconomic forces is too complex to describe here, but can be conveniently summarized by relating movements in an environmental parameter to changes in per capita income.

Figure 4.2: Illustrated Effect of Changes in Per Capita Income on Environmental Parameters

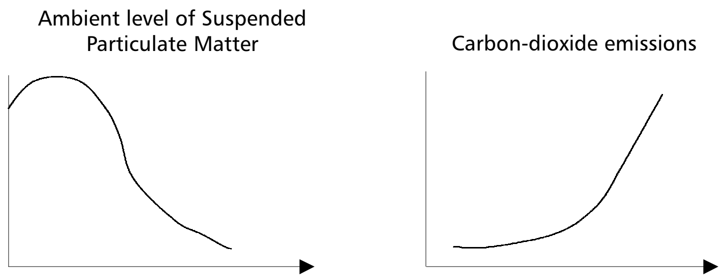


Figure 4.2 gives a stylized picture of this relationship for two parameters (SPM and CO_2). The trends pictured are merely illustrations. They do not represent the experience of a specific country, but simply provide a rough indication of the changes that can be expected with economic progress. The ambient level of SPM tends to be especially high at low levels of per capita income. It may initially rise as per capita income begins to grow, but it falls off sharply as the country becomes richer. A quite different pattern is observed in the case of CO_2. At low levels of per capita income, the volume of emissions is modest because the country's fleet of cars and trucks is small. But the extent of car ownership rises quickly as per capita income increases, and the volume of emissions increases accordingly. The implication of such trends is clear. As growth and development continue, the list of parameters being monitored will have to be adjusted accordingly. The same applies to the mixture of environmental regulations and controls that are in place. Some may eventually become obsolete, while others must be introduced.[12]

[12] Environmental standards can also differ even among countries at the same stage of development. There are relevant differences in the way the receiving environment reacts to pollution. An oil spill in the stormy North Sea, for example, does less lasting damage than a spill off the almost tideless Mediterranean coast; contaminated land matters less when it is far from homes and reservoirs.

Monitoring stations. A second crucial feature of the program is the network of stations used to collect data. Because air pollution is greatest in urban areas, the monitoring effort is usually concentrated in and around cities. Each geographic area has distinctive meteorological and topographic features and its own spatial distribution of air pollution sources.[13] The pattern of atmospheric dispersion is also unique for cities located in river valleys, coastal areas, or mountain valleys. Even within a particular city, pollution will vary with the terrain, elevation, meteorological conditions, traffic density, and time of day. Finally, seasonal variations must be taken into account. The concentration of air pollutants tends to be highest in the winter season when the least dilution and dispersion occur.

Improved quality is expected during the rainy season when most pollutants in the ambient air are washed to the ground by rainwater. The location of monitoring stations should take into account the ease of access to the site, the safety of the site, travel time to the laboratory (for quickly degrading samples), and the availability of power connections for monitoring equipment. Periodic visits to each site are also necessary to verify that no new emission sources that could jeopardize the representativeness of a site have appeared.

Clearly, a rather dense network of monitoring stations—coupled with frequent sampling from all locations—would be required to amass the raw data needed to construct representative indicators of air quality for an entire city or urban area. Such an elaborate network is rarely available, even in industrialized countries. At the other extreme, a minimum network of monitoring stations might consist of just a few monitoring stations in a residential zone, and a similar number located in an area with heavy motor traffic and in an industrial zone. Finally, additional data is needed to determine the baseline status, or background pollution, in the general area. This last set of monitoring stations should be located at sites representing all topographic features of the area, such as hilly terrain, valleys, and plains. The microclimatic conditions at each

13 The spatial pattern of pollution sources generally depends on factors such as the location of industrial enterprises that are heavy polluters, transport routes, and traffic patterns in the city.

of these locations will vary, influencing the dilution and dispersion of pollutants, and their ambient concentration.[14]

Most developing countries opt for something more than a minimum system, though not as elaborate as the versions found in industrialized countries. Some countries make use of intermittent or mobile sampling to reduce their resource requirements. These techniques, however, may not provide representative coverage with regard to temporal and spatial considerations. A more flexible approach is to set up monitoring stations or sampling points at carefully selected representative locations. Sites are chosen on the basis of the data required and any prior knowledge about emission and dispersion patterns of the pollutants being monitored. This approach generally requires fewer sites than other methods and, therefore, is cheaper to implement. In addition, various types of estimations may be needed to fill in the gaps in such a strategy.

Table 4.1 gives some examples of possible locations that may be part of this flexible approach. If previous compilations of emissions data are available, they will be helpful in choosing monitoring sites where population exposure is significant. Without such information, surrogate statistics—for example, population density, traffic flows, or fuel consumption—can be used to identify pollution hot spots. Should none of this information be available, special surveys may have to be designed to provide areawide or local information on pollution problems. These surveys often make use of either passive samplers or mobile monitoring laboratories, or both.

The frequency of sampling will depend on the range of variation in the parameters monitored, the concentration of pollutants, and the availability of financial and human resources. In the absence of any background data on parameters, an arbitrary frequency is chosen based on some knowledge of local conditions. Once sufficient data has been collected, the sampling frequency can be adjusted as required.

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[14] A methodology for handling large data sets and condensing the primary data into summary measures or indicators is provided in Appendix 3.

Table 4.1: Possible Monitoring Sites Relevant to Exposure Assessment

Site classification	Description
City/urban center	An urban location representative of general population exposure in the metropolitan center (e.g., pedestrian precincts and shopping areas)
Urban background	A site distanced from emission sources and therefore broadly representative of citywide background conditions
Suburban/residential	A location situated in a residential area on the outskirts of the city
Curbside/near road	A sampling site within 1-5 meters of a busy road
Industrial	An area where industrial sources make an important contribution to long-term or peak concentrations
Rural	An open countryside location distanced as far as possible from roads, and populated and industrial areas
Source/target-oriented	Any special, source-oriented site (for example, garages, car parks, or tunnels; or a site located at a targeted receptor point such as a school or hospital)

Source: Adapted from WHO (2000a).

Monitoring technologies. Monitoring operations can be carried out manually or with the help of automated equipment. The latter provides better reliability, more precise measurements, and the ability to monitor on a continuous basis. Automated equipment, however, is often expensive and difficult to maintain. In contrast, manual methods are relatively inexpensive, easy to employ, and yield data of acceptable quality so long as methods allowing quality assurance and quality control are followed. Monitoring equipment is chosen after taking into account factors such as equipment costs and reliability and the desired quality of the data. Ultimately, the monitoring system may include a combination of automated and manual equipment. The types of equipment used include passive samplers, active samplers, automatic analyzers, and remote sensors. Their advantages, disadvantages, and approximate capital costs are given in Table 4.2.

When passive samplers are used, an "integrated air sample"—that is, a sample collected over a defined exposure time such as a week to a month—obtained by molecular diffusion to a pollutant-specific absorbent material. Pollutants collected in this way are analyzed in the laboratory. When active samplers are used, a known volume of air is pumped through a collector such as filter or an absorbent (typically a chemical solution) for a specified period of time. The pollutants captured are then sent for laboratory analysis. Finally, if automatic analyzers are employed, samples are collected and analyzed on-line and in real time, usually by electro-optical techniques such as ultraviolet or infrared absorption, fluorescence, or chemiluminescence. Monitoring methods that rely on remote sensors utilize long-path spectroscopic techniques to make real-time measurements of pollutants. Automatic analyzers and remote-sensing techniques do not require laboratory analysis.

Quality assurance and quality control. Whatever the degree of aggregation or complexity of the indicators being produced, statisticians must make every effort to ensure the credibility of their results. Procedures for quality assurance and quality control (QA/QC) are therefore an integral part of any monitoring program.

A program of quality assurance focuses on several premeasurement activities mentioned earlier in this chapter. A program of quality control, on the other hand, is concerned with measurement-related activities such as the calibration and operation of monitoring equipment (including laboratory equipment), data management, field audits, and the training of personnel involved in monitoring and laboratory analysis. Both

Table 4.2: Assessment and Costs of Equipment for Air Monitoring

Method	Advantages	Disadvantages	Capital Cost
Passive Samplers	Very low cost Very simple No dependence on electricity Can be deployed in large numbers Useful for screening, mapping, and baseline studies	Unproven for some pollutants In general provide only monthly and weekly averages Labor-intensive deployment/ analysis Slow data through-put	US$10-70 per sample
Active Samplers	Low cost Easy to operate Reliable operation/ performance	Provide daily averages Labor-intensive collection and analysis Laboratory analysis required	US$1,000-3,000 per unit
Automatic Analyzers	Proven High performance Provide hourly data On-line information	Complex and expensive to operate High skill require-ments High recurrent costs	US$10,000-15,000 per analyzer
Remote Sensors	Provide path or range-resolved data Useful near sources Multicomponent measurements	Very complex and expensive Difficult to support, operate, and calibrate Not really compa-rable with point data Subject to atmo-spheric visibility and interference	US$70,000-150,000 per sensor, or higher

Source: WHO (2000b) .

components are essential to ensure successful implementation of any monitoring program. The purpose of QA/QC activities is to ensure that

(i) measurements are accurate, precise, and credible;

(ii) data are representative of ambient or exposure conditions;

(iii) results are comparable and traceable;

(iv) measurements are consistent over time;

(v) data capture is extensive and evenly distributed; and

(vi) resources are used in an optimal manner.

Table 4.3 lists the main components of QA/QC activities.

Table 4.3: Major Components of Quality Assurance/Quality Control Activities

Quality Assurance	Quality Control
Definition of monitoring and data quality objectives	Establish a chain for calibration/traceability
Network design, management and training systems	Network audits and inter-calibrations
Site selection and establishment	System maintenance and support
Equipment evaluation and selection	Data review and management
Routine site operations	

Source: WHO (2000).

Data compilation and measurement. The data collected via monitoring stations is often voluminous and is one of the major sources of information on air quality during the early stages of the program. Eventually, other data suppliers should emerge. Table 4.4 lists some potential contributors and the types of data they might provide. However, this network of data suppliers could take several years to develop and the following discussion focuses on the handling and use of information obtained through the monitoring system.

Table 4.4: Potential Suppliers of Data on Air Quality

Source	Type of data
Ministry of Environment/ Department of Environmental Protection	Ambient air quality data, data on emissions from various points sources
Ministry of Industry	Impact of industrial activities on air quality
Ministry of Housing	Air quality in residential areas, indoor air quality
Ministry of Agriculture	Air quality relating to agriculture and forests
Ministry of Transport	Air quality relating to traffic
Meteorological Institute	Rainfall, composition of rain, wind speed and direction, temperature, humidity, atmospheric pressure, etc.

At least two agencies have responsibilities relating to the data obtained from the monitoring system. Officials in the Ministry of Environment (or its equivalent) are usually in charge of the network of monitoring stations, the data bank containing all records of the monitoring exercise, and several other functions.[15] Statisticians in the environmental statistics unit in the NSO have responsibility for a number of "downstream" operations such as the preparation of indicators and their subsequent dissemination. The methodologies employed to collect and store the monitoring results are primarily the responsibility of environmental authorities, but even at this stage the NSO has a role to play. Statisticians, for example, should be sure that their environmental counterparts follow internationally accepted methods for field and laboratory analyses and make use of international statistical classifications such as those developed by the UN and the Economic Commission for Europe (ECE).

Environmental authorities should also follow certain guidelines for compiling and validating of the information gathered by the monitoring system. The purpose of the guidelines is to facilitate subsequent tasks such as data standardization, transformation, and estimation.[16] The guidelines include the following:

(i) Data recorded by each monitoring station should be stored separately, along with summary information on the air quality statistics at each monitoring site. These statistics should be readily available to all users.

(ii) All air pollution concentration statistics should be accompanied by a description of the sampling and analytical methods used.

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15 A useful distinction can be made between a database and a databank. The latter is a passive storage system where data are filed in the form delivered by the original supplier. In the database, data are selected according to defined criteria and transformed in accordance with a specific format to allow data handling and manipulation between files. A data bank would best describe the type of data collected from the monitoring system and stored by environmental officials. Once this data is transferred to the NSO, and possibly combined with data from other sources, it may be reformatted and undergo other statistical routines. At that point, the data collection would most accurately be described as a database.

16 The guidelines are based mainly on ECE (1990) and ESCAP (1999).

(iii) Any qualifying statements regarding the functioning of the monitoring station or the existence of unusual ambient conditions should be properly noted and stored along with the data collected.

(iv) Any summary statistics on air quality for individual monitoring stations should be clearly linked to the specific geographical areas they relate to.

Interpreting the results. Once data obtained through the monitoring process has been properly stored, the authorities will want to construct indicators that can be compared with national or international standards for long-term exposure to a pollutant. The options available depend on the number of monitoring stations, the frequency of samples taken, and the time period for which observations exist. With only a minimum amount of information, it is inadvisable for statisticians to produce aggregate indicators for an entire city or region. The differences between stations in terms of meteorological conditions and pollution patterns mean that such indicators have little reliability. In a minimum network, results are generally reported station-by-station. Essentially, the stations represent themselves. For each station, data can be reported as arithmetic means calculated for a specified period of time. Trend information can then be derived from the mean values and the results compared with the guidelines for acceptable long-term exposure to the pollutant.

Short-term exposure can be measured in percentile values (for example, the 95th or 98th percentile) to determine the occurrence of peak concentrations.[17] Alternatively, an observed high value—usually the second or third highest measurement in a sample—can serve this purpose. These indicators are used to assess the risk of short-term exposure by calculating the number of days per year (at a station) during which a guideline value or threshold for short-term exposure is exceeded.

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17 An observation in the 95th percentile would mean that 95 percent of all observations fall below that value.

A more concise way of describing air quality would make use of average air pollution concentrations and changes in their values over time. Levels of concentration are typically expressed as mean values, calculated on the basis of daily or monthly values for each year. Supplementary information should also be produced describing the type of monitoring station, the surrounding land use or average traffic condition, the geographic location (elevation and terrain), dispersion characteristics based on local meteorology, methods used for air sampling and analysis, and major emission sources (motor vehicles, industrial establishments, and so on). The report for each station would also include the number of days per year the guidelines for pollutants are exceeded.

The types of indicators constructed on the basis of minimum data can highlight peak trends in pollutant concentrations at individual monitoring stations, but they cannot meet all of the needs of policy makers. Air (unlike water) is a continuous medium and statisticians will soon be under pressure to produce more general indicators for air quality. With only a very few monitoring stations, a brief historical series, and infrequent samples, this temptation should be resisted. However, as experience is gained and a more elaborate monitoring network is established, some generalizations can be considered.

Development of a more general set of indicators can be pursued on a step-by-step basis. Geographic integration is often the first phase. Statisticians can begin by identifying geographic areas that are homogeneous.[18] Monitoring facilities must be adequate throughout the designated area and meteorological conditions should be roughly comparable. Ultimately, this type of aggregation yields indicators for a single pollutant stated in terms of "urban peak concentration," rural peak levels," and so on, with the results compared with an appropriate national or international standard.

Figure 4.3 gives three examples of one approach, showing aggregates for concentrations of CO, SO_2, and particulates as calculated by the

[18] A rural-urban breakdown is the most common division into homogeneous areas. However, even some rural areas may include one or more establishments that are significant polluters. A careful assessment is therefore essential.

Department of Environment, Transport and the Regions in the United Kingdom. The results are presented as simple line graphs stated in terms of the composite average and range (maximum and minimum). Such figures can be readily interpreted by the public and nonexpert decision makers to identify trends, compare levels with national or international standards, and assess progress toward long-term objectives.

Prior to the preparation of these aggregates, the underlying data was subjected to an elaborate series of tests to ensure that only reliable, quality-controlled data was used. The purpose of the tests was to determine whether there was a good reason to exclude data from certain monitoring sites. The main reasons for ultimately excluding data follow:

(i) inadequate data capture in a specific year;

(ii) a discontinuous data record, usually because a monitoring site was unable to contribute data to the aggregate indicator in every year;

(iii) trends that were not representative, typically because the data collected at a site was inconsistent with data observed at other sites.

At a later stage in the development of the program, statisticians may choose to go beyond the geographic integration of indicators for individual pollutants so as to produce a single air pollution or "headline" indicator. This indicator will have to be based on the combined measured concentrations of different pollutants. A composite indicator of this type cannot be developed without abundant and ratified data, and numerous tests to demonstrate the robustness and representativeness of the measure.[19]

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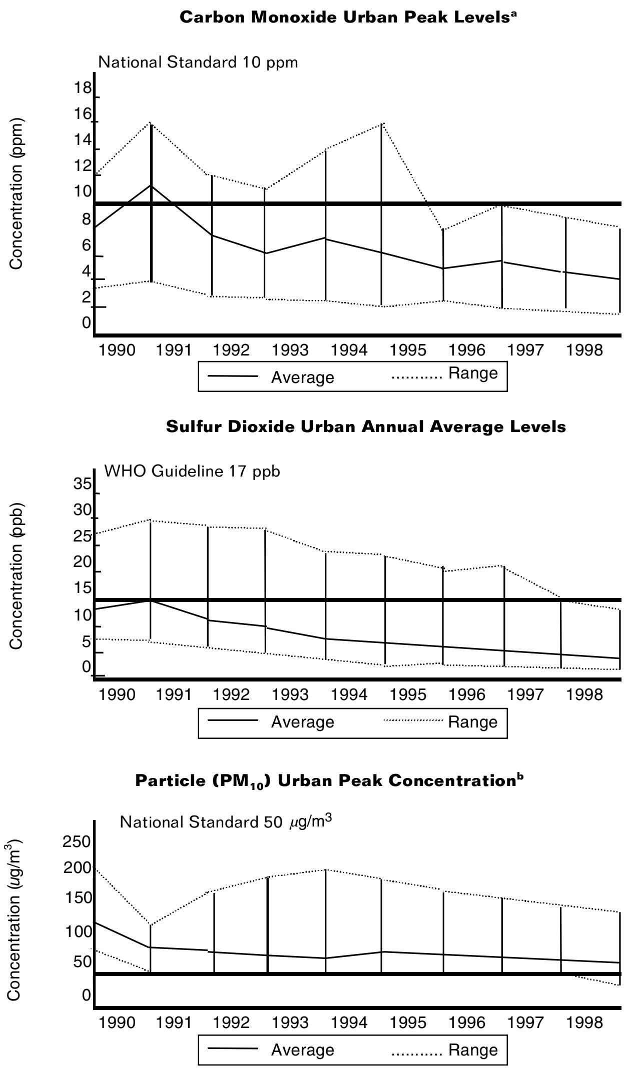
19 For a discussion of this process and a description of the tests applied, see ECE (1999), pages 6-9.

Figure 4.3: Reported Indicators of Air Pollution in the United Kingdom



[a] Peak measurements for carbon dioxide are running 8-hour means in a year.
[b] Peak measurements of particulates (PM_{10}) are represented by the 99th percentile of daily maximum running 24-hour means.
Source: ECE (1999).

In conclusion, the statistics gathered by the monitoring system pass through several stages as environmental specialists and statisticians work to transform the raw data into information that can be used by health authorities, regulatory officials, and the general public. An overview of the complete process is presented in Figure 4.4. A minimum level of data production can include provision of daily, monthly, and annual summaries with simple statistical and graphical analyses that show both time and frequency distributions of the monitoring data. The information and indicators derived from these sources must be reported or disseminated in a timely fashion to end users.

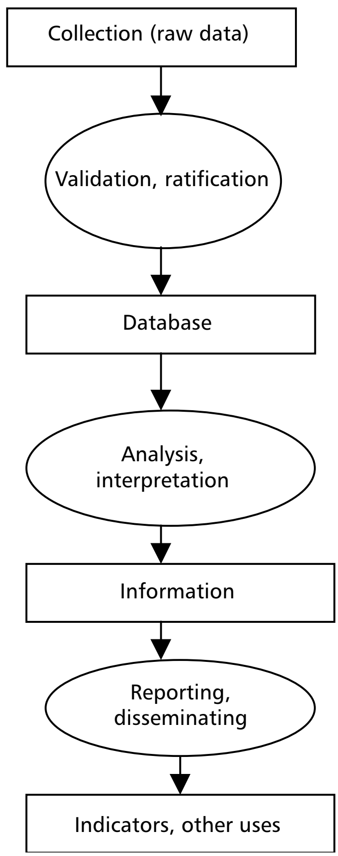
Air Parameters

The air pollutants monitored in most countries generally fall into three broad categories: gaseous pollutants, SPM, and odors. Some of the common gaseous pollutants are ammonia, SO_X, NO_X, CO, and hydrocarbons. These gases, along with SPM, are generated by both stationary and mobile sources.[20] Hydrogen sulfide and mercaptans are two ubiquitous odorous gases and their emissions are usually attributed to industrial sources or to natural geothermal sources. All these air pollutants are harmful to human health. Any comprehensive program of air pollution management should monitor their presence regularly. An overview of the monitoring techniques, sampling methods, and equipment requirements for each of the eight pollutants noted above is given in this section. Meteorological parameters such as temperature and humidity are also considered.

Meteorological parameters. A number of meteorological parameters can influence the patterns of dilution and dispersion of atmospheric pollutants. The most important of these parameters are

[20] The most important stationary sources of emissions are industrial establishments; certain process emissions occurring in agriculture, mining, and quarrying; and emissions by households such as from heating and cooking. Various categories of emissions are discussed in the section on Emission Sources and Inventories.

Figure 4.4: Stages in Processing Data in a Monitoring System



temperature and its changes with altitude, the mixing height (that is, the height above ground where the pollutants diffuse), wind speed and direction, atmospheric pressure, and humidity. Any comprehensive program to monitor air quality will need to take these factors into account.

Temperature. In a regular monitoring program several measurements of temperature will be required, including the daily mean temperature, and daily maximum and minimum. Different types of thermometers are used for these purposes. The basis for measuring the temperature of an object is any physical property of the object that is a function of temperature. Alterations in the physical property of the object must be proportional to alterations in temperature recorded by the thermometer. When measuring atmospheric temperature, the physical properties most widely used are thermal expansion and changes in electrical resistance. Depending on the physical property chosen, the most common thermometers used for this purpose are a liquid-in-glass type or an electrical type.

Certain safeguards must be taken to ensure the accuracy of measurements. Specifically, if a thermometer is in the air and directly exposed to solar radiation, some of this radiation can be absorbed. The instrument may then give a reading higher than the actual air temperature. To protect the thermometer from direct exposure to solar radiation, it is installed under a screen or shield. The screen or shield also protects the thermometer from precipitation and prevents accidental damage. There should be ample space between the instrument and the walls of the screen to ensure that there is no physical contact. Most screens allow natural ventilation or free circulation of the air surrounding the thermometer. The walls of the screen are usually double-louvered, and the roof is double-layered, with provisions for ventilation of the space between the two layers. Free circulation of air through the screen allows the temperature of the inner wall to adapt to ambient changes. The floor of the screen should be designed for easy removal of snow and ice in cold climates. Normally, the screen with the thermometer inside is mounted at a height of 1.25-2 meters above the ground when measuring free air temperature over a large area.

Air temperatures-including the daily mean, minimum, and maximum-are routinely monitored using a liquid-in-glass thermometer. This thermometer relies upon the differential expansion of a pure liquid with respect to its glass container to indicate temperature changes. Mercury is commonly used as the liquid to measure the temperature in higher ranges, while ethyl alcohol or another pure organic liquid is used for lower temperature ranges. A liquid-in-glass thermometer has two components: a bulb where the liquid is stored, and a stem or tube with a fine bore attached to the main bulb. The bulb is completely filled with the liquid, while the stem is partially filled at all temperatures. As the temperature rises, the liquid in the bulb expands and moves up to the stem. Changes in temperature are indicated by changes in the length of the liquid in the stem, which is calibrated with respect to a standard thermometer. A scale of temperature is marked on the stem, or on a separate scale tightly attached to the stem to record readings.

