

Monitoring

Objectives

Pollutants of concern for the environment must be monitored to obtain reliable information on the quality of ambient air and media. Such information is a necessary part of any environmental management system, whether in the private or the public sector. It provides a basis for informed decisionmaking and the development of environmental management strategies. To ensure that decisions are made on a sound basis, it is essential to be confident that the measurements reflect the existing situation; in other words, the data must be of clearly defined and documented quality. Hence, quality assurance and quality control are important. The way in which samples are taken and analyzed is as important as the results of the measurement (analysis) itself. A quality assurance system should include institutional as well as technical aspects.

Environmental releases from major industrial sources are monitored as part of the overall monitoring of sources of the pollutants of concern within an airshed or water basin. The objectives of monitoring systems also include process optimization, auditing, and compliance with regulatory requirements such as emissions standards.

Methodology

Monitoring plans are designed and implemented for collecting data on ambient air and water quality and on releases of pollutants of concern from major point sources. The elements of a monitoring plan normally include selection of the parameters of concern; the method of collection and handling of samples (specifying the location, the frequency, type, and quantity of samples, and sampling equipment); sample analysis (or, alter-

natively, on-line monitoring); and a format for reporting the results.

Ambient levels of pollutants such as heavy metals are measured in air, water, and soil, along with other parameters, at specified locations and frequencies and using specified equipment and methods. The objective is to collect and analyze representative samples to produce data for use in the environmental management system. To ensure acceptable ambient levels, concentrations of pollutants in the environment are predicted, using models and information on emissions from some of the major pollution sources, and are then monitored (that is, verified by actual observation). Corrective action, follows, when necessary.

Ambient Air Quality

Although, in theory, all pollutants should be monitored, in practice, only the significant pollutants are monitored, at best. Usually, monitoring is limited to some key pollutants such as suspended particulate matter (SPM). A good air quality management system usually reviews the probable emissions sources and the environmental receptors in the area of concern and then selects the pollutants to be monitored. One such pollutant is particulate matter of less than 10 microns in aerodynamic diameter (PM_{10}). (Some modern air quality monitoring systems are being developed to monitor $PM_{2.5}$ and PM_1 , that is, particulates of sizes less than 2.5 microns and 1 micron, respectively.) Other pollutants normally monitored include sulfur oxides, ozone, and nitrogen oxides. In some places, other priority pollutants may be included in ambient air monitoring: examples are volatile organics such as benzene and vinyl chloride, polynuclear aromatic hydrocarbons (PAHs), dioxins, furans,

asbestos, inorganics, and arsenic, cadmium, lead, mercury, nickel, and other heavy metals.

Locations of monitoring stations are determined on the basis of the receptors in the airshed. A network of monitoring stations is usually established to estimate the exposure levels. Normally, a monitoring station is also set up to measure background concentrations in cases where the resultant ambient levels of a particular source or sources are to be computed. The quality assurance plan should include the rationale for selecting the number and location of monitoring stations, the monitoring frequency, the equipment, and the method of sample collection. Monitoring may be continuous or may be done for short durations of, say, 1 hour, 8 hours, or 24 hours to determine the maximum and average for the set period.

Table 1 presents examples of the common ambient air monitoring systems used for some pollutants of concern.

Water Quality

Water quality management usually involves monitoring of key pollutants that serve as indicators of acceptability for a specific use. For example, there may be restrictions on pollutant levels for water used in irrigation and stricter restrictions for water destined for human con-

sumption. Further information on these issues is provided in the Water Quality Management chapters of this *Handbook* and in Jorgensen and Vollenweider (1988); World Bank (1993); Le Moigne et al. (1994); and Lee and Dinar (1995). Table 2 lists some pollutants of concern and methods of monitoring them.

On the basis of the nature of the water body (canal, river, lake, or sea) and its uses, the quality assurance plan establishes the number and locations of monitoring stations to estimate exposure levels, including exposure of aquatic ecosystems.