Maximum temperature is measured by a mercury-in-glass thermometer with a constriction in the bore between the bulb and the beginning of the scale. The constriction prevents the mercury column from falling when the temperature drops. The thermometer is mounted at an angle of about two degrees from the horizontal with the bulb at the lower end to ensure that the mercury column in the stem rests against the constriction and does not fall by the force of gravity. When measuring minimum temperatures, a thermometer containing spirits, ethyl alcohol, pentane, or toluol is used. The thermometer has a dark glass index immersed in the liquid. Like the maximum-temperature thermometer, the minimum-temperature model is mounted at a near horizontal position.

Thermometer readings should be taken carefully and precisely to avoid any alteration of temperature due to the direct exposure of the sensor to sunshine or snow when the screen door is opened. Observers must also take care to avoid parallax error (an error made by the observer while taking readings due to the wrong positioning of the eye and the thermometer scale). Readings from both the maximum and minimum thermometers should be taken and reset at least twice daily. The readings should also be compared regularly with measurements from a standard thermometer to ensure that there are no errors.

Manual means of recording temperatures from the thermometers through direct observation do not give continuous results. Mechanical thermographs make use of bimetallic or Bourdon-tube sensors for continuous recording in a graph. Thermographs are prepared by a rotating chart mechanism. These devices are relatively inexpensive, easy to operate, reliable, and portable. Bimetallic thermographs rely on the movement of a recording pen, which is controlled by temperature-induced changes in the curvature of a bimetallic strip or helix, one end of which is rigidly fixed to an arm attached to the frame of the instrument. While the general mechanism of a Bourdon-tube thermograph is similar to that of a bimetallic thermograph, its temperature-sensitive element is in the form of a curved metal tube with a flat elliptical section, filled with alcohol.

Electrical thermometers are generally used for automatic and continuous measurements of temperature. These thermometers produce an output signal proportionate to the change in temperature. They are suitable for use in remote locations, and for recording, storing, and transmitting data to the monitoring station. The most common types of electrical thermometers are electrical resistance elements, thermistors, and thermocouples. More advanced devices employ digital measuring techniques and are used when the output data for a large number of monitoring stations are recorded and processed in a digital computer. The accuracy and precision of the digital technology are high.

Humidity. When measuring humidity, analysts can choose from four basic methods:

(i) thermodynamic methods (psychrometers),

(ii) methods based on the change in dimensions of hygroscopic substances (hair hygrometers),

(iii) methods relying on the change of electrical resistance due to absorption or adsorption, and

(iv) condensation method (dew- or frost-point hygrometers).

Techniques relying on condensation and electrical resistance are used in automatic meteorological monitoring stations and are frequently employed for upper-air measurements.

Two types of psychrometers are available: a stationary screen version and the portable Assman or whirling version. In the typical meteorological station, stationary screen psychrometers are used to measure humidity in the air. The device consists of two mercury-in-glass thermometers and dry-bulb and wet-bulb thermometers, which are installed under a screen to protect them from direct radiation. The metallic shields are separated from the rest of the apparatus by insulating materials.

Adequate space and ventilation are provided for free movement of the air surrounding the thermometers. The dry-bulb thermometer is a normal thermometer similar to that used for recording normal air temperature. The wet-bulb thermometer contains liquid mercury that is moistened by wet muslin dipped into distilled water and kept in a wick. Water from the wet-bulb thermometer evaporates and lowers its temperature reading, while the dry-bulb thermometer shows the corresponding air temperature at any given point of time. The difference in the readings of the two thermometers is recorded. Atmospheric humidity is calculated from a standard chart that indicates the empirical relationship between the difference in temperature readings of the dry- and wet-bulb thermometers and the relative humidity in air.

Care should be taken to ensure that thermometers are not exposed to direct sunshine or frost when readings are being taken. The muslin cloth and the wick in the wet thermometer should also be cleaned regularly to prevent contamination. For continuous monitoring of atmospheric humidity, thermographs are prepared from the readings of the dry- and wet-bulb thermometers.

The hair hygrometer is useful for measuring atmospheric humidity in conditions where extreme temperatures and very low humidity are rare. Electrical thermometers are increasingly used to record dry- and wet-bulb temperatures because they give more precise and accurate results. Dew-point hygrometers are used as a reference standard for determining dew point or frost point in the atmosphere. They are very expensive devices.

Rainfall. Measurements of rainfall should be designed to capture a sample representative of the true amount falling over the area to be monitored. Measurements can be conducted either with manual, nonrecording instruments or with continuous recording devices. Nonrecording rain gauges are the most widely used method for measuring rainfall. These are open receptacles with an orifice where rainfall is collected. The amount collected in a gauge is measured with a graduated stick to determine the depth. Alternatively, rainfall can be determined by measuring the volume or weighing the contents. The volume of the gauge and its orifices should be adjusted for the expected rainfall of the area. Normally, gauges are placed at ground level with the base firmly mounted to withstand the force of strong wind and to avoid toppling.

Rain gauges are preferably kept at a site free from any physical obstacles. If that is not possible, the site should be so chosen that no object is closer to the gauge than a distance twice the obstacle's height above the gauge orifice. To avoid rainwater splashing into the gauge, the gauge should not be located on a hard, flat or concrete surface.

Two types of nonrecording rain gauges-standard and storage gauges-are available. Standard gauges are used to record daily, weekly, or monthly measurements. They normally consist of a collector placed above a funnel leading into a container. The collector has a vertical wall deep enough to prevent rain from splashing in and out, and the slope of the funnel must be sufficiently deep (at least 45^{o}). The container should have a narrow entrance to minimize the loss of collected rainwater through evaporation due to solar radiation. Rain gauges used to measure weekly or monthly rainfall should have a larger capacity and stronger construction.

Storage gauges are used to measure total seasonal rainfall in remote areas. The components are similar to those of standard gauges, but the container is large enough to store the seasonal rainfall. An antifreeze solution such as ethylene glycol or a mixture of ethylene glycol and methanol can be kept in the container to convert any snow falling into the gauge into a liquid state and to prevent rainwater from being converted into snow in cold weather. A layer or thin film (0.5 mm) of evaporation suppressant should be placed in the container to reduce evaporation. When an ordinary, nonrecording rain gauge is used, measurements are taken with the help of a graduated measuring cylinder made of glass or plastic. Another alternative is to use a graduated dip rod of cedar wood or some other material that does not absorb water appreciably and possesses only a small capillary effect.

Three types of recording gauges are available to measure rainfall. These are the weighing type, a tilting or tipping-bucket type, and a float gauge. If the weighing-type instrument is used, the container, together with the rainfall in it, is weighed continuously by means of a spring mechanism or a system of balance weight. The float-type instrument allows rain to pass into a chamber containing a light float. The rainfall passes into the float chamber, causing the float to rise. The vertical movement of the float is transmitted through a suitable mechanism to the proportional movement of a pen on a chart, recording rainfall on a continuous basis.

When a tilting-bucket gauge is used, rainfall is collected in one of two chambered buckets that are balanced in unstable equilibrium about a horizontal axis. In its normal position, the bucket rests against one of its two stops. Rainwater flows from a collector into the uppermost compartment of the bucket. After a predetermined amount of rainwater enters the compartment, the bucket becomes unstable and tips over to a rest position, with the other compartment now placed in a position to collect rainwater. The shape of the bucket compartments is such that rainwater is emptied from the lower one. The time when each bucket tips over and spills a specified quantity of water is recorded and the total amount of rainfall can then be determined.

Continuous recording of rainfall can be obtained with the use of any of these devices by preparing a chart, or by mechanically or electronically converting the values to a digital form that is recorded at uniform time intervals. The movement of a float, bucket, or weighing can also be converted into an electrical signal that is received at a distant monitoring station.

Sulfur dioxide. This gas is one of the major pollutants generated during the combustion of fossil fuels (for example, power generation and automobile exhaust) and other industrial activities such as smelting of sulfur-containing ores, manufacture of sulfuric acid, and petroleum refining. SO_2 is partially oxidized in the air to form sulfur trioxide, a compound that readily combines with water vapor to form sulfuric acid. When sulfuric acid is present in the atmosphere, it contributes to acid rain.

Like SPM, SO_2 can be monitored manually or with automated equipment. Manual techniques may be static or mechanical, but the latter is preferred due to its proven reliability and relatively moderate capital and operating costs. When mechanical techniques are employed, a measured volume of air is sucked into the monitor with the help of an air pump (blower). The air is drawn in at a specific flow rate (for example, 0.5 liter/minute or 1 liter/minute) for a specific period of time (1 hour, 4 hours, or 24 hours). The air stream passes through a prearranged number of bubbler/impinger tubes. These tubes have inlet and outlet devices to allow the air to pass through. They are filled with a reagent that absorbs the SO_2 present in the air to form a complex. This complex is then made to react with other chemicals to form a second, colored complex. The intensity of the color is measured by means of a colorimeter or spectrophotometer, and can be directly related to the amount of SO_2 present in the corresponding air sample by means of a calibration curve.

The sampling period with manual techniques varies from 30 minutes to 24 hours, depending on the expected pollution levels. Short-term sampling conducted during a period ranging from 30 minutes to one hour is common practice when high levels of SO_2 concentration are expected. Long-term sampling over a 24-hour period is done when relatively low concentrations are anticipated.[21] Different combinations of absorbing reagent volumes, sampling rates, and sampling times can be chosen, depending on the specific requirements. Sample volumes must be adjusted so that linearity between the absorbance and concentrations is maintained. In most instances, sampling is carried out at least twice a week at any monitoring station.

The apparatus required for manual monitoring with mechanical equipment include a bubbler/impinger tube, an air pump/blower, a flow-control device, a membrane or glass fiber filter, flow calibration equipment, a timer, a spectrophotometer, and a thermometer.

The concentration of SO_2 can be determined according to the following equation:

$$SO_2\ (\mu g/m^3) = \frac{(A - A_0) \times 10^3 \times B_g}{V_r} \times D$$

[21] A high level of concentration would be one close to or exceeding 1,000 μg/m^3. A low level of concentration would be 25 μg/m^3 or less.

Where	A	=	sample absorbance
	A_0	=	reagent blank absorbance
	10^3	=	conversion of liters to cubic meters
	Vr	=	the sample volume corrected to 25°C and 760 mm Hg, liters
	B_g	=	the calibration factor, mg/unit of absorbance
	D	=	dilution factor

Automated techniques for continuous SO_2 monitoring are employed in air pollution control programs that mandate a continuous record. The availability of automated equipment simplifies several of the analytical steps that must be performed manually when mechanical equipment is used. Automated techniques, however, are expensive.

Automated monitoring can be based on any of several sophisticated principles relating to conductivity, colorimetry, electrochemical diffusion, gas chromatography coupled to flame photometry, and ultraviolet fluorescence (UVF). The most popular and widely used method is the UVF technique. With this method, SO_2 molecules in the sample air stream are excited to an unstable energy state by ultraviolet radiation. This high energy state decays with emission of secondary fluorescence radiation. The intensity of the fluorescent radiation is proportional to the concentration of SO_2 present in the air sample. The apparatus required for continuous monitoring varies, depending on the type of analytical technique chosen.

Oxides of nitrogen. These gases are the products of high-temperature combustion of fossil fuels. They are created during various industrial processes such as power generation, the use of industrial boilers and diesel generators, petroleum refining, and the production of inorganic chemicals (for example, nitrogenous fertilizers). The automobile exhaust from diesel-run vehicles is another important source. The most common gases of this type are nitric oxide and nitrogen dioxide.[22] Like SO_2, NO_x contribute to the formation of acid rain.

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22 Nitrous oxide is also formed in the atmosphere. In that case, however, it results mainly from biological activity in the soil and is not considered to be a pollutant.

Monitoring operations are conducted with either passive or active samplers. A process of passive sampling makes use of diffusion tubes to determine the average concentration of NO_x during the exposure period, which typically ranges between two and four weeks. This method is particularly well suited for baseline studies and for assessing the spatial distribution of NO_x in an urban environment. A passive tube sampler uses a chemical as an absorbent to determine the amount of NO_x in the atmosphere. After thermal desorption, the sample is analyzed by spectrophotometry or by ion exchange chromatography. This method is widely used in the United Kingdom and Europe.

Manual or automated means can be used for active sampling of NO_x. Manual sampling is a semicontinuous method. In this case, a measured volume of air is sucked into the sampler with the help of an air pump (blower). The air enters at a specified flow rate (0.3 liter/minute to 0.6 liter/minute) during a specific period . The air stream passes through a prearranged number of bubbler/impinger tubes (glass tubes with inlet and outlet devices). The tubes are filled with a reagent, which absorbs the NO_x in the sample air and forms a complex. This complex, in turn, is made to react with other chemicals to form another highly colored complex (an azo-dye). The intensity of the color of the complex is measured by means of a colorimeter or spectrophotometer, and can be directly related to the amount of NO_x present in the air sample by means of a calibration curve. The manual method is relatively simple to implement and the apparatus required is inexpensive.

The sampling period for the manual technique may vary from 15 to 30 minutes for short-term sampling and from 4 to 24 hours for long-term sampling. The choice of a sampling period depends on the expected pollution levels-that is, the concentration of NO_x in the ambient air at the monitoring station and the monitoring procedure used. The volume of absorbing reagents used, the volume of the sample collection, and sampling rate are adjusted to match the duration of the sampling period. Sampling should be carried out at least twice a week at each monitoring station.

The monitoring equipment includes a bubbler/impinger tube, an air pump/blower, a flow control device, a membrane or glass fiber filter, flow calibration equipment, a timer, a spectrophotometer, and a thermometer.

Estimates of the concentration of NO_x in the ambient air are based on the following equation:

$$NO_x\ (\mu g/m^3) = \frac{(A - A_0) \times Y}{V} \times D$$

Where A = sample absorbance
A_0 = reagent blank absorbance
Y = volume of absorbing reagent, ml
V = the sample volume corrected to 25°C and 760 mm Hg, m^3
D = constant

Automated techniques for continuous monitoring of NO_x are used in pollution control programs that mandate continuous records and for checking regulatory compliance. Several types of automated analyzers are available. They make use of various techniques such as colorimetry, NDIR, and chemiluminescence. All automatic devices monitor nitric oxide (NO) and nitrogen dioxide (NO_2) separately. The results are then summed to determine the total concentration of NO_x in the ambient air. Alternately, one oxide can be converted into the other before the measurement is made.

Among the various automated devices available, the chemiluminescence technique is the most popular because it is relatively cheap, and accurate, and is applicable to a wide concentration range. When using this method, NO is made to react with ozone to form NO_2 and oxygen. Part of the NO_2 (about 7 percent) remains in an excited state, which then reverts to the ground state with emissions of radiant energy. The emitted radiation is received by a photomultiplier tube, whose output is amplified and fed to a recorder. The intensity of this radiation is proportional to the amount of NO present in the sample air.

After its conversion to NO, concentrations of NO_2 in the ambient air can also be measured by this device. Air samples are directly drawn into the analyzer to establish an output signal for NO. A switching valve then directs the air sample through the converter where NO_2 is converted quantitatively to NO. The detector then records a signal for total NO_x. Finally, the concentration of NO_2 is measured by subtracting, electronically, the NO signal from the signal for total NO_x. The time required to monitor NO_x in a chemiluminescence device is generally less than a minute. The apparatus required for this technique includes a particulate filter, a thermal converter, an ozone generator, a reaction chamber, and a vacuum pump.

Suspended particulate matter. Airborne particulates, known as SPM, come in many sizes. The larger, coarser types of particles are a local nuisance, contributing to poor visibility and soiling. However, smaller particles have serious consequences for the health of those exposed to them because they can penetrate deep into the lungs and airways. Most the SPM released into the air comes from industrial processes that involve the handling of materials (including loading and unloading) and the combustion of fossil fuels. Automobile exhaust is another major source of particulate matter.

SPM can be monitored using either manual or automated equipment. Manual techniques may be static or mechanical, but the latter is generally preferred due to its proven reliability and modest capital and operating costs. In the manual process, SPM is measured gravimetrically using electrically powered samplers. The samplers are equipped with an air pump/blower that draws in ambient air at a constant volumetric flow rate for a specific period of time. The air to be sampled passes through a glass fiber filter of known weight. The weight of particulate matter deposited on the filter can be used to calculate the mass concentration of SPM in the ambient air when the mass of collected particulate is divided by the volume of air sampled. This method is applicable for measuring the mass concentration of all particulate matter with a diameter ranging between 0.1 and 100 micrometers.

The sampling period can vary, depending on the concentration of SPM in the ambient air. If the ambient concentration is expected to be low, each sample is collected continuously over a 24-hour period. When the level of SPM is expected to be high, a sampling duration of 6-8 hours is adequate for each sample.

The gravimetric technique can also be used to determine the concentration of finer particles in the ambient air. When measuring the ambient concentration of particles of 10 micrometers (PM_{10}) or less, the air sampler draws ambient air at a constant flow rate into a specially shaped inlet where the particulate is inertially segregated into one or more size fractions within the PM_{10} size range. Each size fraction of particulate is then collected on a separate filter paper for a specified sampling period.

When particulate matter in a size range of 2.5 microns ($PM_{2.5}$) is to be tested, ambient air is drawn into a specially shaped inlet at a constant volumetric flow rate for a specific period of time. As the air is drawn in, it passes through an inertial particle size separator or impactor. Typically, the designed flow rate for $PM_{2.5}$ through the inlet is 1,000 m^3/hour measured as actual volumetric flow rate at the temperature and pressure of the sample air entering the inlet. Particles in the size range of $PM_{2.5}$ are separated from the sample air for collection on a polytetrafluoroethylene filter.

The apparatus used in these operations include a sampler (with air pump/blower), a sampler shelter, a flow recorder and flow controller, an orifice calibration unit, a timer, membrane or glass fiber filter, a manometer, a barometer, a thermometer, and an analytical balance.

The calculation for these tests makes use of the following equation:

$$\text{SPM}\ (\mu g/m^3) = \frac{(W_f - W_i)}{V_T} \times 10^6$$

Where	W_f	=	final weight of filter, grams
	W_i	=	initial weight of filter, grams
	V_T	=	total volume of air sampled, cubic meters
	10^6	=	conversion of gram to microgram

Automated techniques for continuous monitoring of SPM are usually employed in air pollution control programs that mandate continuous record. They may also be used for checking regulatory compliance. These techniques are comparatively expensive and specialized skills are required to handle the equipment. Three choices of automatic techniques are available:

(i) tapered element oscillating microbalance (TEOM),

(ii) beta-ray absorption analyzers, and

(iii) light scattering systems.

Of the three, the TEOM and beta-ray systems are widely used and thoroughly tested. The light-scattering device was developed recently and is less proven.

Carbon monoxide. One of the most common and widely distributed gaseous pollutants, CO results primarily from the incomplete combustion of carbonaceous materials. The principal sources are automobile exhaust, space heating, municipal and industrial incineration, and burning of wastes. Other sources include power plants, industrial boilers, diesel generators, coke ovens, blast furnaces, steel furnaces, organic chemicals, and petroleum refining.

CO is a colorless, odorless, tasteless, and stable gas that is lighter than air. In high concentrations, it causes various physiological changes and, eventually, death. Regular exposure at low concentrations can also have a significant impact on health. Industrial workers and urban inhabitants who are repeatedly exposed to this gas suffer from various illnesses.

A variety of techniques can be used to monitor the amount of CO in the ambient air. They include a continuous method known as NDIR technique, a gas chromatographic technique (semicontinuous method), an electrochemical technique (continuous method), an infrared spectrophotometric method, a semiquantitative detector tube technique, and a colorimetric method. Of these, the most common is the NDIR spectrophotometric technique. This is an automated method, which is generally regarded as the most reliable alternative. The NDIR technique depends on the absorption of infrared radiation by CO. The analyzers on which the technique is based have several advantages, being relatively insensitive to flow rates, reasonably independent of changes in the temperature of the ambient air, and offering a short response time. A drawback is that this method (like others) is insensitive to low-level concentrations of CO.

The analyzer used in the NDIR spectrophotometric technique consists of a sample cell, a reference cell, two infrared sources, and a detector cell. The reference cell is filled with a nonabsorbing gas such as nitrogen, and the sample cell is continuously flushed with the sample (ambient air). The CO in the air absorbs radiation emitted from the infrared source at wavelengths between 4.5 and 4.9 micrometers. The detector is made up of two compartments separated by a thin metal diaphragm and filled with CO.

If there is no absorbing gas in the reference cell, most of the infrared energy emitted from the source is transmitted to one compartment of the detector cell. The remainder of the infrared energy-an amount inversely proportional to the concentration of CO in the sample-reaches the other compartment of the detector cell. The unequal amounts of infrared radiation transmitted to the reference cell and the sample cell result in a pressure difference across the diaphragm which, in turn, causes the diaphragm to pulse back and forth. Displacement of the diaphragm is detected electronically and amplified to produce an output signal that is recorded. The signal provides a measure of ambient carbon CO. The NDIR method can also be used for the analysis of batch-type samples collected in bags or evacuated cylinders from the ambient air. Commercial NDIR analyzers can detect CO concentrations ranging between 0 and 100 parts per million (ppm).

Hydrocarbons. Hydrocarbons are a group of gaseous pollutants generated by automobile exhaust and industrial processes such as petroleum refining, and roasting and heating processes in ferrous metallurgical units and organic chemical units. Both methane and nonmethane hydrocarbons are found in the air. The methane version is more abundant and generally less hazardous than nonmethane hydrocarbons. Hydrocarbons themselves, are not particularly harmful when released into the air. However, in the presence of sunlight they undergo chemical reactions with NO that are also present in the atmosphere to form "photochemical oxidants." These oxidants pose a real threat to human health and agriculture. Nonmethane hydrocarbons, which have a higher level of photochemical activity than methane hydrocarbons, are a more serious problem.

The analysis of hydrocarbons in the atmosphere consists of a three-step procedure involving collection, separation, and quantification. In the first step, the sample air is drawn with the help of a pump. The air enters an evacuated canister (cylindrical tube) at a specific, predetermined rate for a specific period of time. Air containing methane and nonmethane hydrocarbons is then passed through a gas-chromatography column, where the two classes are separated. Separation is based on the different adsorption/desorption rates of the absorbent materials present in the column. When the methane and nonmethane hydrocarbons exit the column, they are injected into a device known as a flame ionization detector (FID). In the FID, the sample gas is injected into a flame created by burning hydrogen in either air or oxygen. As the two classes of hydrocarbons are burned, they release ions creating electrical currents across the electrodes inside the FID. These currents are amplified and displayed on an output meter/detector. The signal output of the detector is proportional to the two groups of hydrocarbons and is quantified when compared with standard concentrations of hydrocarbon free gases. Results of the monitoring can be expressed in parts per million by volume (ppmV) or parts per million by carbon (ppmC).

Hydrogen sulfide. This is an odorous gaseous pollutant that is offensive at low concentration and toxic at high concentrations. Repeated exposure to low concentrations of hydrogen sulfide (H_2S) has an irritating effect on the mucus membranes, eyes, and the respiratory tract. H_2S is generated from geothermal sources, anaerobic biodegradation (in the absence of oxygen) of municipal garbage at landfill sites, and industrial processes such as roasting and heating processes in ferrous metallurgical industries, and the krafting process in the pulp and paper industries.

H_2S can be monitored manually or with automated equipment. The manual technique is similar to that used for SO_2 and NO_x. A measured volume of air is drawn at a specific flow rate (1.5 liters per minute) for a specific period of time (up to two hours) with the help of a blower and passed through impinger tubes containing a reagent that reacts with the H_2S to form a complex. This complex is then made to react with other reagents to form a colored complex, the intensity of which is measured with the help of a spectrophotometer or colorimeter. The concentration of H_2S can be calculated from the spectrophotometer or colorimeter reading with the help of an empirical relationship based on the recorded absorbance and the concentration of H_2S.

The equipment required for this operation includes an impinger tube, an air pump/ blower, a flow control device, flow calibration equipment, a timer, spectrophotomer/colorimeter, and a thermometer. The amount of H_2S present in a sample can be determined using the following equation:

$$H_2S\,(\mu g/m^3) = \frac{(A - A_0)\times 10^3 \times B_g \times V}{V_S A}$$

Where A = sample absorbance
A_0 = reagent blank absorbance
10^3 = conversion of liters to cubic meters
B_g = calibration factor, mg/unit of absorbance
V = volume of absorbing solution, ml
V_S = volume of sample air corrected to 25°C and 760 mm Hg, liters
A = volume of aliquot, ml

Increasingly, the atmospheric concentration of H_2S is being monitored by automatic, continuous methods. In this case, the ambient concentration is determined by measuring the change in reflectance due to the formation of a complex from the reaction between H_2S and a reagent. The sample air is passed through a flow meter and a humidifier that maintains constant humidity in the reaction chamber required for the reaction, and then on a reagent (lead acetate) impregnated on paper tape. H_2S in the sample air reacts with the reagent on the tape (known as a sensing tape) to form a complex of lead sulfide. This reaction alters the reflectance of the sensor/paper tape due to the darkening caused by the complex. The resultant change in reflectance is detected by a photocell. Output from the photocell is transferred to an electronic device that produces a proportional signal, which is amplified and recorded continuously on a chart. A chart speed of 1 cm/minute is suitable for short-term analysis, and a chart speed of 1-5 cm/hour for long-term sampling. The rate of change in reflectance is proportional to the concentration of H_2S in the sample air.

The equipment used for monitoring includes a H_2S analyzer, which consists of a flow meter, a humidifier, a sensing surface exposure chamber, an optical system/photo cell, and an electronic detector, bubbler, pump, and recorder.

The concentration of H_2S is calculated using the following equation:

$$H_2S\,(\text{ppb/v}) = c(\mu - b)/(r - b)$$

Where
- c = concentration of reference standard, ppb/v
- μ = unknown sample analyzer reading, as received percent of scale
- b = blank analyzer, percent of scale
- r = reference standard analyzer reading, percent of scale

Mercaptans. These are odorous, gaseous compounds that are offensive at low concentrations and toxic at higher concentrations. Mercaptans are produced from geothermal sources, industrial processes (for example, the krafting process in a pulp and paper mill), and food processing units. They are usually monitored in ambient air near their industrial sources.

Monitoring procedures for mercaptans may be conducted manually or with an automated sequential sampler. When manual (mechanical) techniques are used, samples are collected by bubbling the air through a bubbler (a glass tube with inlet and outlet devices that allow the air to pass through). The bubbler contains a predetermined volume of an absorbing solution and the air passes through at a specific flow rate

(0.6 liter/minute to 2 liters/minute) for a specific period of time up to a maximum of two hours. The absorbing reagent captures the mercaptans present in the sample and a complex is formed. This complex is then diluted and made to react with other chemicals to form a colored complex. The intensity of the color of the complex is measured by means of a spectrophotometer, and the results can directly be related to the amount of mercaptans present in the sample by means of a calibration curve.

Both the sampling rate and sampling time can be adjusted, depending on the expected concentration of mercaptans in the ambient air at the monitoring station. However, these variables should be set so that linearity between the absorbance and concentrations is maintained. Typically, sampling is conducted at least twice a week at any monitoring station.

The equipment for manual methods includes a midget bubbler, an air pump/blower, a flow control device, a membrane-fiber filter, a flow meter, flow calibration equipment, a timer, a thermometer, a barometer, and a spectrophotometer.

The concentration of mercaptans is determined according to the following equation:

$$\text{Mercaptan}\ (\mu g/m^3) = A \times 1000/V_r$$

Where A = mass of the mercaptan read from calibration curve, mg

1000 = conversion factor, liters/minute

V_r = volume of sample air at standard conditions, liters

The volume of air sampled at standard conditions (25°C, and at one atmospheric pressure) is calculated as follows:

$$V_r\ (\text{Liter}) = Q \times t \times \frac{p}{101.3} \times \frac{298.15}{T}$$

Where Q = average flow, liters/minute

t	=	sampling time, minute
p	=	average atmospheric pressure, kPa
T	=	average temperature of air sample, K
101.3	=	pressure of standard atmosphere, kPa
298.15	=	temperature of standard atmosphere, K

Ammonia. A colorless, pungent, and suffocating gas, ammonia is generated naturally by the degradation of organic matter. High concentrations may be encountered, however, in urban or industrial areas as a result of emissions from local industrial sources. Likely sources include fertilizer plants, inorganic chemical plants, coke ovens and refineries, as well as the combustion of fossil fuel and the incineration of wastes. High levels of concentration of this gaseous pollutant are harmful to all forms of life.

The presence of ammonia in ambient air is usually monitored by mechanical techniques. The method is similar to that used for SO_2 or NO_x. A measured volume of sample air is drawn with the help of an air pump (blower) at a specific flow rate (1-2 liters/minute) for a specific period of time (usually one hour). The air stream passes through bubbler/ impinger tubes filled with a reagent that reacts with the ammonia in the air sample and forms a complex. This complex is made to react with other chemicals to form a second, colored complex. The intensity of the color is measured colorimetrically against a reagent blank (prepared with the same absorbing reagent), and is directly related to the amount of ammonia present in the corresponding air sample by means of a standard curve. The equipment required for this operation includes a bubbler/ impinger tube, a vacuum pump/blower, a flow meter, a glass fiber filter, a timer, a spectrophotometer, and a thermometer.

The amount of ammonia present in the air sample is estimated using the following equation:

$$NH_3\ (\mu g/m^3) = \frac{(A - A_0) \times 10^3 \times B_g}{V_r} \times D$$

Where A = sample absorbance

A_0 = reagent blank absorbance
10^3 = conversion of liters to cubic meters
V_r = the air sample volume corrected to 25°C and 760 mm Hg, liters
B_g = calibration factor, mg/unit of absorbance
D = dilution factor

Emission Sources and Inventories

The network of monitoring stations and the raw data compiled from this source are the core of any program to improve air quality. However, other types of information will also be needed, possibly soon after the program is launched. Some of these concepts and supporting data are discussed in this section.

Inventory of emissions. To formulate an effective set of policies and regulations, public officials need a good idea about the types of emissions released into the atmosphere and their major sources. An inventory of emissions can be developed to meet this need. In the ideal case, a specialized system is used to monitor emissions at their source. Unfortunately, this option requires elaborate equipment and highly trained personnel. Such systems currently exist only in a few countries, and even in those instances the data collected is fragmented and must be supplemented with estimates. It is clearly impractical for most developing countries to consider such a sophisticated and expensive alternative. However, construction of a simple version of an emissions inventory is feasible. The approach outlined here focuses on the identification and analysis of hot spots. The results should provide users with enough information to set the priorities for their program and to make tentative decisions on the policies and regulations needed.

The first step in this short-cut approach is to identify the most important point sources of emissions (for example, specific industrial establishments). Statisticians can begin by establishing a cutoff point that distinguishes between large and small establishments. Typically, the cutoff point would be firms with less than 10 or less than 25 employees. Those with a work force smaller than the cutoff point are excluded from the exercise. Up to 90 percent (and probably more) of all establishments would be eliminated by this criterion, but their omission should not bias the results. Studies in industrialized countries have shown that no more than 10 percent of all establishments are responsible for over 95 percent of air emissions. Furthermore, the big polluters are generally large firms with many workers.

Once the list of large establishments is finalized, analysts should try to determine those that are prone to cause pollution. Potential polluters can be identified with the help of international studies,[23] local expertise, and any previous studies carried out within the country. If possible, all establishments that are potential polluters should be visited. Should their number be too great or too widely dispersed to visit, a subset can be identified. To be representative, the subset should take into account both the size of the firms and the industries involved. Alternatively, the initial inventory can be restricted to a specific geographic area and to a very few types of emissions.[24]

Next, a field survey must be conducted on the basis of the final list of potential polluters. Interviewers may seek information on annual levels of production, raw material usage, energy use, production processes, measures employed to control emissions, and any other relevant information. From the survey, interviewers should be able to carry out a subjective evaluation of emission levels in each establishment. Emission scores are assigned to each establishment, with values ranging from zero (no emissions observed) to 5 (extremely high emissions). A similar evaluation of emission control measures can also be conducted. In that case, assigned values might range from 1 to 5, with the lowest value being given to establishments with satisfactory control measures and the highest to a situation where controls do not exist or are totally inadequate. The

[23] One useful international source is WHO (1993).

[24] For a discussion and some examples of these estimation procedures, see ADB (1999), pages 46-49; and UN Statistical Division (1999), Chapter 2.

results of these evaluations can be used to identify hot spots-for example, a specific geographic location where the density of industrial polluters is great, a particular establishment responsible for a disproportionate amount of emissions (a point source that is a hot spot), or various industries with high emission potential. Results of the evaluations should be widely distributed so as to provide analysts and policy makers with as much information as possible to combat industrial pollution.

Inventory of depositions. Still another component in a fully developed system for monitoring air pollution would be an inventory of depositions. The methodology for estimating wet deposition is rather well developed, but the same is not true for the calculation of dry deposition. The latter depends crucially on variables such as deposition velocity, the distribution of pollutants between the aqueous and dry phase, and the reliability of measurement methods. For these reasons, very few programs to monitor air quality consider dry depositions. A deposition inventory can be a valuable adjunct to a program for monitoring air quality, but it requires considerable expertise and should probably receive a lower priority than an inventory of emissions. It is recommended that countries at an early stage in the program of environment statistics defer development of this tool until a time when more experience has been accumulated.

Categories of emission sources. The practice of identifying emission sources by category is a common one, though it has no direct relevance to the data on air quality obtained via the system of monitoring stations. The convention is helpful, however, when readings for certain parameters exceed quality standards. In such a case, environmental managers will need to refer to the emissions inventory, and their task is made easier if records distinguish between different categories of emission sources.

At the most general level, sources of pollution can be described as stationary or mobile. Many stationary sources are associated with industrial activities. Within the industrial sector, two types of emissions from stationary sources are identified.

(i) Emissions resulting from the combustion of fossil fuels. The industrial activities producing these emissions are usually intended to generate power or heat. Compounds emitted include SO_2, NO_x, SPM, CO, VOC, and CO_2. Both the release and deposition of these compounds depend on the fuel used, the specific production process, and the existence of any cleanup technology, if any.

(ii) Process emissions associated with production processes. Many production processes require the physical or chemical transformation of materials. Others involve auxiliary substances that are used either for cleaning or for facilitating a chemical reaction. Industrial processes may release a large number of compounds into the air. The compounds may be associated with an input for the process, a chemical reaction occurring at an intermediate stage, or the final product itself. Because of these characteristics, the task of monitoring process emissions is more complicated than that of monitoring the combustion of fossil fuels.

A third stationary source exists in the household sector. Many households use biomass, coal, wood, kerosene or other "dirty" fuels for heating and cooking. The resultant pollution can be substantial if a large number of households in a city or urban area rely on these energy sources. The emissions, however, are much closer to the ground than those from stationary industrial sources and therefore have a more localized impact. Household emissions of combustible fuels are generally treated as part of the environment statistics of human settlements.

In addition to the two stationary sources in the industry sector, there is one important mobile source of emissions: the combustion of fossil fuels when transporting people and freight. The main emissions from motor traffic include SO_2 and SPM (both originating mainly from diesel fuels), NO_x, CO, VOC, lead (from leaded gasoline), and CO_2. Motor vehicles are concentrated in urban areas and, like households, their emissions are at ground level. Therefore, the pollution associated with transportation tends to be localized. If traffic congestion is substantial, emissions will be greater owing to frequent stops, accelerated starts, and idling motors. The poor quality of fuel is another factor contributing to pollution. Diesel fuels that are not desulfurized and leaded gasoline with high benzene content are especially dirty fuels. The amount of pollution attributed to motor traffic will also be higher if vehicle maintenance is generally poor, or if the vehicle fleet is relatively old.

Estimating Air Emissions

Air emissions come from many sources and no single method of estimation is possible. However, the task is simplified somewhat when the focus is on individual categories of emissions. The estimation procedures that may be employed for different categories of emissions are described in this section.

Emissions from fossil fuels. The combustion of fossil fuels is a relatively homogeneous process since the fuels and technologies for combustion and cleanup are limited. If energy statistics are available, figures on fuel usage can be derived. Preliminary estimates of emissions can then be calculated using WHO emission factors (WHO 1993) or local emission factors, if these are available. At this point, the estimates should be adjusted to take account of cleanup technologies. The results of this procedure can be compared or combined with data acquired from actual measurements. If data on the maximum allowed emissions is available from records of emission permits, this source can also be used to check the estimates.[25] The accuracy of the estimation procedure will vary substantially, depending on the precision of the data on which the estimates are based. For SO_2, the sulfur content of the fuel is the most important determinant. In the case of NO_x, the combustion technology is the critical factor. In general, emission factors are less accurate than data on fuel consumption.

25 Swedish officials use the maximum allowed emissions to compute the emissions of SO_2 and NO_x for all but the largest combustion plants. This approach may result in overestimates in Sweden, but in many developing countries the same procedure may yield an underestimate since actual emissions often surpass the allowed levels.

An example of the procedures used to estimate industrial emissions is presented in Table 4.5. The data refer to the city of Dhaka. At the time of the study, about 400 industrial establishments were registered. A far greater number was not registered, for most of these establishments either were too small to have significant emissions or were not regarded as major air polluters. A review of the register revealed that only 32 establishments were at least of medium size. These firms were widely dispersed around Dhaka. Most were in industries such as textiles and clothing, printing, beverages, and chemical processing, and their contribution to air pollution was primarily from boiler stacks. Because all boilers and furnaces used natural gas as fuel, the only significant emissions from these industries were assumed to be NO_x, CO, and VOCs.

Based on average boiler size and estimated steam production, gas consumption was computed, and from these figures emissions of CO and VOC were derived. Metallurgical, glass, and refractory establishments also used gas furnaces exclusively. In these operations, some SO_2, NO, and a considerable amount of SPM would be emitted. Estimates of average emissions per day per furnace were assumed for metallurgy and related industries. Finally, the many small-scale units around the city were assumed to contribute an amount of air pollution equal to the sum of emissions from medium-scale units.

Based on these calculations, analysts were able to identify the major industrial polluters and estimate industrial emissions. They concluded that industrial pollution was probably less than that attributed to vehicular traffic. The use of a relatively clean fuel (natural gas), coupled with the fact that industrial emissions are released at a much greater height than traffic emissions, were two considerations supporting this conclusion.

Process emissions. As noted in the preceding section, a large number of different compounds are released into the air by industrial processes. A careful review of production statistics will yield no more than partial information on this subject, since production methods, cleanup technologies, and operating conditions are also relevant. Generally, countries that have only recently begun to compile environment statistics should probably postpone the development of an inventory of process emissions for at least a few years.

Table 4.5: Estimates of Industrial Emissions in Dhaka, 1992 (no. of units and kilograms of emissions per day)

Item	Medium-Size Units		Total	Small-Scale Units	Total Dhaka
	Textiles[a]	Metallurgical[a]			
Units	14	18	32	>300	>330
SPM	–	360	360	360	720
CO	3,500	900	4,400	4,400	8,800
HC	3,500	900	4,400	4,400	8,800
NO_x	–	1,800	1,800	1,800	3,600
SO_2	–	180	180	180	360

[a] Includes related industries.
Source: Bangladesh Department of Environment (1992).

Once a country is ready to proceed, it will be critical to determine which types of emissions deserve priority. Although thousands of chemical compounds are released into the air, only a handful are of national importance and just a few assume local significance. A careful screening of production statistics would be the first step in this exercise. WHO (1993) has produced a list of process emissions identified according to the International Standard Industrial Classification (ISIC) and this information should be helpful in the screening.[26]

The types of emissions and not the volumes are the overriding feature in assigning priorities. Toxic substances can have effects at a very low level, while more common emissions such as NO_x are released in great quantities but have only moderate effects. The list of special compounds in Table 4.6 may be helpful in compiling a preliminary list of substances to be included in the inventory. Other lists produced by OECD and national agencies are also available and can be consulted. However, users should bear in mind that some chemicals and toxic substances that are now banned in industrialized countries may still be used or even produced in their own country.

[26] Additional information can be found in WHO (2000b).

Traffic emissions. Some problems encountered when estimating traffic emissions are the amount and variety of pollution sources and their mobility. Emissions also vary depending on the types of vehicles in use, their age and state of maintenance, the type and quality of fuel, driving patterns, and other factors. Analysts will need to start by determining the composition of the active vehicle population. Usually, such information can be obtained from official registrations systems for license plates, car ownership, or insurance.[27]

Table 4.6: Compounds to Consider in an Inventory of Process Emissions

Arsenic	Coke oven emissions	Perchloroethylene
Asbestos	Ethylene dibromide	Policyclic organic matter
Benzene	Ethylene dichloride	Radionuclides
Beryllium	Ethylene oxide	Trichloroethylene
1,3 Butadiene	Formaldehyde	Vinyl chloride
Cadmium	Gasoline vapors	Vinylidene chloride
Carbon tetrachloride	Mercury	
Chloroform	Methylene chloride	

In addition to the statistics gathered on vehicle population by category, the most important set of data is the set of emission factors by driving mode, by vehicle age, and type. Standardized estimates of emission factors have been published and can be used, but locally derived estimates and road measurement values are preferred.[28] An example of one set of emission factors for metropolitan Manila is shown in Table 4.7. Using

[27] The system should be checked to verify that it is up-to-date. If not, further adjustments will need to be made.

[28] Characteristics such as maintenance practices, driving patterns, and the age of the vehicle population vary widely from country to country and their effects will be reflected in the values of emission factors. The appropriateness of standardized factors can be questionable in some instances.

Table 4.7: Emission Factors in Metropolitan Manila (g/km)

Vehicle type	CO	HC	NO_x	Sulfur	Lead	Particulates
Car	49.5	6.0	2.7	0.011	0.073	0.1
Utility vehicle (gas powered)	60.0	6.0	2.7	0.014	0.092	0.12
Utility vehicle (diesel powered)	2.5	0.7	1.4	0.115	0	0.9
Taxi	1.9	0.65	2.0	0.081	0	0.6
Jeepney	2.5	0.7	1.4	0.121	0	0.9
Truck	12.4	3.7	12.5	0.374	0	1.5

Source: ADB (1995).

an approach similar to that described here, and based on the emission factors given in the table, analysts determined that trucks and buses accounted for 41 percent of all emissions in Manila, jeepneys and taxis contributed 24 percent and utility vehicles were responsible for 20 percent.

To conclude, three types of emission inventories have been described in this section. None of this information may be available in countries that only recently launched an environment statistics program. However, these inventories are important components of any program and their development should be considered once sufficient experience has been gained. The highest priority should probably be assigned to industrial emissions, followed by traffic emissions.

5

WATER RESOURCES AND WATER QUALITY

Concerns about the quality and availability of water resources have a long history. The constant attention accorded this subject reflects man's dependence on water for personal use, farming needs, and industrial processes. Today, the pollution of inland and marine waters is recognized as a serious and growing problem. The quality of potable water and the threat of waterborne diseases (for example, cholera and typhoid) are critical public health issues in many developing countries. Flooding has become a recurrent event in many parts of the world, while in some countries water diversion schemes have come under attack for causing damage to ecosystems and precipitating changes in local climates.

Chapter 5 begins by considering how monitoring procedures vary, depending on the type of water body being monitored. The determinants and characteristics of each submedium are distinct and require equally distinctive monitoring strategies. With so many options, generalizations become difficult or even misleading. This chapter therefore begins with a discussion of general issues and then goes on to describe the monitoring systems for three submedia-rivers, lakes, and groundwater-along with several related features such as sampling frequencies, laboratory techniques, and measures for quality control. A number of parameters that are usually included in any monitoring program are examined in the section Water Parameters. Methods of measuring effluent discharges are considered in the section Estimating Water Discharges, and the main issues to be addressed when monitoring water quantity are outlined in the section Water Quantity and Uses.

Statistical Relationships

Most countries collect statistics on effluent loads (discharges into receiving water bodies), water quality, and water quantity. The significance of these topics is obvious, but the organization and interpretation of the data are by no means straightforward. Problems arise because of several unique characteristics of this medium. First, water, unlike air, is a medium consisting of several submedia: watercourses (ranging from brooks and streams to large rivers), lakes, and groundwater resources such as aquifers and salt-water bodies. Each submedium has its own particular set of attributes that must be taken into account in the statistical process. Moreover, water quality varies not only between submedia but also within a particular water body. The water quality of a river, for example, changes over its course due to natural circumstances (for example, differences in the river bedrock or inflows from tributaries) and human-caused factors such as municipal and industrial discharges or the construction of physical barriers such as levies or dams.

Second, the statistics for the three topics are closely interrelated or interdependent. This interdependence makes it difficult to interpret results and to identify lines of causation. The relationship between water quality and the discharge of effluents is an obvious one. When a waterway's natural capacity to transform and recycle discharges is exceeded, its water quality deteriorates. Discharges into the water depend mainly on conditions in the industry sector-that is, on determinants such as production technologies, market demand, and product mix. Quality, however, is determined not only by discharges but also by the hydrological regime. The natural factors making up this regime include the geological characteristics of the subsoil, soil properties, and meteorological determinants (for example, precipitation, temperature, and radiation during different seasons of the year). Policy makers would like to know precisely how various economic activities alter water quality, but, in practice, it is almost impossible to distinguish these effects from those of natural factors.

The interrelationships between water quality and quantity create similar problems. The simple fact that a small body of water is more easily polluted than a large one is an example. Water quality may be a function of the volume of effluents discharged, but it also depends, indirectly, on factors relating to quantity-for example, hydrological conditions and the volume of water used for irrigation, industrial purposes, and other needs. Policy makers cannot be sure that their efforts to control the discharge of effluents will yield the desired results unless they have corresponding data on precipitation, evaporation, and water usage. Furthermore, all this information must be available for each body of water being monitored.

Third, the statistical approaches employed in each of the three fields are not fully compatible. Methods for recording discharges and monitoring water quality are well established, but no clear connection between the two approaches exists. The main reason for this discontinuity has to do with the widely different sets of determinants noted above. The subject of water quantity poses its own set of problems. No comprehensive system is available to link data on surface water and groundwater with related issues such as water usage and hydrological conditions. To deal with this multiple set of concerns, statisticians employ an accounting approach that differs fundamentally from the methods used to track the discharge of effluents or monitor water quality.

Monitoring the Quality of Surface Water

Programs to monitor water quality are generally intended to serve at least two purposes. One is rooted in the laws, regulatory directives, and water-quality standards of the country. The results of a monitoring exercise should enable public officials to judge quality in relation to legal standards, assess the environmental state of the country's water system, and identify key trends. A second purpose is to supply both government officials and the general public with findings that can be used to develop and implement measures to improve water quality.

To meet the information needs of policy makers, two types of networks may be required:

(i) An extensive network generally consists of numerous sampling sites, comparatively few annual samples, the analysis of just a few variables, and one or only a few years of sampling history.

(ii) An intensive network consists of sampling sites providing data for detailed investigation, numerous annual samples or the measurement of many variables, and several years of observations.