Typically, monitoring of water quality for human consumption includes measurements of fecal coliform; toxic organics such as benzene, trichloroethane, tetrachloroethene, chlorophenols, and pesticides; polynuclear aromatics such as benzo(a)pyrene, carbon tetrachloride, polychlorinated biphenyls (PCBs), dioxins, and furans; oil and grease; pH; toxic metals, including arsenic, cadmium, chromium, copper, lead, and mercury; and cyanides, as well as color, taste, odor, turbidity, and hardness (see WHO 1984). The quality of data obtained from analyzing collected samples or from continuous monitors should at least be of a level at which the cost-effectiveness of sampling and monitoring techniques is balanced with the adverse consequences of erroneous data.

Table 1. Examples of Ambient Air Monitoring Systems

<i>Parameter</i>	<i>Sampling or monitoring system</i>
SPM/PM ₁₀	ISO/TR7708/DP 4222 (measurement of atmospheric deposit; horizontal deposit gauge method) ISO/DP 10473 (measurement of the mass of particulate matter on a filter medium; beta ray absorption); ISO/DIS 9835 (determination of a black smoke index) 40 CFR, Part 50, Appendix J (for PM ₁₀); Appendix B (for SPM)
Sulfur dioxide	ISO 4219/4221; 40 CFR, Part 50, Appendix A (pararosaniline method)
Nitrogen dioxide	ISO 6768, 7996; 40 CFR, Part 50, Appendix F (gas phase chemiluminescence method); Salzman automatic colorimeter (method used in Japan)
Ozone	40 CFR, Part 50, Appendix D; measurement of photochemical oxidants using the neutral buffered automatic potassium iodide colorimetric method; used in Japan
Lead	ISO/DIS 9855; 40 CFR, Part 50, Appendix G (extraction with nitric and hydrochloric acids and analysis by atomic absorption spectrometry)
Asbestos	ISO/DIS 10312/VDI 3492 (fibers counted using scanning electron microscope)

Note: SPM, suspended particulate matter; CFR, United States, *Code of Federal Regulations*; ISO, International Organization for Standardization.

Table 2. Examples of Monitoring Systems for Water Bodies and Liquid Effluents

<i>Parameter</i>	<i>Sampling or monitoring system</i>
<i>General</i>	
PH	pH meter ISO (1980–91), Water Quality Standards APHA, ASTM, BS, DIN, SCA
BOD	Determine dissolved oxygen concentration in the test solution before and after incubation (APHA, ASTM, BS, DIN, ISO, SCA); 40 CFR, Part 136; USEPA Method 405.1
COD	Digest with potassium dichromate in strong acid solution with silver sulfate as catalyst after sample homogenization (APHA, ASTM, BS, DIN, ISO, SCA); 40 CFR, Part 136; USEPA Method 410.1
AOX	USEPA Method 1650 (titrimetric)
TSS	Filtration 40 CFR, Part 136; USEPA Method 160.2; APHA, BS, DIN, ISO, SCA
Total dissolved solids (TDS)	Pretreatment with membrane filtration, followed by evaporation APHA, BS, DIN, ISO, SCA
Phenol	Extract with MIBK, followed by GC analysis USEPA Methods 420.1, 420.2
Sulfide	React with dimethylphenylenediamine and ferric chloride in acid solution to form methylene blue; USEPA Methods 376.1, 376.2
Oil and grease	Extract with light petroleum, evaporate solvent, and measure weight USEPA Method 413.1
<i>Organic compounds</i>	
Total organic carbon	UV oxidation followed by infrared analysis USEPA Method 415.1; APHA, ASTM, DIN, ISO, SCA
Organics	40 CFR, Part 136.3 (GC, GC/MS, HPLC, ASTM D4657-87)
PAHs	Gas chromatography with flame ionization detection
Pesticides	Gas chromatography; 40 CFR, Part 136.3, Table 1-D.
<i>Inorganic substances</i>	
General reference	40 CFR, Part 136.3, Table 1-B.
<i>Metals</i>	
Arsenic	Atomic absorption spectroscopy; APHA, ASTM, SCA
Cadmium	Atomic absorption spectrometry; APHA, ASTM, BS, DIN, ISO, SCA Inductively coupled plasma emission spectrometry; ASTM, DIN, SCA
Chromium	Atomic absorption spectrometry; APHA, ASTM, BS, DIN, ISO, SCA Inductively coupled plasma emission spectrometry; ASTM, DIN, SCA
Lead	Atomic absorption spectrometry; APHA, ASTM, BS, DIN, ISO, SCA Inductively coupled plasma emission spectrometry; ASTM, DIN, SCA
Mercury	Flameless atomic absorption spectrometry; APHA, ASTM, BS, DIN, ISO, SCA
Nickel	Atomic absorption spectrometry; APHA, ASTM, DIN, SCA Inductively coupled plasma emission spectrometry; ASTM, DIN, SCA
Zinc	Atomic absorption spectrometry; APHA, ASTM, BSI, DIN, ISO, SCA