Both extensive and intensive components are found in some monitoring programs. In such a case, one subnetwork consists of a number of sampling stations where data is collected for only a few parameters. A second, intensive subnetwork makes use of a few stations with frequent samples being collected for several variables.

The time horizon associated with monitoring activities is another distinctive feature. Most programs will have a legal justification and are therefore long-term in character. Their emphasis may change as new laws are passed or when new methods of water quality management are perfected, but the need to measure water quality will continue. Long-term programs, however, must sometimes be supplemented by special surveys or other short-term projects. For example, it may be desirable to survey certain water bodies on an occasional basis or to conduct one-time surveys of a particular pollution problem such as the occurrence of a pesticide in surface waters.

The topography, geology, and hydrology of the area to be monitored should also be taken into account. In the case of a river monitoring system, for example, the designers must be sure to locate stations at sites that are representative of all hydrological features such as zones of turbulent flow, zones of normal flow, and confluences. The land uses of the surrounding catchment area also affect water quality. The water quality of a river will vary, depending on whether the catchment area consists primarily of forest or agricultural land.

Finally, sampling frequency depends on various determinants such as the monitoring objectives, the statistical variation of the parameters, the concentration of pollutants, and the availability of financial and human resources. In the absence of any background data on the parameters, a preliminary decision about sampling frequency can be made on the basis of some knowledge of local conditions. When a sufficient amount of data has been collected, the frequency can be modified as required. Statistical methods can also be employed to determine frequency, provided that some data on water quality at a given location is already available and is normally distributed. In that case, the number of samples that must be collected during a given period of time (day, week, month, year, or season) so as to obtain an average value for a particular parameter can be calculated using the following equation:

$$N \geq \left(\frac{ts}{U}\right)^2$$

Where	N	=	the number of samples to be taken
	t	=	student-t statistic for a given confidence level
	s	=	the standard deviation
	U	=	acceptable level of uncertainty

River monitoring networks. Many countries operate programs to monitor river water. Major rivers are typically singled out for attention, although the more elaborate networks may include some small rivers and streams. In addition, there are various international programs supported by organizations such as OECD and the EU, and the Global Environmental Monitoring System (GEMS) operated jointly by WHO and UNEP.

National river monitoring networks are generally intended to serve one or more of the following purposes:

(i) provide a general characterization of rivers in the country;

(ii) monitor the water quality of rivers draining specific areas (for instance, reference sites in forested or uncultivated areas) or leaching substances from agricultural watersheds; and

(iii) supply the data needed to estimate riverine loading from land into coastal areas, or the loading of transboundary rivers from one country to a neighboring country.

Many networks serve multiple purposes. For example, data obtained via monitoring may be used to make a general characterization of river water quality and to estimate the nutrient loading of coastal areas. Often, a network will consist of two or more sub-networks, with a few intensive sampling sites on major rivers and numerous basic sampling sites located at less important tributaries and river reaches.

Decisions regarding the number of sampling sites and their locations depend, in part, on the program's objectives and costs. However, other factors must also be addressed if statisticians wish to develop indicators that are representative of conditions over long stretches of a river or large regions of a country. One of these factors is the areal density of the network. In developed countries with large river systems, a comprehensive network may consist of several hundred sites, but in many countries the number is far less. The density of sampling sites can range from 1 site per 10,000 square kilometers to more than 5 sites per 1,000 square kilometers, although 1-2 sites for every 2,000 square kilometers is typical. Another determinant is the population of the area under study. The density of sampling sites in relation to population varies from 2 to 500 sites per million inhabitants. The length of the river itself is relevant, with each sampling site representing from 6 to 6,000 kilometers of river. Most sampling sites will be located downstream of specific sources of effluent discharge. However, one or more monitoring stations should be situated upstream of major discharge points to determine the pollutant loads from an industrial or municipal discharge. Finally, the primary data should be accompanied by a description of the location where it was gathered (for example, information on the catchment area).

Networks created to monitor water quality and the loading from specific catchments may encompass up to 20 small streams and require detailed studies of both water quality and the characteristics of the catchment (for example, land use or soil type). A different configuration is appropriate when the purpose is to estimate the riverine loading of contaminants from land to sea, or in a transboundary river. Generally, these networks consist of sampling sites located at downstream points in all major river systems. The geography of the country also influences the design. Countries that have a long coastline compared to their area tend to have a large number of relatively small river systems. Consequently, numerous sites are needed to estimate loads to coastal areas. A much smaller number is required in countries dominated by a few large river systems.

Lake monitoring networks. Programs to monitor the water quality of lakes are less common than those for river-based systems. Attention generally focuses on the largest lakes or those known to have specific problems such as acidification or eutrophication.[29] In many developed countries, local governments operate lake-monitoring programs and methods are not standardized at the national level.

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[29] Eutrophication is the enrichment of water by nutrients (especially nitrogen and phosphorus compounds, and also organic matter). The result is an accelerated growth of algae and higher forms of plant life, which upset the balance of organisms present in the water and jeopardize the quality of the water.

Lake-monitoring programs may either use intensive sampling procedures or rely predominantly on surveys. A program based on intensive methods will have a sampling frequency of several times per year and cover only a small number of lakes. The survey-type approach focuses on a large number of lakes that are sampled over long intervals (every five years, for example). The lakes to be surveyed are either determined subjectively or identified by statistical criteria. Sometimes, a survey program will be supplemented by a series of intensive annual studies of a relatively few lakes.

The purpose of a survey-type approach is to determine the general environmental state of lakes and, perhaps, to identify specific problems that will be followed up by a more detailed study. Intensive programs are necessary to determine the exact environmental state of a lake, but they are relatively costly due to the higher level of detail sought. Other issues that intensive programs may address include the chemical water quality, biological status, seasonal effects, level of nutrients, acidification, toxicity, and eutrophication.

Monitoring the quality of groundwater. Two important characteristics distinguish groundwater from surface water and should be borne in mind when designing a monitoring network. These are:

(i) the slow movement in groundwater with relatively large residence times; and,

(ii) the considerable degree of physical and chemical interdependence between groundwater and the material of an aquifer.

Most networks are intended to identify trends in water quality and to serve as a general means of surveillance. Other possible objectives are to detect the intrusion of seawater in countries with long coastlines, evaluate the impact of airborne pollutants, or comply with legal requirements governing the quality of drinking water.

Three general types of networks for monitoring the quality of groundwater are in use: basic, specific, or temporary networks. A basic network is intended to provide general information about the quality of groundwater. Ideally, it will cover the entire country, and monitoring operations will be of a permanent nature. Reference stations providing background information on the natural quality of the groundwater are an integral part of a basic network. The information gathered via this network forms the basis for evaluating future trends in quality and for specific investigations of hydro-geological conditions. The design of a basic network will generally take into account the following principles:

(i) Stations could be placed in a square net or some other geometrical pattern with a fixed distance between them.

(ii) Stations should be placed in the main aquifers.

(iii) Stations should also be located in other important aquifers in the area that are selected to ensure that the results are representative.

(iv) Reference stations providing background information should be established outside areas affected by direct human activities such as groundwater pumping and other anthropogenic changes.

Specific networks are meant to monitor selected areas or specific kinds of pollutants emitted from point sources. Such a network can function independently, or it can be an extension of the basic network. In the latter case, it will have to fulfill the need for data in areas between different sites of effluent discharge (point sources) in the larger basic network. A specific network can have a permanent character, but it may also be in operation only while information is needed at the particular location. For example, around landfills a specific network may be operated as long as the landfill is active and for a specified period after the landfill is closed.

Temporary networks are established to collect data for particular projects. The network will be operational during the project period, after which it is closed. Eventually, some stations may be transferred to a basic or specific network. A temporary network will usually be more dense than a basic or specific network and the data obtained on groundwater quality will be used in a variety of studies conducted on the area.

Whatever the type of network, there appears to be no generally accepted guidelines for the minimum density of monitoring sites. However, some of the factors that govern decisions about location and density include the following:

(i) size of the area to be monitored

(ii) geological and hydrogeological complexities

(iii) sizes of the main aquifers

(iv) land use in the area

(v) ease of access to the area

Possible sources of groundwater contamination include diffuse sources from the atmosphere; diffuse sources from land use (primarily farming); and point sources such as landfills, contaminated sites, and leaking sewer systems. The density of monitoring stations will be higher when point sources rather than diffuse sources are the main concern. Areas known to have a high rate of infiltration also need to be monitored intensively. A lower density is acceptable in areas with sparse populations, minimal amounts of arable land, and no serious point sources of contamination. Finally, the designers of any network should attempt to monitor all major aquifers if financial and human resources permit.

Sampling frequencies. The foregoing description of each monitoring system noted certain differences in sampling frequencies. This issue is an extremely important one and deserves more attention. Both the quality of the data and the overall cost of the monitoring exercise depend crucially on the frequency of sampling, and more details are provided here.

The sampling frequencies recommended for GEMS/Water project stations are summarized in Table 5.1. Three types of monitoring sites or stations are identified. Baseline sites are required to determine the generality of runoff behavior in the region or country. In the case of river monitoring, at least some stations should be located in natural catchments where little or no human activity exists and where most of the catchment is natural landscape. Usually, a majority of the stations will be trend sites. In a river monitoring system, these stations would be situated downstream of major polluters. Flux sites are generally placed where rivers discharge into the sea, where they cross national boundaries, or where there is an interchange between surface water and groundwater.

The number of minimum and optimum samples varies with the submedia. Rivers, depending on their size and flow regime, are frequently sampled over the year. The quality of groundwater aquifers is more stable and usually requires fewer samples; no specific recommendations are made. Sampling is required less often in lakes than in rivers, but data may need to be collected more frequently for specific causes such as eutrophication. In the case of specific issues such as river flux or eutrophication, the required number of samples in a given period of time is generally greater.

In countries where seasonal variations are great, more frequent samples will need to be collected. To monitor the quality of surface water, the following recommendations are offered in the GEMS project:

(i) Weekly samples should be collected for one year.

(ii) Daily samples may be collected on seven consecutive days, once in each quarter.

(iii) Hourly samples may be collected over a 24-hour period, once in each quarter, and every four hours for a period of seven consecutive days in each quarter.

In the case of groundwater, samples may be collected at weekly or fortnightly intervals for some time so as to establish the water

Table 5.1: Recommended Annual Sampling Frequencies for GEMS/Water Quality Stations

Station Type	Rivers/Streams	Type of Water Body Lakes/ Reservoirs	Groundwater
Baseline	Minimum: 4 samples, including high and low water stages Optimum: 24 samples (i.e., fortnightly sampling and weekly sampling for total suspended solids)	Minimum: 1 sample at turnover (sampling at lake outlet) Optimum: 1 sample at turnover and 1 vertical profile at end of stratification period	
Trend	Minimum: 12 samples for a large drainage area (ca 100,000 kilometers) Maximum: 24 samples for small drainage area (ca 10,000 square kilometers)	Eutrophication issue: 12 samples, including twice monthly during summer Other issues: Minimum: 1 sample at turnover Maximum: 2 samples (one at turnover, and one at maximum thermal stratification)	Minimum: 1 sample for large, stable aquifers Maximum: 4 samples for small alluvial aquifers Karstic aquifers: same as rivers

Table 5.1: Recommended Annual Sampling Frequencies for GEMS/Water Quality Stations (continued)

Station Type	Rivers/Streams	Type of Water Body Lakes/ Reservoirs	Groundwater
Global river flux	Large basins (>200,000 square kilometers):[a] 6 samples for some particulate metals[b] 12 samples for all other variables Small basins (<200,000 square kilometers):[a] 24 samples for basic monitoring variables[c] 12 samples for expanded nutrients, organic contaminants, and some expanded metal monitoring[d] 6 samples for some particulate analysis[b]		

[a] For global river flux stations, a continuous record of water discharge and weekly sampling for total suspended solids is recommended.

[b] For particulate arsenic, cadmium, chromium, copper, lead, mercury, selenium, and zinc.

[c] For temperature, pH, electrical conductivity, dissolved oxygen, calcium, magnesium, sodium, potassium, chloride, sulfate, alkalinity, nitrate plus nitrite, total phosphorus filtered and unfiltered, silica, chlorophyl a, organic carbon dissolved and particulate, organic nitrogen dissolved and particulate.

[d] For dissolved and particulate fractions of aluminum, iron and manganese; and for dissolved arsenic, cadmium, chromium, copper, lead, mercury, selenium, and zinc.

Source: WHO (1992).

characteristics at a monitoring station. Afterwards, samples may be collected less frequently over the year.

Monitoring stations and equipment. A wide range of terminology is used to describe the various types of monitoring stations. Usually, the stations are identified by the information provided. Some of the more important types of stations follow:

(i) benchmark or reference stations aimed at characterizing catchments that are undisturbed, as far as possible, by man;

(ii) boundary stations intended to describe fluxes either between legal boundaries or between submedia (from a river to a lake or ocean, or from a surface stream to groundwater);

(iii) impact stations used to monitor well-defined pollution sources; and

(iv) representative stations that can be used to provide summary information for a large area, usually with long records.[30]

Either automatic or manual equipment can be used. In the case of automatic equipment, the monitoring devices include probes immersed in a water body and measurement occurs in situ. These devices employ a self-contained, battery-operated instrument that can be used up to 300 meters below water level. With automatic equipment, the task of laboratory analysis is greatly simplified. The costs, however, are substantial compared with those for the manual approach and operation requires special skills. If manual methods of monitoring are used, additional sampling apparatus and reagents are needed, depending on the parameters to be analyzed.

30 Other types of stations are (i) stationary stations providing data intended to fulfil legal commitments; (ii) operational stations set up to manage day-to-day issues of water quality by local, regional, or national agencies; and (iii) research stations operated as part of specific scientific projects.

The analytical methods used with automatic water quality monitors (or on-line instruments) closely parallel those used in the laboratory. The main difference between laboratory instrumentation and on-line instrumentation is in the robustness of construction of the equipment and the availability of auxiliary systems in automatic monitors to allow for sample preparation, instruments/sample line cleaning, and instrument calibration.

Ideally, an automatic monitor will use low-cost, non-invasive measurement techniques, produce highly accurate results, and require little or no maintenance. In reality, a more realistic goal is to obtain results of acceptable accuracy at modest costs, with a service requirement not greater than once per week. The main features of an automatic water monitor that would be required to achieve this goal are as follows:

(i) appropriate location of sampling sites;

(ii) strong construction designed for a specific purpose (including adequate physical protection provided by the instrument housing) and robustness of the operational methodology;

(iii) tolerance for extremes of temperature likely to be encountered;

(iv) resistance to the ingress of dust and water;

(v) tolerance for electromagnetic fields, electrical transients, and power supply disturbances;

(vi) minimum supervision and maintenance requirements; and

(vii) a design that allows for easy access and repair.

Monitoring applications require predictable, long-term analytical performance in terms of accuracy and reproducibility to ensure data comparability. Attributes such as a fast response time and high sample-throughput rates are normally of less importance. The selection of a monitoring instrument (which is governed by the method of analysis) should take into account the use for which the data is intended. For example, instruments based on well-documented colorimetric methods can produce data of predictable and consistent quality.[31] Finally, the degree of complexity inherent in any installation depends on both the measurement technique and the nature of the sample. Most parameters can be measured in a straightforward manner, but a few, such as a phenol or a treated or partially treated waste effluent, require a high level of operator input.

Sampling and laboratory techniques. Technicians should be familiar with some basic principles and techniques of sampling regardless of whether the system is manual or automated. The spatial and temporal variability of the parameters are two of the more prominent factors to be considered in the case of river monitoring. The dilution and dispersion of pollutants are subject to temporal variability owing to seasonal changes and related climatic effects. Spatial variability of pollutants, on the other hand, is evidenced by the extent to which pollutants are mixed with the water. In a typical river body, spatial variation of pollutants is governed by the width and depth of the river and water velocity. Thus, for a shallow river where the flow is low, samples are collected from an average depth in the middle of the river, whereas for a deep river with a high flow, samples need to be collected at various depths.

A variety of different types of samples may be required, depending on the purpose and availability of resources. For instance, samples may be collected at a particular time from a single location, or from various locations over a period of time. The different types of sampling methods used are described below.

A grab or spot sample may be "discrete" (that is, the sample is collected at a specific location, depth, and time) or "depth-integrated"

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[31] These instruments sometimes have a long response time. Such delays can be inherent in the chemistry involved. Instruments based on such methods may not be ideal for control applications requiring a fast response, but are generally well suited to monitoring applications.

(the sample is collected over the entire depth of the water column at a specific location and time). Obviously, grab or spot samples can only represent the composition at the time and location when collection occurs. The grab method is useful for the following purposes:

(i) characterize water quality at a particular time and location,

(ii) provide information regarding the minimum and maximum measurements of a parameter,

(iii) allow collection of variable sample volumes,

(iv) monitor a stream that does not flow continuously,

(v) analyze parameters that are likely to change, and

(vi) establish a history of water quality over relatively short time intervals.

A composite sample (also known as a time composite) is a mixture of grab samples of equal or weighted volume, all collected at the same location at different points in time. Composite samples are useful for assessing the average concentration/load of pollutants (for example, assessing the average load of a particular pollutant in an effluent treatment plant). This method of sampling reduces the time and effort that would otherwise be required to obtain several grab samples and then compute the average from a range of data. Normally, a composite sample is collected over a 24-hour period, but it can be taken for different shifts or cycles of any particular operation.

Integrated (or composite) samples are mixtures of grab samples collected from different points simultaneously. These are useful for monitoring the water quality of rivers or other water bodies when variations in width or depth are significant. Integrated samples provide an estimate of average water quality at the time of sampling. Special equipment is required to collect samples at particular depths without contaminating the overlying layer of water. The method is relatively complicated since it requires a knowledge of both the water flow and the composition of various layers.

Usually, more than one laboratory analytical method is available for almost all water quality parameters. The most appropriate technique depends on the concentration of the pollutant in the sample, the degree of precision or accuracy required, the complexity of the analysis, and the possibility of interference from other chemicals. In addition, technicians should be aware that the samples obtained for some parameters will be "nonconservative," meaning that values can change in the time between collection and analysis in the laboratory. In such a case, safeguards are needed to ensure that the sample is immediately stabilized before dispatching it for laboratory analysis.

Elements of quality control.[32] The selection of an appropriate format for data storage is a simple, but critically important step to ensure data quality. The format should provide ready access to all relevant sample details such as date and time of sampling and grid references. It should allow easy examination of the data for errors, and facilitate the rearrangement of the data into subsets as required.[33] Second, it is important that all associated information be recorded alongside the actual sample value. This information is needed not only for the purposes of the monitoring scheme, but also to help validate the data. Third, a common format for data transfer should be used by all suppliers and users so that no errors are introduced when the information is transferred from one group to another.

The simplest check for errors in data entry is to identify values falling outside an expected range. These outliers can be verified, corrected, or discarded as appropriate. However, data should only be discarded when it is clear that an error exists. Outliers occurring as a result of random variation are valid and their exclusion will bias

32 In addition to the procedures described here, the reader should refer to the discussion of quality control in Chapter 3 which, contains additional material of a general nature that is relevant.

33 A number of commercial database systems can serve these purposes.

results. Methods for checking data in relation to the expected range include the following:

(i) When checking the sample data gathered for the parameters, one way to identify errors is to flag all observations greater than three standard deviations from the mean of the parameter. The validity of the flagged data can then be verified with the supplier or source.

(ii) A similar approach is to flag the highest and lowest X percent of the data for a determinant (where X percent is some suitably small value such as 1 percent).

(iii) The information recorded for fields other than parameters such as grid references may also include errors and should be checked. Dates before or after the start or finish of a monitoring exercise are obviously wrong. Grid references that do not correspond to the appropriate water body are also incorrect. In some cases, other variables can be used for cross-checking. For example, dates that are not synchronized with sample codes would mean that either the codes or the dates are wrong.

Another method of quality checking is to use a statistical quality assurance scheme, in a way similar to analytical quality control. A number of data records are selected at random (with replacement) and checked for mistakes. The proportion of errors in the database is estimated from the proportion of errors in the randomly selected records, and a confidence interval for the proportion is set. Quality standards are being met if the true proportion of errors is below the prescribed level, estimated at a certain level of confidence.

Water Parameters

A large number of parameters may be included in any program to monitor water quality, and several are considered in this section. Physical parameters are discussed first, followed by chemical and biological parameters. In each case, the reasons for monitoring are summarized, the typical sampling frequencies are noted, and the recommended testing procedures and apparatus are described.

pH and temperature. pH is defined as the negative logarithm of the hydrogen ion concentration, that is, $\log[H^+]$ in water. Pure water is ionized to a very small extent into its basic components, H^+ and OH^-, and at equilibrium, the product of concentrations of H^+ and OH^- is constant - 10^{-14}. Thus

$$[H^+] + [OH^-] = 10^{-14}$$

The above equation is easier to express in logarithmic form, as follows:

$$\log[H^+] + \log[OH^-] = {}^-14$$

Changing all terms to negative

$$-\log[H^+] - \log[OH^-] = -({}^-14) = 14$$

Thus, as defined earlier,

$$pH + pOH = 14$$

It is clear from this equation that as pH increases, the pOH decreases and vice versa. Water with a pH level of less than 7 (when the concentration of H^+ ions is greater than that of OH^- ions) is considered acidic. On the other hand, when the pH is above 7 (when the concentration of OH^- ions is greater than that of H^+ ions), the water is considered alkaline.

A number of processes, such as water softening, precipitation, and corrosion control, are dependent on pH. Measuring the pH is therefore important when monitoring water quality. Measurement is a relatively simple process, which can be accomplished with the help of a commercially available pH electrode (probe). Most commercial pH probes come with a temperature probe. Temperature is also monitored every time pH is monitored. In case the pH probe does not have a temperature probe, the temperature can be measured by a good quality mercury thermometer having markings for 0.1°C.

The commercial probe that is generally used consists of a glass tube (electrode) and a display that indicates the pH. It is important that the probe be calibrated, using freshly prepared standard solutions of known pH. Once calibrated, the probe is lowered into a sample solution or directly in a water body in the field and the pH is read on the display of the unit. The probe must be kept in the sample until it displays a steady reading. Because pH is affected by temperature, it is important to report the temperature at which the pH is measured.

Temperature is of more general significance in the monitoring process because it affects several chemical and biochemical reactions that occur in nature as well as in water and wastewater treatment plants. Temperature also affects precipitation and the dissolution of pollutants in water. Finally, the discharge of effluents at high temperatures can alter the aquatic ecology of the receiving waters. Measuring water temperature is therefore critical when monitoring water quality.

Solids. The term "solids" refers to the matter suspended or dissolved in water. "Total solids" are the residual materials left in a vessel or plate after all the water in a sample has been evaporated by drying in an oven at a specified temperature. Total solids include total suspended solids (TSS)-that is, the material left on the filter when the water sample is filtered-as well as total dissolved solids (TDS), which is the material that passes through the filter.

The presence of suspended solids in natural waters may be undesirable for various reasons. It can increase the turbidity of the water, which affects light penetration. This characteristic, in turn, affects the biological life in the water body. It may also be aesthetically undesirable for such purposes as bathing and recreation. The presence of dissolved solids can alter the taste of water and, at high concentrations, can affect the physiology of the consumer. Waters with high dissolved solids content are unsuitable for industrial applications or for irrigation. The analysis of solids is also important for determining the efficiency and control of physicochemical and biological wastewater treatment processes, as well as for assessing regulatory compliance.

Under normal conditions, the initial frequency of sampling will vary from one submedium to another. In rivers, sampling may initially be once every two weeks; for lakes the frequency would be once every two months, and for groundwater, once every three months. After sufficient experience has been gained, statistical analysis of the data can determine if these sampling frequencies should be altered.

The testing procedures for determining the concentration of solids in a water sample requires that a known volume of water be evaporated and the weight of the residual solids measured. Total solids are measured by placing a known volume of a well-mixed sample in a preweighed dish and dried to constant weight in an oven at 103-105°C. To determine TDS, a known volume of well-mixed sample is filtered through a standard glass fiber filter and the filtrate is evaporated to dryness in a preweighed dish. The calculation for the TDS is similar to that for total solids.

TSS are determined by calculating the weight of the solids on the filter. For this, the filter paper is weighed before a known volume of a sample is filtered through the paper. After filtration, the filter paper along with the residue is dried in an oven to a constant weight at 103-105°C, and then the filter paper is weighed again. The difference in the two weights gives the weight of the residue retained on the filter paper.

Total solids can be calculated as follows:

$$\text{mg total solids/L} = \frac{(A - B) \times 1000}{\text{sample volume (mL)}}$$

where A = weight of dried residue + dish in mg

B = weight of dish in mg (determined prior to placing the sample in the dish)

TDS can be calculated as follows:

$$\text{mg total dissolved solids/L} = \frac{(A - B) \times 1000}{\text{sample volume (mL)}}$$

where A = weight of dried residue + dish in mg
B = weight of dish in mg (determined prior to placing the sample in the dish)

TSS can be calculated as follows:

$$\text{mg total suspended solids/L} = \frac{(A - B) \times 1000}{\text{sample volume (mL)}}$$

where A = weight of dried residue + filter in mg
B = weight of filter in mg (determined prior to filtering the sample)

The apparatus required for measuring solids includes evaporating dishes of 100 mL capacity made of porcelain, high-silica glass, or platinum; a drying oven for operation at 103-105°C; a muffle furnace for operation at 550°C; a desiccator; an analytical balance capable of weighing to 0.1 mg; and wide-bore pipets.

Dissolved oxygen. An essential compound in natural waters, dissolved oxygen (DO) is necessary to sustain aquatic life and is critical in wastewater treatment process control. The presence or absence of oxygen also determines the "oxidation state" of natural waters, which in turn governs the state in which several pollutants occur in water.

In natural waters, the concentration of DO changes from day to night, and it is useful to measure and report diurnal variations. The frequency of monitoring varies with the purpose. For example, DO concentrations in lakes may be measured once a month whereas those in influent and effluent streams of a wastewater treatment plant may have to be monitored continuously and recorded electronically.

A common and convenient method of measurement is to use a membrane electrode. The electrode that measures the oxygen concentration is covered with an oxygen-permeable membrane. This feature makes it convenient to use this technique in the field as well as in the laboratory. Commercially available DO meters come with meters that read the DO concentrations in mg/L directly. It is important to calibrate the electrode using the type of sample to be monitored. For fresh, unpolluted waters, the meter can be calibrated with distilled water. For seawaters or estuarine waters, seawater should be used for calibration. The manufacturer's instructions for calibration must be followed.

Biochemical oxygen demand. One of the most common parameters included in any water monitoring system is biochemical oxygen demand (BOD). This parameter is usually defined as the amount of oxygen required by bacteria while stabilizing decomposable organic matter in a sample under aerobic conditions (that is, in the presence of oxygen).

Measuring BOD involves a set of standard laboratory procedures that can serve several purposes. For example, the procedures may be used to determine the oxygen requirements for biochemical degradation of organic material (carbonaceous demand) or the oxygen required to oxidize inorganic material such as sulfides and ferrous iron present in wastewater, effluents, and polluted waters. The same methods can be used to measure the oxygen needed to oxidize a reduced form of nitrogen (nitrogenous demand), unless oxidation is prevented by an inhibitor. The BOD test is also used to estimate pollution levels in bodies of surface water and groundwater, and pollution loads from domestic and industrial wastes discharged into natural watercourses. Finally, the test allows analysts to measure the waste loadings of treatment plants and to evaluate the BOD-removal efficiency of these treatment systems.

The sampling frequencies depend on the purpose of the exercise and the type of source where BOD will be monitored. During the initial stages of a monitoring program, the sampling frequencies recommended under normal conditions would be (i) once every two weeks for rivers, (ii) once every two months for lakes, and (iii) once every three months for groundwater. After sufficient experience has been gained, a statistical analysis of the data can be done to determine if these sampling frequencies should be altered. When measuring the waste load or the removal efficiency of a treatment system, BOD should be monitored at both the inlet and the outlet of the treatment system at least once a day (assuming a continuous flow of input and output of an effluent stream).

To measure BOD, a sample is placed in a full, airtight bottle and incubated at a specified temperature for a specific time. The test involves microbial biochemical reactions that are governed, to some extent, by temperature. This temperature effect is held constant by conducting the test at a specific temperature. Normally the samples are incubated at a temperature of 20°C (which is approximately the median value for natural bodies in temperate countries) for a five-day period. During this time, 70-80 percent of the total organic matter present in the sample is degraded. DO in the sample is measured both initially and after incubation, and BOD is computed from the difference between these two results.

Some samples, such as untreated industrial wastes, disinfected wastes, high-temperature wastes, or wastes with extreme pH values, may not contain a microbial population sufficient for biodegradation of organic matter. In that case, a population of microorganisms (known as seed) from other sources (for example, an effluent from a biological treatment system) is introduced to ensure biological degradation of organic matter to CO_2 and water.

Since the solubility of oxygen in water is limited (about 9 mg/L at 20°C), waste that is expected to have high amounts of BOD is diluted with distilled or demineralized water (free from any toxic substances such as chlorine, chloramines, or copper). This step ensures that DO is present throughout the period of the test. The dilution water is also aerated to saturate it with oxygen before use.

The apparatus required for the test includes an incubation bottle of 250-300 mL capacity with ground glass stoppers (to prevent trapping of air) and an air incubator or water bath, which is thermostatically controlled at 20±1°C. In the basic test, BOD can be estimated according to the following equation:

$$\text{BOD (mg/L)} = \frac{D1 - D2}{P}$$

When dilution water is seeded,

$$\text{BOD (mg/L)} = \frac{(D1 - D2) - (B1 - B2) \times F}{P}$$

Where	D1	=	DO of diluted sample immediately after preparation, mg/L
	D2	=	DO of diluted sample after 5 days incubation at 20°C, mg/L
	P	=	decimal volumetric fraction of sample used
	B1	=	DO of seed control before incubation, mg/L
	B2	=	DO of seed control after incubation, mg/L
	F	=	ratio of seed in diluted sample to seed in seed control
		=	(% seed in diluted sample)/(% seed in seed control)

Chemical oxygen demand. Chemical oxygen demand (COD) is the amount of oxygen required for complete oxidation of organic matter in a water sample by a strong chemical oxidant. The COD of a water sample is usually related to BOD. Like the BOD test, the COD test is used to estimate the pollution level in surface water and groundwater, and pollution loads from domestic and industrial wastes discharged in natural watercourses. This test is particularly useful once a correlation between COD and BOD has been established, since it is much quicker (usually 2.5 hours) than a BOD test (5 days). After establishing this correlation, the COD test can be substituted for the BOD test. The sampling frequency of COD will then be the same as that for BOD.

Several pieces of apparatus are required when testing for COD. Digestion vessels, which may be borosilicate ampules or borosilicate culture tubes with tetrafluoroethylene (TFE)-lined screw caps, are needed. Other pieces of equipment include a heating block of cast aluminum with holes to fit the tubes or ampules, and a block heater or oven to operate at 150±2°C. The oven may be used only when it is certain not to affect the tube caps after two hours of exposure at 150°C.

The procedure for testing requires that a known volume of a sample be added to a known volume and concentration of potassium dichromate (a strong chemical oxidant) and concentrated sulfuric acid. The mixture is placed in tubes or ampules and tightly capped with TFE-lined screw caps. The tubes are then heated for two hours at 150°C on a preheated block. Upon cooling, the mixture is titrated against ferrous ammonium sulfate (FAS) of a known concentration. A ferroin indicator (1-2 drops) is used to indicate the end point of the titration, represented by a sharp color change from blue-green to reddish brown. A reagent blank with the same volume of distilled water as in the sample is used to determine the quantity of FAS required to neutralize the quantity of potassium dichromate added to each sample. Typical digestion volumes are as follows: sample (5.0 mL), digestion solution (3.0 mL), sulfuric acid reagent (7.0 mL), and total final volume (15 mL).

The amount of COD in the sample can be determined by the following equation:

$$\text{COD (mg/L)} = \frac{(A - B) \times M \times 8000}{\text{mL sample}}$$

Where A = mL of FAS used for the blank
B = mL of FAS used for sample

$$M = \text{molarity of FAS} = \frac{\text{Volume of potassium dichromate solution titrated}}{\text{Volume of FAS used in titration}} \times 0.10$$

Chlorides. An abundant element on the earth's crust, chlorine occurs as chlorides in the water environment, which lend taste to water. If the corresponding ion with chloride is sodium, water can be distinctly salty at even moderate concentrations. If, however, the corresponding ions are calcium and magnesium, the salty taste does not occur even at fairly high concentrations. Chlorides can affect metallic pipes, structures, and growing plants.

Chlorides may be monitored along with other anions, such as sulfates, phosphates, nitrates, and nitrates. Quarterly sampling of groundwater should be adequate but more frequent samples (once a month) may be required in streams and rivers. In waters that receive industrial wastes, sampling should occur even more often. Chlorides can be monitored satisfactorily using an ion chromatography technique, which is described in detail in the section on nitrates (nitrogen).

Cyanides. All cyanides are extremely toxic to aquatic life as well as to humans. Hydrogen cyanide (HCN) is especially dangerous.

The sampling frequency for cyanides in natural waters would be once a quarter (roughly the same as for other inorganic parameters). However, more frequent monitoring—typically, once a month or possibly more often—is needed for streams that receive industrial wastes containing cyanides. To determine the efficiency of industrial effluent treatment systems, daily measurement of cyanides is necessary.

When monitoring cyanides, utmost care must be taken not to breathe, touch, or ingest the compound. The procedure for testing must also be carried out under a hood. To determine total cyanides, the sample is first distilled in the presence of acid. Hydrogen cyanide is liberated in the process and absorbed in a sodium hydroxide solution. The cyanide concentration of the resulting solution is then determined colorimetrically.

The cyanide in the sodium hydroxide solution exists as CN^- rather than HCN. The CN^- is treated with chloramine-T at pH <8 to form CNCl. This gives a red-blue color when a pyridine-barbituric acid reagent is added. The color is proportional to the concentration of the cyanide, which can be compared with standards of known cyanide concentrations to determine the concentration in the sample. The color is read at 578 nm on a spectrophotometer. The colorimetric method is suitable for samples containing 5-20 μg cyanide/L. If the samples contain larger concentrations than 20 μg/L, they can be diluted as necessary.

The apparatus required for distillation includes a 1 L boiling flask with an inlet tube and provision for a water-cooled condenser, a gas absorber with a gas dispersion tube equipped with medium-porosity fritted outlet, an adjustable heating element with TFE-sleeved ground glass joints or neoprene stoppers and plastic threaded joints for boiling flask, and a condenser. For colorimetric determination, a spectrophotometer that can read at 578 nm with a light path of 10 mm or longer is needed.

Fluorides. These are essential in drinking water for the prevention of dental caries in children. When concentrations in natural waters are low, authorities will often add fluoride to drinking water in water treatment systems. However, when concentrations are high, fluorides can cause fluorosis, a condition that results in the mottling of teeth and damage to bones.

In the case of groundwater that is used for drinking, the concentration of fluorides should be monitored once a quarter. In rivers and streams, it may be monitored more frequently, along with other inorganic parameters of interest.

One method for determining the concentration of fluorides is ion chromatography. However, the results obtained with this technique can be distorted when fluoride exists only at low concentrations and other substances are also present in the water. To avoid this possibility, the colorimetric method is the option outlined here. To eliminate interference effectively, distillation with sulfuric acid may be necessary. The only possible interference after distillation would be chloride, which can be eliminated, if present, by adding silver sulfate to the distilling solution.

When the distilled sample containing fluoride is treated with SPADNS [sodium 2-(parasulfophenylazo)-1,8-dihydroxy-3,6-naphthalene disulfonate] reagent and zirconyl acid reagent (zirconyl chloride solution in hydrochloric acid), the mixture produces a color that can be read at 570 nm. The intensity of the color is proportional to the amount of fluoride present in the sample. The sample color is compared with standards of known concentration to determine the concentration of fluoride in the sample. The colorimetric method is applicable for samples containing 0-1.5 mg fluoride/L. If the sample contains higher fluoride concentration, it may be suitably diluted.

Nitrogen. One of the most abundant elements on earth, nitrogen exists in several forms in water. The most reduced state is ammonia (NH_3)

while the most oxidized state is nitrate (NO_3^-). Other forms of nitrogen that exist in natural waters are nitrite (NO_2^-) and organic nitrogen. Organic nitrogen occurs in such natural biochemical compounds as proteins, nucleic acids, and urea and in several synthetic organic compounds. Nitrogen, along with phosphorus, is an essential nutrient for aquatic organisms and often limits the growth of these organisms. However, excessive nitrogen can lead to eutrophication, which results in algal blooms. Excess quantities of nitrates and nitrites in drinking water can cause in infants an illness known as methemoglobinemia or blue-baby syndrome.

Organic nitrogen and NH_3 are usually measured at the same time and, together, are known as "total Kjeldahl nitrogen" or TKN. NH_3 can be measured separately as well, and this procedure is described below. NO_3 and NO_2 can be conveniently measured using an ion chromatograph.

The sampling frequency for monitoring nitrogen under normal conditions could initially be once every two weeks for rivers, once every two months for lakes, and once every three to six months for groundwater. A statistical analysis of the data obtained can then be done to determine whether this frequency should be altered. To determine the nitrogen removal efficiency of a continuously operated wastewater treatment system, all nitrogen forms are monitored at the inlet and outlet of the treatment system once a day.

When monitoring NH_3, the preferred method applicable for a concentration range of 0.03 mg/L to 1,400 mg/L uses an ammonia-selective electrode. This electrode is commercially available and reads millivolts on the meter. Dissolved ammonium is converted to NH_3 by increasing the pH of the sample to above 11 by adding sodium hydroxide (NaOH). The volume of NaOH added is noted. Standards of known NH_3 concentrations are prepared and millivolt readings are noted to prepare a standard curve. Samples of an unknown concentration are then used and the readings noted. From the standard curve, one can read the concentration when the millivolt values are known. If the sample contains more NH_3 than the range of the test, it is diluted to bring the concentration within the range of measurement for this method.

The concentration of NH_3 can be estimated using the following equation:

$$\text{mg NH}_3\text{ - N/L} = \text{A} \times \text{B} \times \left[\frac{100 + \text{D}}{100 + C}\right]$$

Where A = dilution factor
B = concentration of NH_3-N/L from the standardization curve
C = volume of 10 N NaOH added to the calibration standards, in mL
D = volume of 10 N NaOH added to the sample, in mL

NO_3^- and NO_2^- are most conveniently measured using an ion chromatograph. Ion chromatography can be applied to other anions as well. This technique avoids the use of hazardous chemical reagents that are required in the case of other methods. Ion chromatography can be used for most natural waters, as well as for drinking water and wastewater when particles less than 0.2 µm in size have been filtered out. With this method, a small volume of the water sample is injected into an eluent stream and passed through a series of ion exchangers. Anions are separated based on their relative affinities for the ion exchanger. Commercially available ion chromatographs can be used to monitor NO_3^- and NO_2^- and manufacturer's instructions should be followed for the determination.

Organic nitrogen can be measured by the Kjeldahl methods (macro or micro), in which amino nitrogen in organic compounds is converted to ammonium in the presence of sulfuric acid, potassium sulfate, and cupric sulfate (a catalyst). The ammonium is then converted to NH_3 by the addition of an alkali and then distilled. The distilled ammonia is absorbed in boric or sulfuric acid and determined by NH_3-selective electrode as described earlier. When the sample contains NH_3 as well as organic nitrogen, NH_3 is removed by distillation after addition of a borate buffer and NaOH. The NH_3 concentration in the distillate is determined by the NH_3-selective electrode. The organic nitrogen concentration is determined by the difference in the ammonia concentrations before and after Kjeldahl digestion.

Pesticides. Residues of pesticides can be found in storm water runoff from agricultural fields and can contaminate surface water as well as groundwater. A number of these compounds or their degradation products are toxic or carcinogenic and should be monitored. The method described here refers to organochlorine pesticides that have traditionally been used in agriculture.

Surface water and groundwater sources that are used as drinking water sources—especially those that can potentially be contaminated by agricultural runoff—must be monitored once a month, or more often if required. After obtaining and analyzing the initial results, a decision on future monitoring frequency can be made.

The procedure for measuring pesticides in water depends on liquid-liquid extraction and gas chromatography. In liquid-liquid extraction, the pesticides are extracted from the water phase into an organic solvent (or mixture of solvents). After extraction, they are concentrated by evaporating the solvent and reading the sample in a gas chromatograph. In the gas chromatograph, the extracted pesticides are passed along with an inert carrier gas through a column packed with material that adsorbs and desorbs the individual compounds. The time at which the compounds are detected after coming out of the column determines the specific compound, and the amount detected gives the concentration of the compound in the sample. Gas chromatographs are commercially available and can be used for determining pesticides. It is important that the packed column bed and the carrier gas are free of any impurities so that they do not lead to erroneous results. Standards of known pesticide concentrations can be run through the procedure to determine the readings on the recorder. Samples can then be compared with the standards to obtain pesticide concentrations in the samples.

The apparatus required for monitoring pesticides includes glass sampling bottles with TFE-lined screw caps, an evaporative concentrator, separatory funnels, a chromatographic column, and a gas chromatograph equipped with a glass-lined injection port, an electron-capture detector, and a recorder.

The pesticide concentration can be calculated with the following equation:

$$\text{Pesticide concentration } (\mu g/L) = \frac{A \times B \times C \times D}{E \times F \times G}$$

Where A = nanograms standard pesticide
B = peak height of sample (mm or area count on the recorder)
C = extract volume (μL)
D = dilution factor
E = peak height of standard (mm or area count)
F = volume of extract injected (μL)
G = volume of sample extracted (mL)

Phosphorus. Like nitrogen, phosphorus is an essential nutrient of all life forms and is often a limiting nutrient in natural waters. It usually occurs in natural waters and wastewaters as phosphates—orthophosphates, condensed phosphates, and organically bound phosphates—which may be dissolved or suspended in particles or bodies of aquatic organisms. Since phosphorus is a limiting nutrient, excessive amounts can cause eutrophication of the water body and result in algal blooms. Phosphorus reaches water streams from human and animal waste products, fertilizer runoff from agriculture and farming, and some industrial wastes. As in the case of other inorganic parameters, phosphorus should be monitored more frequently in wastewater treatment plants and less frequently in natural waters.

The procedure for monitoring total phosphorus requires that samples are digested using persulfate in the presence of sulfuric acid. For determination of dissolved phosphorus, the sample is filtered through a 0.45 μm filter. Colorimetric analysis using ammonium molybdate, potassium antimonyl tartrate, and ascorbic acid is a common method of phosphorus determination.

Ammonium molybdate and potassium antimonyl tartrate react in the acid medium to form phosphomolybdic acid, which is reduced to molybdenum blue by ascorbic acid. The color formed after this treatment is compared with standards of known phosphorus concentrations. This method is applicable for samples containing 0.01-2.0 mg P/L. For higher concentrations, the samples can be diluted appropriately. The concentration of phosphates can be satisfactorily determined using an ion chromatograph in the same manner as described in the section on nitrates.

The apparatus required for this test consists of acid-resistant conical flasks that are used for persulfate digestion. Color can be determined with a spectrophotometer that can read at 880 nm.

Sulfates. These occur abundantly in natural waters. They are also present in mine water drainage, which can percolate into groundwater. When associated with sodium and magnesium, sulfates can be cathartic. Sulfates in groundwater may also be reduced to sulfides by bacterial action, and in this form pose additional problems.

Sulfates may be monitored once a quarter in groundwater, but more frequently (once a month) in streams and rivers. In waters that receive industrial wastes, sulfates should be monitored more often.

Sulfates concentration in water samples can be measured by ion chromatography. This technique is described in detail in the section on nitrates.

Sulfides. These compounds commonly occur in groundwater, especially in hot springs. They are also found in domestic and industrial wastewater. Hydrogen sulfide is a foul smelling gas that can be a serious odor nuisance. At high concentrations, it overwhelms the human olfactory system and one stops smelling it. At that concentration, it may be deadly and can kill within a short time. Dissolved hydrogen sulfide is also toxic to aquatic organisms.

Sulfides in groundwater should be monitored once a quarter, but more frequent sampling (once a month) is advisable in streams and rivers. In waters that receive industrial wastes, sulfides may be monitored more often.

Monitoring procedures rely on the fact that sulfides react with dimethyl-*p*-phenylenediamine to produce methylene blue, which can be read at 664 nm on a spectrophotometer. The color obtained from samples of unknown concentration can be compared with that obtained from standard sodium sulfide solutions of known concentrations to determine the sulfide content of the samples. This method is applicable for samples containing 0-1.0 mg sulfide/L. For samples containing higher sulfide concentrations, suitable dilutions must be carried out.

Metals. Though some metals are essential for biological life, others are harmful. Certain metals are beneficial at low concentrations, but toxic at high concentrations. Because metals also affect water and wastewater treatment, they are important in environmental engineering practice.

Because the concentration of metals in the natural environment seldom varies significantly from day to day, an adequate sampling frequency may be monthly, quarterly, or semiannual. For water and wastewater treatment plants, however, weekly or even daily monitoring of influent and effluent samples may be necessary.

The best containers for collecting water samples for metals analysis are made of quartz or TFE. Since such containers are expensive, polypropylene or linear polyethylene bottles with polyethylene caps are frequently used. All bottles should be thoroughly cleaned and washed with metal-free distilled water before use. This step is necessary because metals can occur in nature in minute quantities, and the containers must contain no traces of the metals to be monitored. Though it is preferable to analyze samples as soon as they are collected, they can be preserved easily for up to six months[34] by acidification (that is, the addition of concentrated nitric acid to bring the pH of the sample down to less than 2) and storage at 4°C.

Metals can be analyzed using atomic absorption spectrometry. In this technique, the sample is aspirated into a flame and atomized. A light beam is directed through the flame into a monochromator, a device for isolating an absorption line. The atomized element absorbs light, which is detected by a detector. Each metal has its characteristic absorption wavelength. The amount of energy absorbed in the flame at a particular wavelength is proportional to the concentration of the metal in the sample, over a certain concentration range. Different source lamps are used for different metals, which makes the method relatively interference-free. Among the metals that may be of interest, lead, nickel, and arsenic can be easily monitored using this method. For mercury, the preferred method of monitoring is cold-vapor atomic absorption spectrometry. In this case,

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34 Mercury is an exception to this generalization.

dedicated laboratory glassware must be available. Glassware that is exposed to mercury during other analyses such as COD, cannot be used since it could contaminate the sample and lead to erroneous results.

The equipment needed for these tests includes an atomic absorption spectrometer (AAS). This instrument contains a light source (a hollow cathode lamp or electrodeless discharge lamp) that emits the line spectrum of an element. A flame for vaporizing the sample is also needed, along with a monochromator or filter, and a photoelectric detector attached to a measuring device and display. For determination of mercury, instruments and accessories specifically designed for mercury are used.

The test procedures require that the AAS be fitted with a lamp specific for the metal to be monitored. Standards of known concentration of the metal are prepared and aspirated into the AAS. The readout in the display is noted for each standard and a standard curve is prepared. The water sample is then aspirated into the device and the readout is noted. This result is compared with the standard curve to obtain the concentration of the metal. For mercury, the manufacturer's instructions on cold-vapor atomic absorption spectrometry are followed.