Note: See UNEP, Technical Report 27, for details. APHA, American Public Health Administration, *Standard Methods for the Examination of Water and Wastewater*; ASTM, American Society for Testing and Materials Standards, *Annual*, vols. 11.01, 11.02; BS, British Standards Institute, *Water Quality*, BS-6068; CFR, United States, *Code of Federal Regulations*; DIN, German Industrial Standard Methods for the Examination of Water, Wastewater and Sludge, DIN 38404–09; ISO, International Organization for Standardization, *Water Quality Standard Method*; SCA, Standing Committee of Analysts, U.K. Department of the Environment, *Methods for the Examination of Waters and Associated Materials*.

Point-Source Releases

Releases, including fugitive air emissions, are usually monitored to provide feedback to pollution prevention and control systems and to guide the necessary corrective action. Although releases from transport, households, and other sources are also monitored, this chapter deals solely with industrial sources. The chapter does not cover fugitive emissions; the empirical methods required for monitoring fugitive emissions are addressed in such sources as Bounicore and Davis (1992) and USEPA, *Compilation of Air Pollutant Emission Factors* (AP-42).

Air

Monitoring of air emissions from point sources usually involves monitoring pollutant concentra-

tions. The flow rate of stack gases and their temperature are among the basic parameters usually monitored, along with the level of pollutants present (see Table 3). (In extractive systems, a sample of stack gases is drawn.) The major pollutants monitored in stack gases include particulate matter; sulfur oxides and, in some cases, hydrogen sulfide and total reduced sulfur compounds; nitrogen oxides; carbon monoxide and, in some cases, carbon dioxide; halogens or halides (such as chlorine or hydrogen chloride); volatile organic compounds; and toxic materials, including metals. The parameters are selected on the basis of knowledge of the process and the associated environmental issues of concern, as described in the guidelines for the specific industry sector.

Monitoring methods for stack emissions specify locations, frequency, and equipment; the

Table 3. Examples of Air Emissions Monitoring Systems

Parameter	Sampling and analytical methods
Stack gases	Extractive methods using pitot tubes; 40 CFR, Part 60, Appendix A, Methods 1–4; BS 1756:1977, Part 2
PM ₁₀ /TSP	In situ nondispersive infrared spectrophotometry and extractive gravimetric; ISO 9096; ISO/TC 146/SCI/WG1N16(1994); 40 CFR, Part 60, Appendix A, Methods 5, 5A, 17; BS 3405:1983 VDI 2066, Parts 1, 2
Sulfur oxides	Extractive nondispersive infrared spectrophotometry; ISO 8178; 40 CFR, Part 60, Appendix A, Method 6; BS 1756:1977, Part 4; VDI 2462, Parts 1–7
Nitrogen oxides	Extractive fluorescence; ISO 8178; 40 CFR, Part 60, Appendix A, Method 7, 7A–7E; VDI 2456 Parts 1–7
VOCs	Extractive flame ionization; 40 CFR, Part 60, Appendix A, Method 18; VDI 3493, Part 1
Total hydrocarbons	Extractive nondispersive infrared spectrophotometry; 40 CFR, Part 60, Appendix A, Methods 25, 25A, 25 B; VDI 2460 (Parts 1–3), 2466 (Part 1), 3481 (Parts 1, 2), 2457 (Parts 1–7)
Carbon monoxide	Extractive nondispersive infrared spectrophotometry; 40 CFR, Part 60, Appendix A, Methods 10, 10A, 10B; VDI 2459, Part 6
Chlorine/hydrogen chloride	Extractive nondispersive infrared spectrophotometry; VDI 3488, Parts 1 and 2; VDI 3480, Part 1
Hydrogen sulfide	Extractive electrochemical analysis; VDI 3486, Parts 1–3