Oil and grease. Not strictly a single substance, the materials that dissolve in an extracting solvent are referred to as oil and grease (O&G). They interfere with biological wastewater treatment and can reduce treatment efficiency. In natural waters, O&G can form a film above the water surface, thereby reducing the amount of oxygen that can be dissolved into the water from the atmosphere.

The sampling frequency for O&G can initially be the same as for BOD, COD, and DO. If O&G is absent from the samples, the monitoring frequency can be reduced in subsequent tests.

Testing procedures call for the sample to be treated with a solvent (n-hexane or trichlorotrifluoroethane or methyl-tert-butyl ether). Afterwards, the solvent and aqueous phases are separated using a separatory funnel. The O&G is extracted into the solvent phase, the solvent is distilled out of the mixture from a preweighed distillation flask, and the weight of the distillation flask is noted after distillation is complete. The difference in the weight gives the amount of O&G present in the sample.

The apparatus needed for this test includes a separatory funnel with TFE stopcock, a distilling flask, and a distilling adapter.

Radioactivity. Radioactivity is a phenomenon that occurs naturally or is the result of human activities (for example, nuclear power generation, medical and industrial use of radioisotopes, and atmospheric testing of nuclear devices). It causes the ionization of atoms. When this process occurs in the human body, it may affect cells, tissues, and organs. It can also cause cancer.

Locations that are suspected of having been contaminated by radioactive wastes or believed to have natural radioactivity should be sampled more frequently than locations where radioactivity is not found in natural waters. Initially, monitoring may be once every quarter or once every six months.

Radiation is normally measured by a counting instrument that detects and records the expenditure of energy by a radiation event. Gross alpha and beta radiation can be measured using a commercially available thin end-window proportional counter. The samples are prepared for the counters as per the manufacturer's instruction and then placed in the instrument. Radioactivity in a water sample is determined by comparing it with standards having known radioactivity. For alpha radiation, natural uranium/thorium 230 or plutonium 239/americium 241 are used as standards. For beta emissions, strontium 90 in equilibrium with its daughter element ytrrium 90 or cesium 137 with its daughter elements barium 137 and metastable barium 137 can be used. Calibration standards must be reported along with gross alpha or beta results.

Gamma radiation is measured using a gamma spectrometer. A standard containing known radionuclide activities is used to determine the counting efficiency of the standard-geometry container in the spectrometer. The sample is then put in this container and gamma spectrum is determined.

The apparatus required for gross alpha and beta emission measurement includes counting pans and a thin end-window proportional counter. The apparatus for detecting gamma radiation consists of a gamma-ray spectrometer, a detector, and a counting container of standard geometry.

Coliforms. The presence of these organisms in water indicates the degree of organic pollution of natural waters (resulting primarily from human and animal waste) and is especially important for issues of sanitation. Coliform organisms comprise several genera of bacteria that produce acid and gas from lactose at 35°C within 48 hours. Fecal coliforms are present in the guts and feces of warm-blooded animals and produce gas from lactose at 44.5°C ± 0.2°C.

The initial sampling frequency for coliforms is the same as that for BOD and COD. If the initial results demonstrate that coliforms are absent from the samples, the frequency for monitoring can be scaled down.

Test procedures require that samples containing coliforms be filtered through sterile membrane filters. After incubation at a specified temperature on an appropriate culture medium (a food source for coliforms to grow), the colonies formed on the filter are counted. Each coliform organism forms a colony around it once the filter is placed on the culture medium. This process requires that all equipment and apparatus be sterilized in an autoclave before use.

When membranes are placed on sterile dishes containing a culture medium, coliforms will form bright red colonies with a metallic sheen within 24 hours of incubation at 35°C on an Endo-type medium. The sheen is due to aldehydes produced as a result of the fermentation of lactose. The formation of aldehydes is an important intermediate step in the formation of acid/gas from lactose. The typical sample size should produce between 20 and 80 colonies on the membrane surface. Coliform colonies can then be counted using a low-power (10-15$^{\times}$) microscope with a cool white fluorescent light source. Only colonies with a metallic sheen are counted as coliforms. Other colonies are counted as noncoliforms. For fecal coliforms, the M-FC (membrane-fecal coliform) medium is used and cultures are incubated at 44.5±0.2°C. Fecal coliforms form blue colonies, while other bacteria form gray or cream-colored colonies and should not be counted.

The apparatus used in a test for coliforms includes sterile culture dishes, filtration units, sterile membrane filters, an incubator, and an autoclave.

Coliforms are reported as the most probable number (MPN), as expressed in the following equation.

$$\text{MPN/100 mL} = \frac{\text{Coliform colonies counted} \times 100}{\text{mL sample filtered}}$$

Estimating Water Discharges

Information on water quality is essential but must be supplemented with additional statistics on the discharge of effluents before public officials can formulate an efficient set of water policies. Regulators need to know which sources are responsible for the discharge of particular pollutants and precisely where these discharges occur.[35]

The task of identifying individual sources of pollution and linking specific discharges to each source is a complicated one that relies on both surveys and estimation procedures. The difficulties encountered are the main reason why few countries, if any, presently operate discharge-monitoring programs that match their efforts to monitor water quality. Most programs to track the discharge of effluents have a limited geographic coverage, usually focusing only on specific urban areas. Even in these cases, it is rarely possible to put together a comprehensive picture that captures the effects of both human and industrial discharges. Cost is the main barrier to the development of an elaborate monitoring system. To keep expenditures under control, governments rely on a combination of limited, specific surveys and internationally accepted estimation procedures.

Data organization and concepts. To simplify their task, statisticians usually identify discharges by source and type of emitter. Discharges may come from either from point sources or diffuse sources.

35 Information on where emissions occur can be used to determine the location and type of wastewater treatment facilities that are needed.

Pollution from point sources is mainly associated with the release of wastewater from municipal, agro-industrial, and industrial sites. In countries where mining operations are significant, these activities can also release substantial amounts of wastewater. Pollution from diffuse sources either is spread over large areas or cannot be directly attributable to specific activities. Examples of diffuse sources are pesticides and their decay products contained in surface runoffs, and nitrogen and phosphorus released from fertilizers and animal wastes. These pollutants eventually reach water bodies through runoffs from storms and atmospheric deposition. Effluent discharges by point sources are relatively concentrated and readily identified. It is comparatively easy to estimate the amount of pollutants from point sources and to control their discharges. Pollution from diffuse sources is much more difficult to assess and manage.

In addition to the two pollution sources, statisticians generally focus on three types of emitters:

(i) Productive activities typically account for the bulk of all discharges, the majority of which are from point sources. Some of the pollutants released by industrial activities consist of biodegradable matter, but other nonbiodegradable substances are also found, depending on the product and production process. Agricultural discharges are generally in the form of manure, fertilizers, and pesticides. These compounds, which are spread over large areas of arable land, reach the water through runoff and represent a diffuse source of pollution.

(ii) Households are a second source of effluent discharges. The household sector is responsible for the release of urine and feces, as well as water from washing, personal care, and kitchen activities. The discharges consist mainly of biodegradable matter.

(iii) Runoffs from roofs, roads, and other impermeable surfaces are a third type of discharge. Heavy metals and various forms of accumulated debris are often washed away by rain as part of surface runoff. In some instances, urban storm runoff can be a significant contributor to pollution, even accounting for a larger share of the total pollution load than the untreated sewage of the same community.

Treatment of wastewater.[36] Any program to monitor the discharge of effluents should take into account the role of existing systems for treatment of wastes and water purification. Treatment plants must be established to treat raw wastewater before it is released into ambient waters. If the system for treatment of sewerage is rudimentary (for example, consisting of little more than the use of settlement ponds), biodegradable matter may not be removed and secondary biological treatment is required. Industrial establishments may also be required to modify their production processes by introducing new, low-waste technologies and methods of recycling wastewater.

The major categories of water discharges and treatment methods are the following:

(i) direct discharges released without treatment as well as discharges that may or may not have been subjected to treatment;

(ii) discharges from pits (collected periodically) and dumped, either without treatment or treated after collection;[37] and

(iii) discharges generated by wastewater treatment plants.

To establish a relationship between the data on discharges and the data gathered from monitoring water quality, the discharge points for treated and untreated wastes must be specified.

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36 The following discussion draws on ESCAP (1999), Chapter 5.

37 In the absence of a sewerage system, household wastes may be periodically collected from latrines and emptied into pits. These pits often leak or spill over excess fluid into the surrounding soil and therefore pose a threat to groundwater.

BOD is the preferred parameter for gauging the need for general wastewater treatment (see the section Monitoring the Quality of Surface Water). For household wastewater, this parameter, alone, is considered as sufficient. However, in the case of industrial discharges and runoffs from hard surfaces, other pollutants should be involved, including heavy metals and pesticides. If hazardous wastes are also present, it may be necessary not only to monitor discharges but also to track the final destinations of these pollutants. Eventually, the monitoring program may have to be expanded to cover raw waste and sludge as well as the major sources of water pollution.

Statistical methods. As already noted, most programs to monitor discharges are confined to urban areas and the discussion here follows that practice. Three components-industries, households, and wastewater treatment facilities-figure prominently in the calculation of water discharges. Industrial establishments are usually clustered around major cities and account for a significant proportion of all discharges. The sheer number of households helps to explain the volume of pollutants attributed to this sector. The composition, size distribution, and types of pollutants associated with these two groups naturally differ and the statistical methods employed must take these characteristics into account.

The role played by wastewater treatment plants is obviously different from that of the two major sets of emitters. The purpose of these plants is to reduce the amount of waste in the influents entering the water system. Much depends on the type of technology employed. The more effective a particular method of treatment is, the greater the reduction of the influent load. Thus, statisticians must have some idea of how well treatment plants perform so as to estimate the effluent load.

The coefficients used to estimate effluent discharges and reductions in the influent load are the heart of any monitoring system. The statistical methods used to develop these coefficients differ for each of the three components noted here. In the case of the industry sector, there is ample evidence to indicate that the largest establishments are responsible for up to 80 percent of all industrial discharges in developed countries, and the figure should be comparable for developing countries. Each industrial establishment represents a point source of discharges, but the coefficients for major polluters are the most important and should receive the most attention.

The population of industrial establishments in an urban area is usually too large to consider any direct method of measuring effluent discharges for every polluter. The exercise can be simplified by dividing the urban industry sector into subgroups that can be more easily handled by a few estimation routines. Several criteria could be used for this purpose.[38] However, because economic statistics are expressed in monetary units and the number of employees, these measures offer the most practical (and cheapest) means of defining different subgroups.

With the help of economic statistics, the industrial establishments in an urban area can be divided into two or three categories. Decisions regarding the boundaries between categories should be made after studying the current size distribution of all industrial establishments. An illustrative breakdown is given below, but, in practice, the dividing lines between categories will depend on the characteristics of the industry sector.

Small producers may be identified as those with less than 25 employees, less than 10, or less than 5. Generally, economic information on this group is scanty. Some industrial surveys include a sample of small producers and if this information is available, the same cutoff point can be adopted here. Effluent discharges can be estimated for this group on the basis of the workforce if labor surveys or censuses provide this data.

Producers of intermediate size may be defined as establishments with 25-100 employees. Generally, more information will be available for this group than for smaller producers, and physical, monetary or employee data can be used to estimate discharges. If the statistical program of the NSO includes occasional sample surveys of these firms, additional questions should seek data on the release of wastewater, input and output coefficients, relevant features of the production process, and wastewater treatment.

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38 Input-output coefficients would be a more logical source of information for the development of these criteria but few countries have an up-to-date input-output table, especially one expressed at a sufficient level of detail.

Large producers will include all the remaining firms (in this case, those with more than 100 employees). Ideally, this subset should be the subject of a special survey, and effluent-discharge coefficients for each firm should be determined in a direct manner. If sufficient resources are not available to mount a special survey, other options can be considered. Should the total number of large firms be too great or too widely dispersed to survey all, a subset can be identified. To be representative, the subset should take into account both the location and the industries involved. The list of firms to be surveyed can also be restricted to a smaller geographic area and to just a few types of industries. Another alternative is to add relevant questions to any recurrent survey program for firms in this size category.[39]

The large number of households in an urban area make it impractical to consider any direct method of estimating discharges. Generally, the distribution and composition of urban households differ markedly from national averages and the pattern in the rural sector. Household surveys and population censuses can be consulted to obtain some idea of these characteristics. A problem unique to the household sector is the role of slums and squatter settlements. Few household statistics consider this subset and, if they are included, the data may be lumped together with other figures under the heading of "marginal housing." In either case, it will be very difficult to determine the relevant characteristics of this group and a special survey may be needed.

Researchers have noted several characteristics that should be borne in mind.[40] First, the release of effluents into water by rich and poor households will be similar in several ways, but differences in the wastewater streams of the two groups will be significant. Rich households tend to use more water for washing and bathing, in part owing to the availability of piped water. Second, methods for wastewater disposal, treatment, and release can be markedly different for rich and poor households. In slum

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39 Questions to be appended to an existing survey might refer to physical input/output coefficients, water usage and sources, wastewater treatment, financial outlays in environmental protection, and so on.

40 See, for example, ESCAP (1999), Chapter 5.

areas, wastewater is often released directly into the environment through open sewers or pit latrines. Third, household surveys are a possible source of information on methods of sewage collection and treatment. Firms engaged in communal waste disposal and treatment services may also be able to supply data or advice that will be helpful in constructing estimates.

The ultimate goal of the exercise is usually to estimate discharges of BOD per household. Statisticians usually begin by classifying the urban household population according to the water treatment system being used. Discharge coefficients-expressed in grams of BOD per person per day-can then be determined for each group. Discharges of BOD per household can be expressed in terms of the following equation:

Discharge of BOD per household =
Standard emission factor * number of persons * socio-economic correction factor * treatment degree correction factor.

The socioeconomic correction factor refers to the total amount of wastewater produced (expressed in grams of BOD). The treatment correction factor applies to the type of wastewater treatment used. This subject is discussed below and examples of correction factors are given.

To compute the effluent load, statisticians must first determine the extent to which influents have been reduced by wastewater treatment. The simplest and most rudimentary form of treatment, which is known as the primary method, merely separates settleable materials from the wastewater. If a secondary or biological treatment process is also used, organic material is mineralized through the action of bacteria and the level of BOD is further reduced. When a third or tertiary process is available, selected minerals such as phosphorus are removed by binding them to insoluble substances. In many developing countries, wastewater treatment-if it exists at all-is limited to primary treatment, owing mainly to cost considerations.[41]

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[41] Primary treatment will not significantly reduce coli bacteria and other serious contaminants. Significant reduction can be achieved only with secondary treatment.

Illustrative values for effluent discharges and pollution reduction factors are shown in Table 5.2. Secondary treatment is clearly more effective than primary treatment. In fact, primary treatment does very little to reduce the amounts of potassium and nitrogen compounds in wastewater. Many of the values in the table have a rather large range, suggesting that estimations specific to each urban area are preferable to the use of benchmark values.

Table 5.2: Examples of Emission Factors and Pollution Reduction Factors for Household Waste

Parameter	Emission Factor	Pollution Reduction Factors (percentage reduction)	
		Primary Treatment	Secondary Treatment
Volume (in liters per capita per day)	20-300[a]		
BOD	45-54[b]	5-35	50-98
P	0.6-4.5[b]	0-10	10-85[c]
N	6-12[b]	0-7.5	15-50

[a] The lower value applies to households with septic tanks.
[b] Figures are in grams per capita per day.
[c] The highest rate applies to tertiary treatment with chemical precipitation or coagulation.

Source: Economopoulos (1993), Table 4.2.2.

Water Quantity and Uses

Water stress, which refers to pressure on both the quantity and quality of water resources, has a profound influence on human activities. Adequate water management is essential to ensure that water supplies are available and sufficiently reliable to support all kinds of economic activities and water-dependent ecosystems. Most countries regularly and systematically collect and analyze hydrological and hydrogeological data. Because several agencies are typically responsible for these operations, the information on quality and quantity is not integrated. As a result, policy making and planning for water quantity and quality management are often fragmented.

A country's renewable supply of water is derived from two sources:

(i) rainfall that falls directly on its land area, and

(ii) river water originating from outside the country (external water sources).

The total annual internal renewable water resources of a country is defined as the sum of the annual average freshwater flow of rivers and the groundwater produced from rainfall within the country's borders. Roughly two thirds of this total becomes flood runoff. Only the remaining third is available as usable surface and underground water supplies. Nor is the volume of available water distributed evenly, either throughout the year or between parts of the country. There are both seasonal and spatial variations in supply and the former may be especially significant in the case of river flows.[42]

Water supply. Problems of water scarcity arise when the demand exceeds the supply for any significant period. Shortages occur most frequently in areas with low rainfall or high population density, and in areas with intensive agricultural or industrial activity. In addition to water shortages, overexploitation of water can result in the drying out of natural areas, and to saltwater intrusion in aquifers.

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[42] It is important that statisticians assess of this seasonal variation, which is usually expressed as average monthly river flows. Recorded river flows can also be combined with data on the catchment area to develop indicators of water flow (or runoff) per unit area.

The source of all internal groundwater is rainfall, part of which recharges the groundwater. Groundwater supplies rivers with a base flow during months without rainfall. The inability to adequately recharge groundwater (because of soil compaction or removal of vegetation) is an important factor contributing to droughts and agricultural failures and should be monitored closely.

Normally, each country operates a network of rainfall and river-flow measuring stations. To simplify the task, attention usually focuses on the larger and more stationary water bodies for which long-term availability can be most easily determined. Problems arise nonetheless because groundwater represents a natural reservoir with a stored volume, inflows, and outflows. Estimates of groundwater volume (expressed in terms of exploitable potential per year) can usually be constructed through analysis.[43] Data on outflows is derived from records of groundwater withdrawal (pumping) and measurements of river base flows. However, data for inflows is much more difficult to obtain and is available in only a few countries.

The agencies responsible for collecting information (for example, the department of public works or the department of irrigation) routinely analyze the raw data to derive totals, averages, measures of dependable flow, and time series indicators (including indicators of rainfall intensity). Some of the measures developed may be rather detailed. For instance, available water can be defined as the volume flowing in a river that is available at least 90 percent of the time.

Water usage. Estimates of water availability, however crude, give some idea of supply and can be used in conjunction with data on water utilization. Information on water use is subdivided into two categories:

(i) Consumptive use. This involves the removal of water from its source. Statistics on consumptive use are usually reported as water withdrawals by sector (agriculture, industry,

43 Local changes in usable groundwater volume can be determined from measurements of the depth of the water table or changes in pressure levels for pressurized aquifers.

household, and so on). Consumptive use data can also be identified by source: surface water or groundwater. Groundwater is an important source for domestic use since the quality is usually superior to that of surface water.

(ii) Nonconsumptive use. Examples falling into this category include hydropower generation, fisheries, navigation, and recreation. Nonconsumptive use does not entail water removal and data are not reported in terms of use rates or volumes, but rather in the form of values derived from the use (for example, electricity generation by hydropower plants).

At the national level, two aggregate measures of water quantity are popular. One, a measure of the renewable water resources, is an aggregate annual figure that is used mainly as a basis for developing indicators of water supply availability. A critical level of use is reached when the rate of water withdrawal reaches or exceeds the average annual available water supply. A second measure is the ratio of available water supply to the total population. With this indicator, countries can be ranked according to relative available water per capita or scarcity.

The pattern of water use depends on a number of determinants, but at the macroeconomic level the most important are probably the level of development, the composition of economic activities or the structure of the economy (a factor which, in turn, is related to level of development), and climate. In the EU, agriculture and cooling needs account for nearly two thirds of all water use. European countries with warm climates may abstract more than a quarter of their freshwater resources each year. About 80 percent is consumed and is therefore not available for other purposes. Most of this water is thought to be used for irrigation in agriculture, but no data is available. Instead, statisticians use the land area subject to irrigation as a proxy. The situation is different when abstracted water is used for cooling. In that case, the water is returned and can be used again.

Water use by households and industry has been falling in many developed countries for more than a decade.[44] There are a number of reasons for this decline, including greater awareness of water use, water metering, increased water charges and taxes, restrictions on garden watering, fewer leaks, and widespread use of more efficient appliances such as low- or dual-flush toilets. Groundwater is the source for as much as three quarters of the public water supply in developed countries. It is increasingly preferred as public water supply because it is generally of higher quality than surface water and requires less treatment. This preference has led to overabstraction and a lowering of the groundwater table in many developed countries. The consequences are the drying up of spring-fed rivers, destruction of many wetlands, and saltwater inflow to aquifers.

No comparable information on such trends is available in most developing countries. Many compile little or no information on water uses. The situation could be different, depending on domestic policies, economic structure and other determinants. However, proper management of reservoirs, groundwater reserves and surface water is essential. Without controls, problems of water stress are bound to mount in the longer term.

44 In the EU, for example, the amount of water abstracted from public water supplies declined by around 10 percent during the 1990s.

6

HUMAN SETTLEMENTS

The quality of the environment is inextricably linked to conditions in human settlements that ultimately affect the quality of life values of the people. Important considerations are the quality of housing and water supplies, facilities for sewerage and drainage, energy and transport, as well as the spatial distribution of housing. Careful examination of human settlements has shown that there is a strong relation between poverty and inferior environmental quality (especially in large urban settlements). Typically, the quality of the environment is poorest in slums, dilapidated neighborhoods, and squatter settlements.

Over the next few decades, many developing countries will see increases in their urban population that are roughly equivalent to the growth of the total population. Such trends ensure that the issue of environmental conditions in human settlements will assume even greater significance in the future. Moreover, a deterioration in the urban environment can have economic as well as social repercussions. The bulk of economic activity takes place in urban areas and a worsening of environmental conditions in this sector can jeopardize a country's economic prospects. Policies to improve environmental conditions in human settlements are urgently needed, but they cannot succeed without a strong program of statistics on human settlements.

The subject of human settlements embraces a wider range of issues than does air or water. The first section of this chapter briefly discusses the main issues. This material draws on the work of the United Nations Conference on Human Settlements (UNCHS) and the goals set out in Agenda 21, which deals with the planning and management of human settlements, the provision of environmental infrastructure, and related concerns. The second section examines the organizational and methodological issues.

Key Issues

A multitude of factors affect environmental conditions in human settlements and their interaction requires that a fairly comprehensive statistical effort be mounted. The key subject areas are noted in this section, but statisticians may find it necessary to add to or subtract from this list, depending on local conditions and priorities.

Housing. One of the goals of Agenda 21 is to provide adequate and environmentally sound shelter for the rapidly growing populations of developing countries, particularly the rural and urban poor. Information on this subject is collected via population and housing censuses. Household surveys are another useful tool because they can be tailored to address specific topics such as living conditions in human settlements. Housing statistics generally refer to the type of housing unit or living quarters, tenant arrangements, available facilities, and construction materials used. Concepts and classifications vary slightly from country to country. Some general definitions of these indicators are set out below:

(i) Housing units are separate and independent places of abode. Most units are intended for habitation by one household. Some may not be intended for habitation, but are nevertheless occupied as living quarters. Housing units are further subdivided into conventional and unconventional dwellings. A conventional dwelling refers to a room or cluster of rooms in a permanent building, which is meant for habitation. A conventional dwelling may be occupied or vacant. Unconventional dwellings are units not considered appropriate for habitation, but are nevertheless occupied. This category includes marginal housing units such as improvised houses, housing in buildings not intended for habitation, squatter settlements, slums, and makeshift shelters constructed of waste materials.

(ii) Collective living quarters are units intended for habitation by a number of individuals or several households. Hotels and lodging houses are examples.

(iii) Institutions are defined as permanent structures designed to accommodate groups of people. Examples are hospitals, military barracks, schools, hostels, and prisons. Also included in this category are camps intended as temporary accommodation for refugees, workers, and military personnel.

Tenure refers to the status of the occupant of the dwelling. An owner-occupant owns the unit he occupies, even though he may be paying a loan or mortgage on the unit. A tenant or renter occupies a housing unit, which is not his property. Indicators of materials used for construction usually distinguish between the materials used for external walls and those for the roof. If the walls are constructed of more than one material, the predominant material is usually indicated.

A number of indicators can be used to identify facilities in a housing unit or living quarters. They include the following:

(i) Cooking facilities generally refer to a kitchen where meals are prepared and the room is intended for that purpose. If some space in the unit is used to prepare meals but is not a room, it is denoted as "other space reserved for cooking." Should the unit have neither type of facility, it is referred to as a unit "without kitchen or other space reserved for cooking."

(ii) Means of heating refers to the system used to heat the premises. It may be a communal or central heating system in a building with several units. The type of fuel used is also identified.

(iii) Water supply system refers to the provision of water to housing units by pipes from community-wide systems or from individual installations such as pressure tanks and pumps. The categorization "with piped water" implies water supply "inside the housing unit," or "outside the housing unit" but within 100 meters of the door.

(iv) Waste disposal facilities have two categories. Housing units are designated as "with toilet of any type" or "without toilet of any type." The usual types of toilets are common sewerage, pit latrine, and septic tank.

(v) Other facilities include the cooking fuel used for preparing the principal meals, bathing facilities either within or outside the housing unit, and lighting identified according to the source of lighting for the housing unit.

Another popular measure is the number of persons per room in occupied housing. This statistic, however, is of limited use since it does not include information on room size, quality of construction, or related factors. Nor does it serve as a reliable indicator of overcrowding because the definition of a room varies and differences in room size are not considered.

Land use in human settlements. Undisciplined growth of urban centers threatens access to land owing to the increasing spatial requirements of housing, industry, commerce, and transport, as well as the need for open spaces. Environmentally sound physical planning is necessary to avoid these problems. The process of land mapping and land titling has also fallen far behind the pace of growth of human settlements, delaying the start of development activities. Ineffective land use and poor planning have resulted in chaotic urban growth and the unnecessary use of agricultural land for physical development. Statistics on land use provide an indication of the major categories of human activities carried out in different areas of human settlements. These data describe the geographic distribution of activities in so far as they are reflected in the character of built-up land. However, it is not possible to assess the level or intensity of activities from land use statistics.

Urbanization. The urban sector is where most economic activity takes place and where most pollution occurs. An accelerating pace of urbanization, along with higher rates of rural-to-urban migration, signal the onset of a number of environmental problems such as air, water, and noise pollution; shortages of necessary public amenities, and so on. Proper planning and management of urban growth require accurate and timely statistics. In many developing countries, the existing data is not adequate to provide an overall picture of the urbanization process and its consequences.

Environmental infrastructure. The provision of adequate environmental infrastructure and services–water, sanitation, drainage, and solid waste management–is crucial for improvements in the health and quality of life in human settlements. To a large extent, the presence or absence of these facilities determines the quality of a human settlement. Their presence is also an important means of boosting productivity. For these reasons, data on access to environmental infrastructure and services must be available in some detail.

Drainage and solid waste management are other serious problems in many cities. Authorities are frequently unable to remove more than a portion of the solid waste generated each day. Water disposal systems and storm water drainage are inadequate, particularly in low-income settlements. Few developing countries collect data on either of these aspects. Effective waste management requires an elaborate system of supervised disposal sites, trained personnel, equipment, vehicles, and adequate enforcement mechanisms that many cities cannot afford. Even when reliable data on waste generation exists, the figures are not easily translated into management data. Some wastes are disposed of improperly or illegally, resulting in contamination of soil, groundwater, or air.

Energy usage. An adequate supply of energy is essential for human development. Industrial and commercial activities are the largest consumers of commercial energy in urban centers. The household sector typically accounts for around 25 percent of this total. Improvements in the efficiency of energy usage by households are therefore an important step. Households are also the largest users of noncommercial energy in developing countries. Fuelwood is the preferred source. Unless alternative fuels are available, the poor in human settlements will continue to rely on biomass fuels. Dependence on such sources can lead to deforestation, soil erosion, and desertification.

Transport. The main concerns relating to transport were discussed in terms of air pollution in Chapter 4. Transportation has impacts on the environment of human settlements. It also affects the physical patterns of settlements, access to infrastructure and services, and congestion. Proper environmental management of urban centers can ensure that adequate transport is available while minimizing its negative effects. However, a large amount of information is required in addition to that discussed in connection with problems of air pollution. Both ad hoc and periodic transportation surveys will be essential for planning and managing urban systems.

Construction activities. These activities are one of the major factors distinguishing the "human-made" environment from the natural environment. They affect land use, population density, the availability and quality of housing, utilities, and infrastructure. Building materials frequently account for as much as two thirds of the resources used in the production of shelter and infrastructure in developing countries. Accordingly, construction places a heavy demand on a country's resource base. It is highly desirable that the industry use raw materials that are cheap, durable, and affordable. Unfortunately, little data is available to assess many of the environmental consequences of construction activities. Methodologies vary and there are no standards for data collection.

Population growth and change. Both population growth and rural-to-urban migration strongly influence the demand for shelter, infrastructure, and related services. Much of this migration can be attributed to the especially poor quality of housing, education, and environmental infrastructure in rural settlements. Another reason is that the economic prospects of workers in urban areas are generally superior to those in rural areas. Frequently, the flood of migrants to urban centers overloads the existing housing and infrastructure in major cities.

Organization and Methodological Issues

Clearly, a large number of statistical topics, indicators, and classification schemes are relevant for a statistical evaluation of human settlements (Table 6.1). Not all can be addressed in this Handbook. The efficient organization of all this material from multiple sources is a complex task, but the job can be simplified by constructing an FDES as described in Chapter 3. An example of an FDES is in Table 6.2, which lists several statistical topics grouped together according to common characteristics (in italics). The focus is on environmental impacts and the activities that give rise to these impacts. Other factors that do not directly influence the environmental aspects of human settlements, but are related to activities that do, are treated as background conditions.

In addition to the FDES, there are several methodological issues that must be addressed at an early stage in the program. These include

(i) the distinction between rural and urban settlements;

(ii) the identification of marginal housing units, for example, slums or squatter settlements; and

(iii) resolution of problems of data compatibility and data currency.

Table 6.1: A Summary of Topics and Indicators for Human Settlement Statistics

Topic	Variable (unit of measurement)	Definition/ Explanation	Classification	Likely Sources
1. Population growth and change	Average rate of change in population (percent)			Population census, surveys, projections and estimates
	Net migration (per thousand)	The difference between gross immigration and gross emigration		Population census, surveys, projections, estimates, and civil registration
2. Construction of shelter and infrastructure	Housing units (number)	See text	By structure: conventional, unconventional, etc. By type of building activity: new, restoration, or conversion By type of investor: public, private, informal	Housing census and surveys, building permits, special surveys of the informal sector

Table 6.1: A Summary of Topics and Indicators for Human Settlement Statistics (continued)

Topic	Variable (unit of measurement)	Definition/ Explanation	Classification	Likely Sources
	Decrease in housing stock (number)	Owing to conversion, demolition, destruction by natural disasters, and other activities (e.g., military action)	Reasons for decrease: conversion, demolition destruction by fire, flood, or other activities	
3. Transport	Road vehicles in use (number)		By type of vehicle: commercial or private passenger cars, trucks, buses, tramcars, etc.	Motor vehicle registration records
4. Land use	Settlement land area (square kilometers)	See footnote [a]	By type of land use: residential, industrial, commercial, motorways, recreational, open land	Municipal and administrative records, land surveys, aerial surveys
	Area of marginal settlements	See footnote [b]		

Table 6.1: A Summary of Topics and Indicators for Human Settlement Statistics (continued)

Topic	Variable (unit of measurement)	Definition/ Explanation	Classification	Likely Sources
5. Emissions and waste discharges	Air pollution (tons)	See Chapter 4	See Chapter 4	See Chapter 4
	Solid waste collected (cubic meters, tons)	Solid waste and sludge generated by treatment plants	By type of solid waste: agricultural, industrial, mining, special hospital waste, radioactive waste, households	Ad hoc surveys, municipal records
6. Housing	Occupants (number)	See text	See text	Population and housing census, housing surveys and household surveys
	Rate of occupancy (number)	Average number of persons per room		Population and housing census, housing surveys, and household surveys

Table 6.1: A Summary of Topics and Indicators for Human Settlement Statistics (continued)

Topic	Variable (unit of measurement)	Definition/ Explanation	Classification	Likely Sources
7. Access to infra-structure	Settlements supplied with electricity (number)	Settlements with more than 50 percent of housing units having access to electricity		Municipal records
	Households with water (number)		By distance to water supply: inside hose, within 100 meters of house, more than 100 meters away	Population and housing census, household survey, municipal records
	Households with access to sanitation (number)		By type of sanitation system: community sewerage, individual system, other	Population and housing census, household survey, municipal records
	Households with electricity (number)			Population and housing census, household survey, municipal records

Table 6.1: A Summary of Topics and Indicators for Human Settlement Statistics (continued)

Topic	Variable (unit of measurement)	Definition/ Explanation	Classification	Likely Sources
	Average time spent travelling from home to work place (minutes)		By type of transport: public road or rail, private motorized, others	Household survey, transportation survey
8. Sprawl and dispersion	Primacy rate (percent)	Ratio of the largest city's population to the sum of the populations of the four largest cities		Population and housing census
9. Policies and programs	Expenditure for human settlement development (monetary units)	Financial resources spent for improvement in conditions of human settlements	By type of program: housing, rehabilitation of marginal settle-ments, land develop-ment, infrastructure	National accounts, development plans

Table 6.1: A Summary of Topics and Indicators for Human Settlement Statistics (continued)

Topic	Variable (unit of measurement)	Definition/ Explanation	Classification	Likely Sources
	Community development programs (number)		By type: planning and design, implementation and management, general organization	Development plans
	Violations of building codes and regulations prosecuted (number)		By type: structural, health, fire, public safety	Municipal and legal records

[a] Settlement land use is defined as the occupation of houses, roads, mine and quarries, and other facilities deliberately installed for the pursuit of human activities.
[b] There is no generally accepted means of distinguishing between marginal settlements and other residential areas.

Source: Adapted from UN (1988).

Table 6.2: A Sample Framework for Development of Environment Statistics for Human Settlements

Social and Economic Activities	Environmental Impacts of Activities	Responses to Environmental Impacts	Stocks, Inventories, Background Conditions
Growth and change in human settlements	Conditions of shelter, infrastructure, and services	Policies and programs	Stocks of shelter and infrastructure
Population growth and change	Housing	Pollution monitoring and control	Housing stock
Construction of shelters and infrastructure	Access to infrastructure and services	Environmental standards	Nonresidential buildings, other physical infrastructure
Utilities (energy and water supply)	Human settlements sprawl and dispersion	Monitoring	Environmental inventories

continued next page

A geographic breakdown of the data is essential for environmental analysis. Administrators of particular settlements seek a full set of data for each settlement under their responsibility, but the focus of attention in this chapter is on the information needs of national planners and policy makers. Some classification of human settlements that can be applied throughout the country is required.

The most common approach is to identify settlements as rural or urban. However, the characteristics that differentiate these two types of settlements vary widely within the country and there is no generally accepted method of resolving the confusion. One alternative is to compile

Table 6.2: A Sample Framework for Development of Environment Statistics for Human Settlements (continued)

Social and Economic Activities	Environmental Impacts of Activities	Responses to Environmental Impacts	Stocks, Inventories, Background Conditions
Transport	Conditions of life-supporting services	Treatment, disposal, and reuse of discharges	Emission inventories
Land use	Ambient concentration of pollutants and wastes	Expenditure for pollution control	Background conditions
Other activities	Health and welfare conditions in human settlements		Land use
Emission and waste discharge	Exposure and health effects		Demographic and social conditions

Source: Adapted from UN (1988).

data for the capital city and the three other largest cities or urban agglomerations. If the available statistics do not coincide with the "administrative boundaries" of the city (that is, boundaries defined according to legal or political statutes for the city), data may be given for the "urban agglomeration." This concept includes not only the administrative city but also the suburban fringe or heavily settled territory lying outside, but adjacent to, the city's boundaries. Another approach is to show data for major cities and other selected settlements classified by population size.

The identification of marginal housing units, slums, and squatter settlements is an issue not adequately covered by the statistics and indicators discussed in the chapter. Slums generally refer to older housing, which is underserviced, overcrowded, and dilapidated. Squatter settlements are areas where housing units have been constructed on land to which the occupants have no legal claim. These types of settlements are usually located in suburban areas, particularly at the peripheries of principal cities. Housing censuses and environment statistics on human settlements usually combine slums and squatter settlements together under the heading of marginal housing. Sometimes, marginal housing units are further divided into subgroups: (i) improvised housing units, (ii) housing units in permanent buildings not intended for human habitation, and (iii) other premises not intended for human habitation. Whatever the treatment, statisticians should not lose sight of the fact that the economic and environmental impact of these settlements can be significant.

The periodicity of data collection is another general issue that must be addressed. Most statistics are presented on an annual basis, but environment data is collected over many different time periods, ranging from decades in the case of censuses to hourly, daily, monthly, or even continuous monitoring. One of the statistician's tasks is to process this data for annual presentation. However, annual presentation should not preclude the display of monthly or daily statistics where seasonal or other fluctuations are relevant. In some cases, it may not be possible to present annual data due to the periodicity of (infrequent) censuses or surveys.

Appendix 1

OUTLINE FOR THE PREPARATION OF A COMPENDIUM OF ENVIRONMENT STATISTICS

For purposes of illustration, the outline assumes that the framework chosen for organization of the data and tasks is one based on an environmental medium.

Section A

1. Introduction

   a. Country background, with brief outlines of physiography, biodiversity, and socio-economic conditions
   b. Overview of the status of environment statistics in the country

2. Description of each of six environmental components (atmosphere, water, land/soil, flora, fauna, human settlements) under each of four information categories (social and economic activities and natural events; impact; response; and stocks, inventories, and background conditions).

Each chapter or section should contain textual description (supported by summary tables, charts, bars, and diagrams). The textual description in each section may focus on the following:

   a. A country overview of the individual environmental component
   b. Major problems associated with individual components indicating prime sources/causes of environmental degradation (natural such as flood, drought, earthquake, cyclone, volcanic

Appendix 1 (continued)

activity, etc.; and anthropogenic factors such as industries, urbanization, agriculture, vehicular traffic, etc.)

c. Government or private efforts (such as environmental rules/ regulations/ guidelines formulated and/or programs undertaken, etc.) made to mitigate the impacts, data availability, etc.

Section B:

This section is tabular, providing detailed data that supports the text in Section A.

Section C:

This section should contain the following appendices:

Names of agencies/data sources

Glossary of terms and abbreviations used

Brief outline of the methodology of environmental data collection indicating the duration and frequency of monitoring

Relevant standards

Relevant rules, regulations, acts, policies for protection of the environment and natural resources

References and bibliography

Appendix 2

TWO EXAMPLES OF A FRAMEWORK FOR THE DEVELOPMENT OF ENVIRONMENT STATISTICS

Example No. 1

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
1. FLORA	Agricultural and livestock production (includes land clearing, irrigation, grazing, harvesting, use of fertilizers, and pesticides)	Proliferation, depletion, extinction of species	Protection of endangered species	Inventory of species and genetic resources
	Forestry and logging	Depletion/growth of forests and woodlands	Protection of habitat (land use regulation and zoning, reserves, and protected areas)	Inventory of vegetation cover (e.g., forest inventory)

Appendix 2 (continued)

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
	Competing land use (settlements, agriculture, forestry, mining, recreation, etc.)	Impact of pollution on vegetation cover (e.g., from acidic precipitation)	Forest management including afforestation	Inventory of emissions hazardous to flora
	Emissions hazardous to flora	Impact on land/soil (dissertification and erosion due to removal of vegetation cover, biochemicals in soils)	Pollution monitoring and controls	Land use and characteristics
		Changes in water regime from deforestation and removal of vegetation	Health protection (food quality controls, alternative food resources)	Socioeconomic factors affecting flora (population, food and energy production and consumption)
2. FAUNA	Livestock production	Proliferation, depletion, extinction of species	Hunting, fishing, and breeding regulations	Inventory of species and genetic resources

Appendix 2 (continued)

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
	Hunting, trapping, and game propagation	Migration of species	Protection of habitat (land-use regulations and zoning)	Inventories of habitats/ ecosystems
	Competing land use (agriculture, ranching, settlements, etc.)	Changes of habitats/ecosystems (including species diversity)	Pollution monitoring and controls	Inventory of emissions hazardous to flora
	Emissions hazardous to fauna	Human health and welfare impacts (nutrition-related effects, changes in cost/productivity in livestock production)	Health protection (food quality controls, alternative food resources)	Socio-economic factors affecting flora (population, food and energy production and consumption)
3. ATMOSPHERE	Land use affecting climate (deforestation, desertification, drainage, irrigation, urban sprawl, infrastructure)	Air quality (ambient concentrations of air pollutants)	Monitoring and control of air pollution	Emission inventory (types, sources of air pollutants)

Appendix 2 (continued)

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
	Emission of air pollutants from stationary and mobile sources (industry, agriculture, households, transportation)	Biological and ecological impacts (contamination and destruction of species, disruption of ecosystems by acidic precipitation for example)	Alternative land use production processes and consumption patterns (e.g., alternative energy sources)	Inventories of areas vulnerable to air pollution and climate/ weather extremes
		Impact on land, water and artifacts (e.g., acidic precipitation)	Health protection	Land use and characteristics
		Human health and welfare impacts (e.g., associated with air pollution)		Socio-economic factors affecting air quality and weather (population, food and energy production and consumption)

Appendix 2 (continued)

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
4. WATER a. Freshwater	Water withdrawal (surface water, ground water, other)	Water quality (levels, flow and supply)	Conservation and development of water resources for industry, agriculture and domestic use (including water restoration)	Inventory of water resources
	Water use (industrial, domestic and municipal, agricultural)	Ambient concentrations of biological contaminants, chemical substances and suspended solids and physical characteristics	Water treatment (primary, secondary, tertiary)	Inventory of aquatic ecosystems
	Instream water use (hydro-power generation, transportation, fishing)	Biological and ecological impact (e.g., eutrophication, contamination and destruction of biota)	Conservation of aquatic ecosystems and their biota	Emission inventory (types, sources of discharges/ water polllutants)

Appendix 2 (continued)

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
	Waste water and discharge (includes sedimentation)	Quality of precipitation, erosion, salination, flood, and drought areas	Pollution monitoring and water quality control	Land use and characteristics (e.g., vegetation cover, built-up area, soil types, vulnerability)
		Health and welfare impact (water-borne diseases, productivity/ cost changes in water-using activities)	Health protection	Socio-economic factors affecting water use (population growth, density and migration, production and consumption, infrastructure, water budgets)
b. Marine water	Non-consumptive water use (tidal energy generation, transportation, fishing, etc.)	Ambient concentrations of pollutants (marine waters and coastal areas)	Conservation and development of marine waters and coastal areas (e.g., marine parks and reserves)	Inventory of ecosystems (marine/coastal) and species

Appendix 2 (continued)

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
	Waste withdrawal and use (desalination, consumption)	Biological and ecological impacts (proliferation, depletion, extinction and contamination of marine biota, disruption of habitats	Conservation of marine/ coastal ecosystem	Emission inventory (types, sources of marine water pollutants)
	Competing coastal land use (infrastructure, tourism, recreation)	Human health and welfare impact (e.g., water-borne diseases, impacts of tourism, recreation)	Pollution monitoring and control	Coastal land use and characteristics
	Seabed mining (including offshore oil drilling)			Socio-economic factors affecting water use (population growth, density and migration, production and consumption, infrastructure, water budgets)
	Emissions from coasts and rivers, sea-dumping, oil spills			

Appendix 2 (continued)

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
5. LAND/SOIL a. Surface	Land use (agriculture and livestock , forestry and logging, mining and quarrying, human settlements, transportation, etc.)	Land/soil gain/loss (e.g., land development, loss of agricultural land to competing uses, erosion)	Land use regulation and zoning	Inventory of soil/land (including use and tenure, characteristics and topographic conditions)
	Waste and waste water discharge	Land/soil quality (erosion, desertification, salination, alkalinization, ambient concentration of soil pollutants)	Conservation of soils (e.g., afforestation, desertification control, use of environmentally sound production methods)	Inventory of vulnerable areas (disaster-prone areas, wetlands)
		Terrestrial ecosystems (e.g., changes in energy, material and nutrient flows, system productivity, species growth and diversity)	Waste disposal (including recycling) and pollution monitoring and control	Emission inventory (types and sources) of solids and liquid wastes and soil pollutants

Appendix 2 (continued)

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
b. Sub-surface	Mining and treatment of metallic and non-metallic minerals	Depletion/increase of mineral (including energy) reserves	Reclamation and rehabilitation of land	Inventory of mineral resources (reserves of metallic and non-metallic minerals)
	Extraction of energy resources (fossil fuels, geothermal and nuclear)	Land disturbance (e.g., open pits, waste disposal)	Conservation of land and ecosystems (e.g., mining regulations and control, protected areas)	Inventory of ecosystems
	Discharges (dusts and air pollutants, acid drainings, tailings, liquid wastes radioactive waste disposal)	Ambient concentrations of air and water pollutants	Recycling, substitution of mineral resources	Emission inventory (types and sources of discharges related to mining)

Appendix 2 (continued)

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
		Human health and welfare impacts (e.g., mining accidents, contamination of mine workers, productivity/ cost changes in mining operations)	Pollution control and monitoring	Land use and characteristics (land-use categories, vulnerable and protected areas, topographic and geologic characteristics)
			Health protection (e.g., for mining operations)	Economic factors affecting demand and supply of mineral resources (price/cost, production and consumption patterns, demographic factors)

Appendix 2 (continued)

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
6. HUMAN SETTLEMENTS	Population growth and migration	Urban sprawl and concentration (population density and concentration)	Housing programs (e.g., low-cost housing, rehabilitation and upgrading, finance, building codes and regulations, slum clearance)	Inventory of buildings and infrastructure
	Construction (residential, non-residential)	Housing shortage and occupancy, access to utilities and community services	Land policies and control (zoning, resettlement and land development)	Inventory of hazardous industries, workplaces and activities
	Utilities (energy and water supply)	Marginal housing (slum and squatter settlements, decline of inner cities, sub-standard housing)	Self-help housing and community development programmes	Emission inventory (types, sources of pollutants in settlements)
	Transportation (public, private)	Ambient concentrations of waste and pollutants; noise levels and exposure	Monitoring and quality control of working environment	Land use (pattern, land tenure and characteristics)

Appendix 2 (continued)

Environmental Component	Social and Economic Activity	Environmental Impact of Activities	Response to Impact	Inventories, Stocks and Background Conditions
	Land use in settlements (residential, industrial, commercial, transportation and other infrastructure)	Biological and ecological impacts (especially from urban sprawl and infrastructure development)		Economic factors affecting human settlements (demographic, industrialisation, informal sector, cost/prices, income distribution)

Appendix 2 (continued)