Note: Metals are usually analyzed by the methods outlined in Table 2. BS, British Standards Institute; CFR, United States, *Code of Federal Regulations*; ISO, International Organization for Standardization, *Method for the Gravimetric Determination of Concentration and Mass Flow Rate of Particulate Material in Gas-Carrying Ducts* (Geneva 1994); VDI, Germany, Federal Minister for the Environment, Nature Conservation and Nuclear Safety, *Air Pollution Control Manual for Continuous Emission Monitoring* (Bonn, 1992).

method of collecting, handling, and analyzing samples; and the method of reporting validated results. The sampling points should be at least 8 pipe diameters downstream and 2 pipe diameters upstream of any obstruction or change in flow direction. (For details, see United States, 40 CFR, Part 60, Appendix A; UNEP and UNIDO 1996.) Ports should normally be installed so as to extend at least 5 to 20 centimeters from the exterior of the stack. If the sum of stack inside diameter and port length is less than 3 meters, a minimum of two ports at 90° to each other is needed. In other cases, at least four ports 90° apart are needed. It is important to prevent the sampling process itself from causing changes in concentrations, and several criteria are specified to ensure the representativeness of the sample. Sampling points should be chosen to avoid the possibility of reverse flow, which might affect the validity of samples.

Liquid Effluents

Monitoring of liquid effluents is performed to meet the objectives of environmental management systems. The priorities of the water quality management are used as a guide in setting up the monitoring program. It is important to know the discharge load levels that will not compromise the sustainability of the aquatic system. The liquid effluent monitoring system normally includes selection of the sampling location; parameters to be measured; type of samples to be collected and frequency of measurement; equipment to be used; method of preserving and analyzing the sample; and data reporting and validation, including quality assurance and quality control.

To obtain representative samples, the samples should be taken where liquids are turbulent and well mixed. Sampling points should be located at least 25 pipe diameters downstream of disturbances such as places where streams join, to ensure that mixing is complete and the sample is representative. Sampling at or near boundaries of pipes, tanks, or lagoons where stagnant or otherwise unrepresentative conditions exist should be avoided.

The parameters for each process or effluent stream to be monitored and the frequency of monitoring are described in the guidelines for

specific industrial sectors. Sampling may be performed after each stage, to assess its performance, or at the inlet and the outlet of a treatment train. Fluctuations in the process may necessitate more frequent monitoring if some parameter is expected to reach levels of concern. The number of samples required should be such that at least a 95% confidence level can be attained. The types of samples can be discrete (spot, snap, or grab) or composite. Discrete samples are usually taken when concentrations of individual samples are of greater interest than are averages, as may be the case with compliance monitoring. Composite samples are prepared by mixing a series of discrete samples to get a representative sample over a period of time and for different locations. Sampling quantities should be sufficient for performing analysis and subsequent quality assurance and quality control; as a general rule, the sample should be at least 500 milliliters. Sample containers are selected to minimize contamination of samples or leakages of volatiles, if present.