Example No. 2

Environmental Component	Social and Economic Activity (pressure/driving force)	Environmental Impact of Activities (part of the state)	Response to Impact (response)	Inventories, Stocks and Background Conditions (part of the state)
1. AIR/CLIMATE	Emissions of CO_2, SO_2 and NO_2	Ambient concentrations of CO_2, SO_2 and NO_2, O3 in urban areas	Expenditure on air pollution abatement	Weather and climate conditions
	Consumption of ozone depleting substances	Air quality index	Reduction in consumption of substances and emissions	
2. LAND/SOIL	Land use change	Area affected by soil erosion	Protected area as % of total land area	Arable land per capita
	Livestock per km^2 of aird and semi-arid lands	Land affected by desertification		
	Use of fertilizers	Area affected by salinization and water logging		
	Use of agricultural pesticides			

Appendix 2 (continued)

Environmental Component	Social and Economic Activity (pressure/driving force)	Environmental Impact of Activities (part of the state)	Response to Impact (response)	Inventories, Stocks and Background Conditions (part of the state)
3. WATER a. Fresh water resources	Industrial, agricultural and municipal discharges directly into freshwater bodies	Concentration of lead, cadmium, mercury, and pesticides in fresh water bodies	Waster water treatment, total and by type of treatment (% of population served)	Groundwater reserves
	Annual withdrawals of ground and surface water	Concentration of fecal coliform in fresh water bodies	Access to safe drinking water (% of population served)	
	Domestic consumption of water per capita	Acidification of fresh water bodies		
	Industrial, agricultural water use per GDP	BOD and COD in fresh water bodies Water quality index by fresh water bodies		

Appendix 2 (continued)

Environmental Component	Social and Economic Activity (pressure/driving force)	Environmental Impact of Activities (part of the state)	Response to Impact (response)	Inventories, Stocks and Background Conditions (part of the state)
b. Marine water resources	Industrial, agricultural and municipal discharges directly into marine water bodies	Deviation in stock from minimum sustainable yield of marine species		
	Discharges of oil into coastal waters	Loading of N and P in coastal waters		
4. OTHER NATURAL RESOURCES				
a. Biological resources	Annual roundwood production	Deforestation rate	Reforestation rate	Forest inventory
	Fuelwood consumption per capita	Threatened, extinct species	Protected forest area as % of total area	Fauna and flora inventory
	Catches of marine species			Fish stocks

Appendix 2 (continued)

Environmental Component	Social and Economic Activity (pressure/driving force)	Environmental Impact of Activities (part of the state)	Response to Impact (response)	Inventories, Stocks and Background Conditions (part of the state)
b. Mineral (incl. energy) resources	Annual energy consumption per capita	Depletion of mineral resources (% of proven reserves)		Proven mineral reserves
	Extraction of other mineral resources	Lifetime of proven reserves		Proven energy reserves
5. WASTE	Municipal waste disposal	Area of land contaminated by toxic waste	Expenditure on waste collection treatment	
	Generation of hazardous waste		Waste recycling	
	Imports and exports of hazardous wastes			
6. HUMAN SETTLEMENTS	Rate of growth of urban population	Area of population in marginal settlements	Expenditure on low-cost housing	Stock of shelter and infrastructure
	% of population in urban areas	Shelter index		
	Motor vehicles in use per 1,000 inhabitants	% of population with sanitary services		

Appendix 3

CONVERTING PRIMARY DATA INTO INFORMATION: A METHODOLOGY FOR HANDLING LARGE DATA SETS

Problems relating to the quality of air and water have received the most attention in this Handbook. In Chapters 4 and 5, the construction and operation of systems to monitor these two media were discussed in some detail. The huge amounts of data obtained through monitoring, coupled with the construction of emission inventories and sample surveys, are the core of any national program. Unfortunately, these primary statistics cannot be easily understood by government officials or the general public. This appendix describes a simple methodology to transform the raw data into a more useful type of information.

Environmental indicators (EIs) are an essential part of the effort to summarize the results of a monitoring program. However, the methods of constructing these indicators, the forms of presentation, and the procedures for handling the primary data are equally important. A flaw in statistical procedures can jeopardize the credibility of the entire program. Similarly, failure to produce a simple and easily comprehensible set of indicators will lead to erroneous policy decisions and dwindling public support.

The methodology presented here is best suited for the assessment of large data sets. It allows analysts to condense a large body of statistics into summary measures while retaining the sensitivity of the original data to ascertain trends. The discussion draws mainly on examples referring to air quality, but the same techniques can be used in many other applications. Other environmental topics to which this methodology can be applied are large data sets referring to water quality and contaminated land.

Data rationalization. The job of statisticians is to find some way to summarize the primary data gathered at monitoring stations. Such a process, which is often referred to as data rationalization, must satisfy

Appendix 3 (continued)

at least two criteria. First, rationalization cannot result in any significant loss in data representativeness. Second, the information or indicators to be developed must be in a form that allows easy comparison with internationally accepted standards.

Before the process of data rationalization can begin, a considerable amount of preparatory work must be done. Decisions are needed on each of the following aspects:

(i) identification of specific types of indicators that will satisfy the above criteria and still be easily understood by policy makers and the general public, and
(ii) agreement on a suitable form of presentation that can accurately represent both current conditions and longer term trends in air quality in cities and provinces.

Some examples of pollutants that may be chosen for an initial assessment of air quality in urban areas in a developing country are carbon monoxide (CO), nitrogen dioxide (NO_2), suspended particulate matter (SPM), and sulfur dioxide (SO_2). A similar set of indicators for water quality could consist of biological oxygen demand (BOD), chemical oxygen demand (COD), and so on. More generally, different combinations of pollutants are singled out when evaluating specific problems such as the effects of urban traffic on air quality, the quality of groundwater in a major catchment area, the air in residential zones, and so on. A number of these pollutants, or parameters, are discussed in Chapters 4 and 5 (see the sections Air Parameters and Water Parameters, respectively).

The form in which the indicators are presented is especially important for the users. Sometimes, statisticians choose to develop an index of pollutants, but the approach recommended here is to base the construction of indicators on actual physical and chemical measurements (that is, monitoring data). The advantages of this approach are that the indicators can be easily related to health and ecological effects and are derived from information that is scientifically credible. Such measures

Appendix 3 (continued)

are also more easily understood by the public and nontechnical decision makers than indexes or other relatively complicated statistical expressions.[1]

Presentation of box plots. In this example, a hypothetical set of monitoring data on air quality is assumed to exist. This large body of data will be summarized in terms of a simplified representation of the frequency distribution for each indicator. Data averages are also calculated for various time periods, which depend on two factors: (i) the international standards against which the results are judged, and (ii) the type of health effect (acute or chronic) that each pollutant may produce. Short time periods (1 hour, 8 hours, or 24 hours) can be used to assess acute health effects, while longer time periods (for example, an annual average) refer to chronic health effects. Finally, ecological effects are judged in terms of both short and long time periods (for example, 8 hours and 24 hours), depending on the specific pollutant.

Table A3 suggests several time periods and averages that can be used to gauge health and ecological effects. These measures are based on international guidelines for air quality developed by the World Health Organization (WHO).[2] The guidelines were been developed for Europe, but current evidence suggests that they are applicable worldwide since there appears to be no significant difference in the effects of air pollution on human health and the environment in other geographic areas.

Indicators based on the maximum annual values recorded at multiple monitoring sites are the preferred means of assessing trends in pollutant concentrations. These measures, which are also known as extreme value statistics, are thought to be more sensitive to variations

1 Indicators that are directly derived from primary data also have drawbacks. One is that a different measure must be constructed for each pollutant. The information obtained from monitoring stations is also site-specific and subject to temporal and meteorological variations.

2 The WHO guidelines indicate thresholds for human exposure that should result in no adverse effects. For most pollutants, the guidelines also include a margin of safety based on the confidence of the dose-response relationship. See WHO (2000a).

Appendix 3 (continued)

in air quality than other formulations such as a composite average calculated for a number of monitoring sites. Extreme value statistics can also be used for an evaluation of acute health effects. A drawback is that short-term meteorological variations and site-specific factors can distort trends based on extreme value statistics.[3] To account for this characteristic, the specific indicators proposed in Table A3 combine both extreme value statistics and average statistics of multiple sites. The combination of measures reduces the effects of data variability and makes the analysis of trends more reliable.

Presentation of statistics based on primary data for multiple sites will usually include monitoring results from stations located both inside and outside urban areas. To ensure that trends are being assessed across comparable locations, several broad-site categories should first be identified. In the case of air quality, these categories could include

(i) urban, traffic-dominated (or commercial) sites,
(ii) urban residential sites, and
(iii) rural sites.[4]

After completing this preparatory work, the statistician can turn his attention to the task of data presentation. Primary data for each year for each selected indicator and all monitoring stations in a given region and site category is presented in the form of a simplified frequency distribution function or box-plot diagram. Figure A3.1 gives a hypothetical example for CO levels recorded by sites in an urban traffic zone. The simplified distribution shows only a sample of percentile values: in this

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3 The severity of meteorological conditions can vary from year to year, causing large fluctuations in the maximum value in each year recorded at each site. However, when the distribution function is constructed from data for a large number of monitoring sites, the influence of extreme values for individual sites is significantly reduced.

4 Other categories could be considered when evaluating different issues relating to the quality of air or water.

Appendix 3 (continued)

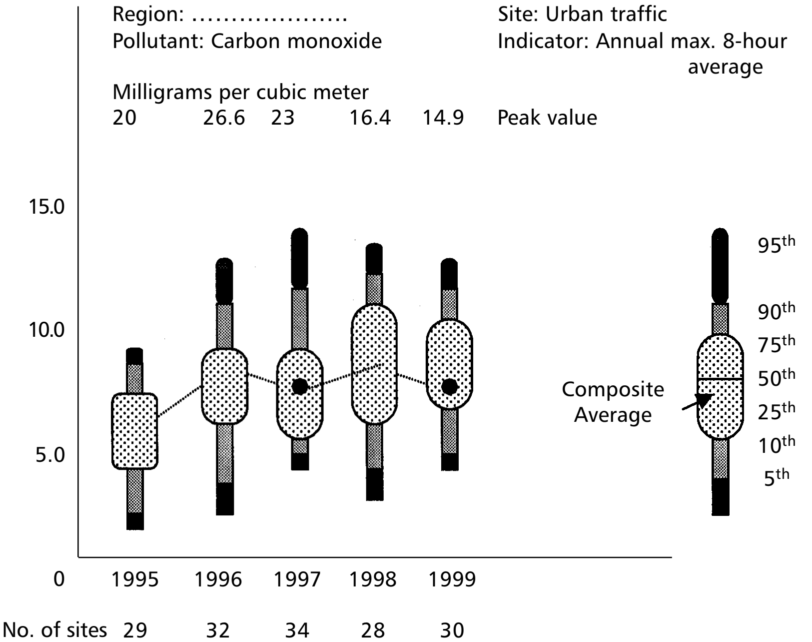
Table A3: Appropriate Time Periods for Presentation of Indicators Relevant to Acute and Chronic Effects and Ecological Effects

Pollutant	Unit	Acute Health Effects	Chronic Health Effects	Ecological Effects
Carbon monoxide	mg/m^3	Annual max. 1-hour average Annual max. 8-hour running average	No chronic health effects	No ecological effects
Nitrogen dioxide	mg/m^3	Annual max. 1-hour Annual max. 24-hour	Annual average	Annual max. 4-hour running average Annual max. 24-hour Annual average
Particulate matter	mg/m^3	Annual max. 24-hour	Annual average	No ecological effects
Sulfur dioxide	mg/m^3	Annual max. 1-hour Annual max. 24-hour	Annual average	Annual max. 24-hour Annual average

Source: OECD (1999c).

Appendix 3 (continued)

Figure A3.1: A Box-Plot Diagram for Carbon Monoxide



case, the 5th, 10th, 25th, 50th (median or composite average), 75th, 90th, and 95th values. The highest reported value is given in numeric form at the top of the box-plot diagram and the number of monitoring sites is given below the simplified frequency distribution for each year. Such diagrams can be generated for almost any combination of region, site category, and pollutant indicator.

Once the data is displayed in this form, interpretation is straightforward. The hypothetical trends in Figure A3.1 show a modest increase in levels of CO between 1995 and 1999, with some annual variability. Concentrations at the most polluted traffic sites declined slightly in the most recent years. However, levels of CO at moderately polluted

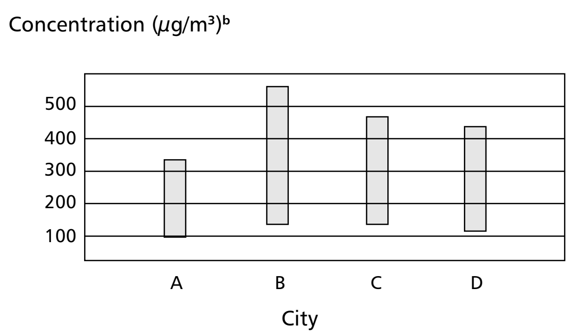
Appendix 3 (continued)

sites (for example, those between the 25th and 75th percentiles) have gradually risen over time. There is also considerable annual variability.

Presentation of peak statistics. The box-plot diagrams described above can be supplemented by constructing peak-statistics bar charts. These figures are used to describe levels of air pollution in cities, or water pollution along stretches of a specific waterway. A bar chart shows the highest and lowest annual maximum values and the composite average for each indicator.

An example referring to the maximum one-hour concentration for levels of nitrogen dioxide is found in Figure A3.2. The chart reports the highest and lowest values, along with the composite average, recorded by monitoring stations in each of four cities. When presenting statistics on the quality of urban air, bar charts must be constructed for each pollutant indicator. Generally, the cities included in these charts are all those with populations greater than one million. For countries with fewer

Figure A3.2: A Bar Chart for Urban Peak Statistics: Concentrations of Nitrogen Dioxide in Major Cities[a]



[a] Figures refer to annual 1-hour maximums.
[b] WHO air quality guideline is 200 μg/m.^{3}

Appendix 3 (continued)

than three cities of one million residents, statistics for at least the three largest cities should be presented.

The type of bar chart described here does not necessarily contain the same data as the box-plot diagram discussed in the preceding section. Ideally, box-plot diagrams provide a means of tracking trends over several years while peak-statistic bar charts refer to the concentration of pollutants during a single year. The time periods chosen for determining averages should–to the extent possible–reflect WHO guidelines in both cases.

Limitations and future development. Many developing countries may lack the monitoring facilities and data-processing capabilities that are desired if the methodology is to meet rigorous statistical standards. For example, the minimum number of monitoring sites recommended to generate box-plot diagrams showing selected percentiles is around 20. The inclusion of data from a large number of sites reduces the impact of year-to-year variability. In fact, the number of monitoring sites should probably be close to 50 to obtain consistent annual trends. Trends observed on the basis of only a small number of sites will almost certainly be somewhat irregular. This shortcoming will be common to most developing countries at early stages in the environment program, but it should not prevent the development of indicators or their dissemination to government officials and the general public. The long-run goal should be to construct a monitoring network that will yield statistically reliable results. In the meantime, the assessment of each indicator should be extremely cautious and qualified.

Annual changes in meteorological conditions may give rise to correspondingly large variations in pollution concentrations and these effects will be exacerbated by a less-than-sufficient network of monitoring stations. One way to account for this problem would be to normalize the data with respect to an "average" meteorological year. Normalization can improve the decision-making content of the information, but it may also diminish public confidence in the environmental data. Thus, it should be treated purely as an interim measure.

Appendix 3 (continued)

Finally, statisticians in developing countries will encounter difficulties when attempting to evaluate trends based on only a few years of observations. The use of relatively short time series for most box-plot diagrams is unavoidable since data for more than 2-3 years will not be available for most monitoring sites. In the future, the availability of additional years of data will significantly improve the reliability of trend analysis.

GLOSSARY

Activity/event variables: Variables that provide information on the characteristics of a particular activity or event that originates from a resource. The activity/event could have both positive and negative impacts on environmental resources. An activity that is part of the overall process of economic development may have a positive impact on the economy, but a negative impact on a particular resource such as land or water. An activity can also be a response intended to mitigate the adverse impacts of development or natural disasters.

Air quality criteria: Quantitative criteria indicating levels of pollution and lengths of human exposure which, if exceeded, may have adverse effects on health and welfare.

Ambient air: The portion of the atmosphere, external to buildings, to which the general public has access.

Aquifer: (i) An underground bed or layer of earth, gravel, or porous stone that contains water; (ii) a geological formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring.

Biochemical oxygen demand (BOD): The dissolved oxygen required to decompose biodegradable organic matter in water. This is a measure of organic pollution because heavy waste loads have a high demand for oxygen.

Biota: All living organisms that exist in an area.

Boundary stations: Stations making up part of a water monitoring network and are intended to describe fluxes, either between legal boundaries or between submedia (from a river to a lake or ocean, or from a surface stream to groundwater).

Carbonaceous matter: Pure carbon or carbon compounds present in the fuel or residue of a combustion process.

Chemical oxygen demand (COD): A measure of oxygen required to oxidize all compounds (organic or inorganic) in water.

Coliform index: A rating of the purity of water based on a count of fecal bacteria.

Composite sample: A sample of water that is a mixture of grab samples of equal or weighted volume, all collected at the same location at different points of time. Also known as a time composite, these samples are useful for assessing the average concentration or load of pollutants.

Dissolved oxygen (DO): A measure of the amount of oxygen available for biochemical activity in a given amount of water. Adequate levels of DO are needed to support aquatic life. Low concentrations can result from inadequate waste treatment.

Effluent: Waste material discharged into the environment, treated or untreated. Generally, the term refers to liquid waste/wastewater.

Emission factor: Refers to a particular source of emissions and is generally expressed as the quantity of gas released into the atmosphere per unit of activity. An activity can refer to travel distances for motor vehicles sources (or, alternatively, fuel consumption), or to a production level for an industry. Emissions from a source are computed as the product of its activity level and the corresponding emission factor.

Emissions or discharges to water: Emissions to water include all discharges of biodegradable substances or other substances soluble in water; discharges mixing with the water or influencing the biophysical or chemical quality of the water. Heavy metals and hazardous wastes are included, together with oily wastes, floating debris, silt, and other suspended matter.

Environmental indicator: A parameter, or value derived from a parameter, which yields information about an environmental phenomenon or event. Environmental indicators usually have a significance that extends beyond that directly associated with a parameter value.

Estuaries: Areas where freshwater meets saltwater (bays, mouths of rivers, salt marshes, lagoons). These brackish water ecosystems shelter and feed marine life, birds, and wildlife.

Eutrophication: The enrichment of water by nutrients (especially nitrogen and phosphorus compounds, but also organic matter). The result is an accelerated growth of algae and higher forms of plant life, which upsets the balance of organisms present in the water and jeopardizes the quality of the water.

Fecal coliform bacteria: Organisms associated with the intestines of warm-blooded animals and commonly used to indicate the presence of fecal material and the potential presence of organisms capable of causing human disease.

Flue: Any passage designed to carry combustion gases and entrained particulates.

Framework: A statistical framework for environment statistics is needed at a very early stage in the work. The framework can be any practical means of structuring and managing environmental information, and a number of options exist. It represents a simplification of the real world and is an integral part of the overall methodology. Essentially, the framework is a theory or model that helps the statistician to organize the data. Different versions may be employed in the same exercise, depending on the subject matter and the data requirements.

Grab sample: A discrete sample of water collected at a specific location, depth, and time. Such a sample may also be "depth-integrated," which means that it is collected over the entire depth of the water column at a specific location and time.

Heavy metals: Metallic elements such as mercury, chromium, cadmium, arsenic, and lead, with high molecular weights. At low concentrations these metals can damage living organisms through accumulation in the food chain.

Hydrology: The science dealing with the properties, distribution, and circulation of water.

Indicators of environmental conditions: Indicators used in the PSR framework to measure the state or quality of the environment.

Indicators of environmental pressures: Designed to measure pressure in the PSR framework, these indicators address the effects of human activities on the environment.

Inorganic matter: Chemical substances of mineral origin, not containing carbon-to-carbon bonding. Generally structured through ionic bonding.

Internal renewable water resources: Usually stated in annual terms, this expression is defined as the sum of the annual average freshwater flow of rivers and the groundwater produced from rainfall within the country's borders.

Mercaptans: Odorous, gaseous compounds that are offensive at low concentrations, and toxic at high concentrations. Mercaptans are produced by geothermal sources and certain industrial processes.

Mixing height: The expanse in which the air rises from the earth and mixes with the air above it until it meets air that is equal or warmer in temperature.

Nitrogen oxides: Gases formed mainly from atmospheric nitrogen and oxygen when combustion takes place under conditions of high temperature and pressure. Nitrogen oxides include nitric oxide (NO) and nitrogen dioxide (NO_2), both of which are harmful gases.

Nonconservative samples: Samples of a parameter for which the values can change in the time between collection and analysis in the laboratory.

Nonpoint (diffuse)sources: Causes of water pollution that are not associated with point sources. Examples include (i) pollution related to agricultural activities such as runoff from manure disposal and from land used for livestock and crop production; (ii) mine-related sources of pollution including new, current, and abandoned surface and underground mine runoff; (iii) pollution related to construction activities; (iv) pollution from waste disposal on land, in wells, or in subsurface excavations that affect groundwater and surface water quality; (v) saltwater intrusion into freshwater flow from any cause.

Oxide: A compound of two elements, one of which is oxygen.

Ozone (O_3): A pungent, colorless, toxic gas that contributes to photochemical smog.

Parameter: A property that is measured or observed.

Particulates: Fine liquid or solid particles such as dust smoke, mist, fumes, or smog, found in the air or emissions.

Point source: A stationary location where pollutants are discharged, usually by an industrial establishment. A point source is any discrete conveyance such as a pipe, ditch, channel tunnel, conduit, well, container, or concentrated animal feeding operation from which pollutants are discharged.

Rate variables: Variables that represent the flow from or into the stock of a resource–for example, the rate of conversion of forestlands to agricultural purposes, expressed as a percentage of total forestland.

Reagents: Chemicals used for laboratory analysis and testing. These could be acids (for example, sulfuric acid, nitric acid, or hydrochloric acid), alkali (such as sodium hydroxide, calcium hydroxide, or potassium hydroxide), or any other chemical compound formed by reacting more than one chemical.

Receiving waters: Any body of water where treated or untreated wastes are dumped.

Reference stations: Monitoring stations designed to provide background information on the natural quality of air or water. Reference stations are an integral part of a basic monitoring network. They are also known as benchmark stations.

Response indicators: Indicators that measure the result of individual or collective actions to mitigate, adapt, or prevent the negative impacts of human actions on the environment, or efforts to halt or reverse damage already inflicted.

Runoff: That portion of precipitation that flows over the ground surface and returns to streams. Runoffs can collect pollutants from the air or land and carry them to receiving waters.

Sedimentation: The process of letting suspended solids settle out of wastewater by gravity during wastewater treatment.

Silviculture: Management of forestland for timber. Silviculture sometimes contributes to water pollution owing to clear-cutting.

State variables: Variables that reflect the quality of a resource in terms of its potential uses, whether these uses occur off-site or in situ. An assessment of the quality or state of the resource could be made either by comparing these statistics to a norm or by monitoring trends.

Stock variables: Variables that provide information on the quantity of a resource. The stock may rise or fall as a result of an activity or event, and the trend in stock value provides an indication of a resource's future availability.

Suspended solids: Tiny particles of solids dispersed but undissolved in a solid, liquid, or gas. Suspended solids in sewage cloud the water and require special treatment to remove.

Topography: Physical features of a surface area including relative elevations and the position of natural and human-made features.

Volatile organic compound: Any compound containing carbon and hydrogen or containing carbon and hydrogen in combination with any other element which has a vapor pressure of 1.5 pounds per square inch absolute (77.6 mm. Hg) or greater under actual storage conditions.

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