The instruments used include pH meters, ion-selective electrodes, redox potential measurement devices, conductivity meters, dissolved-oxygen meters, turbidity meters, colorimeters and spectrophotometers (infrared and ultraviolet), ultraviolet fluorescence, chemiluminescence, flame ionization detector, atomic absorption spectroscope (for metals), flame photometer, electrochemical cell, and photo-ionization detector. The analytical methods to be used are presented in Table 2.

Solid Wastes

The objectives of monitoring solid wastes are to determine the acceptable treatment, storage, transport, and disposal methods that can be used and to obtain information on production processes. Accuracy, the time needed for analysis, and monitoring cost are considered when determining the data to be obtained from monitoring solid waste streams. Representative samples are collected by methods such as moving a cutter through dry flowing material or collecting wet materials from sampling ports in a pipeline. The sampling frequency and the parameters to be analyzed are specified in the guidelines for specific industrial sectors. Analytical methods for solid wastes are provided in USEPA (1986).

Wastes that may leach toxics such as heavy metals are analyzed for their leachability by methods such as toxic characteristic leachate procedure, or TCLP (see United States, 40 CFR, Part 261, Appendix).

Monitoring of some process parameters is essential for processes that are prone to accidental releases. Typically, alarms are set to go off when a selected parameter (an indicator of a potential accidental release) exceeds a predetermined level. For example, the pressure of the polymerization reactor in a high-density polyethylene plant is used to warn of the imminent release of process ingredients to the atmosphere. Similarly, monitoring of oil in liquid effluents in a petroleum refinery can warn operators of possible leakage of oil from storage tanks or process areas to the effluent system when unusually high amounts of oil are detected.

Surrogate Monitoring

In some cases, alternative schemes, termed *surrogate monitoring*, are developed that cost-effectively achieve the objectives of environmental monitoring systems and, in some cases, even the objectives of process optimization. Monitoring of some key parameters reliably indicates the performance of the operating and pollution control systems. The validity of such a scheme is then established by performing a series of tests (say, three tests for each case of worse operating conditions) at regular intervals, usually at least once a year. For example, among the parameters needed to measure the performance of a power generation process are fuel feed rates, including the feed rates of ash and sulfur, in addition to heat content; steam pressure; steam production rate; temperature inside the combustion chamber (at the nearest feasible location of the probe to the burner or combustion zone); air feed rate; flue gas flow rate; minimum power supply to the electrostatic precipitator or minimum pressure drop across the baghouse; carbon monoxide level in the flue gases; and oxygen level in the flue gases (representing the excess oxygen level). Similarly, for aerobic biological treatment systems, the minimum power supply for the aeration equipment per unit of wastewater treated at maximum inlet BOD loads, validated by actual tests of the inlet and outlet streams, may be a

useful indicator of the treatment effectiveness of the system. The monitoring data of some of the key monitoring parameters need to be verified by alternate means to ensure some level of confidence in the monitored results. For example, the flowmeter readings can be verified by taking tank dips to check the results obtained from the flowmeter.

Quality Assurance and Quality Control

Quality assurance means developing a system of activities to ensure that measurements meet defined standards of quality with a stated level of confidence. Development of a plan for quality assurance includes defining monitoring objectives, the quality control procedures to be followed, and quality assessment. Monitoring objectives are defined and are then used to arrive at data quality objectives, including accuracy, precision, completeness, representativeness, and comparability.

Quality assurance includes designing a network, selecting sampling or monitoring sites, selecting instruments and designing the sampling system, and developing a training schedule.

Quality control includes preparing protocols (including standard operating procedures and record keeping) for site operation and equipment maintenance; preparing protocols for equipment calibration; preparing site visit schedules; and preparing protocols for data inspection, review, validation, and usage. Quality assessment includes developing a schedule for audits and reports.

Typical monitoring objectives include establishing a sound scientific basis for policy development; determining compliance with statutory criteria; assessing population and ecosystem exposure and risk; providing public information; identifying pollution sources as a part of air and water quality management systems; and evaluating long-term trends.

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