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URBAN AIR QUALITY MANAGEMENT STRATEGY IN ASIA

Guidebook



*Edited by
Jitendra J. Shah
Tanvi Nagpal
Carter J. Brandon*

URBAN AIR QUALITY
MANAGEMENT STRATEGY
IN ASIA

Guidebook

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*The World Bank
Washington, D.C.*

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FOREWORD

In view of the potential environmental consequences of continuing growth of Asian metropolitan areas, the World Bank and the United Nations Development Programme (UNDP) launched the Metropolitan Environmental Improvement Program (MEIP) in six Asian metropolitan areas—Beijing, Mumbai (Bombay), Colombo, Jakarta, Kathmandu and Metro Manila. The mission of MEIP is to assist Asian urban areas in addressing rapidly growing environmental problems. Presently, MEIP is supported by the governments of Australia, Belgium, the Netherlands, and Norway.

Recognizing the growing severity of air pollution caused by industrial expansion and increasing vehicle population, the World Bank through MEIP started the Urban Air Quality Management Strategy (URBAIR) in 1992. The first phase of URBAIR covered five cities—Mumbai, Jakarta, Kathmandu, Metro Manila and Colombo. URBAIR is an international collaborative effort involving governments, academia, international organizations, NGOs, and the private sector. The main objective of URBAIR is to assist local institutions in these cities to develop action plans that would be an integral part of their air quality management system for the metropolitan regions. The approach used to achieve this objective involves the assessment of air quality and environmental damage to health and materials, the assessment of control options, and comparison of costs of damage and costs of control options (cost-benefit or cost-effectiveness analysis). From this, an action plan can be set up containing the selected abatement measures for implementation in the short/medium/long term.

The groundwork for the URBAIR studies is based on collected data, specific studies, and input from workshops and missions conducted in 1993–1994 by local consultants and experts from the Norwegian Institute for Air Research (NILU) and the Institute for Environmental Studies (IES). This effort resulted in an action plan for air pollution abatement. The *Guidebook* provides the blueprint for local authorities to follow in conjunction with city-specific data to design policies and investment plans for air quality management. Four city-specific studies (Mumbai, Manila, Jakarta and Kathmandu) are available to planners as part of this series. It is hoped that the *Guidebook* will form the basis for analysis of air quality data and formulation of strategies for air pollution control. Local institutions may use the city-specific reports in conjunction with the *Guidebook* to formulate policy decisions and investment strategies.

Maritta Koch-Weser

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ABSTRACT

Larger and more diverse cities are a sign of Asia's increasingly dynamic economies. Two decades of unparalleled growth have, however, come at a cost. Swelling urban populations and increased concentration of industry and automobile traffic in and around cities have resulted in severe air pollution, threatening human health and undermining the productivity of the urban population.

Urban Air Quality Management Strategy (URBAIR) aims to assist in the design and implementation of policies, monitoring, and management to restore air quality in Asian metropolitan areas. This *Guidebook* details the steps in an air quality management system (AQMS). It is intended for use in conjunction with city-level data. Planners, economists, and engineers may refer to it as a sourcebook for technical assistance. It provides details on air quality modeling, choices of abatement measures and how cost-benefit analysis can be used to guide selection of appropriate measures. It summarizes the components of a general action plan to manage and control air pollution.

Laws and regulations are essential instruments in the air pollution control process. Equally important are strict enforcement and institutions capable of regularly assessing air-quality-related damages and their costs. In addition, public awareness of health impacts from polluted air involves the citizens and media in the process. The *Guidebook* outlines common air pollution laws and regulations and policy instruments. The latter may range from simple command and control instruments to communication tools.

The *Guidebook* presents a five-step action plan for creating an AQMS specific to a city's circumstances. Abatement measures in the plan are categorized according to cost-effectiveness, as well as the time required to implement them and when they would become effective.

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ABBREVIATIONS AND ACRONYMS

AADT	annual average daily traffic	NH₃	ammonia
ALARA	as low as reasonably achievable	NILU	Norwegian Institute for Air Research
AQG	air quality guidelines	NOAEL	no observed adverse effect level
AQMS	air quality management system	NO_x	nitrogen oxide
BATNEEC	best available technology not entailing excessive costs	O₃	ozone
CBA	cost-benefit analysis	OECD	Organization for Economic Cooperation and Development
CEA	cost-effectiveness analysis	PAH	polycyclic aromatic hydrocarbons
CFC	chlorofluorocarbons	PAN	peroxyacetyl nitrate
CO₂	carbon dioxide	Pb	lead
CV	contingent valuation	PM₁₀	particulate matter of 10 microns or less
EIA	environmental impact assessment	ppb	parts per billion
ERV	emergency room visits	PVC	polyvinyl chloride
GDP	gross domestic product	RAD	restricted activity days
GEMS	United Nations Global Environment Monitoring System	RHD	respiratory hospital diseases
GNP	gross national product	RSD	respiratory symptoms days
IES	Institute for Environmental Studies	SO₂	sulfur dioxide
IRR	interval rate of return	SPM	suspended particulate matter
LOAEL	lowest-observed adverse-effect level	TSP	total suspended particles
LPG	liquefied petroleum gas	UNDP	United Nations Development Programme
MEIP	Metropolitan Environmental Improvement Program (World Bank)	UNEP	United Nations Environment Programme
µg	microgram (10 ⁻⁶ grams)	USEPA	United States Environment Protection Agency
µg/m³	concentration in micrograms per cubic meter	VOC	volatile organic compounds
mg	milligrams (10 ⁻³ grams)	VSL	value of statistical life
NGO	nongovernmental organization	WHO	World Health Organization
		WLD	work loss days
		WTP	willingness to pay

EXECUTIVE SUMMARY

URBAIR GUIDEBOOK. Larger, more diverse cities are a sign of Asia's increasingly dynamic economies. However, two decades of unparalleled growth in Asia has come at a cost. Swelling urban populations and increased concentration of industry and automobile traffic in and around cities have resulted in severe air pollution. Emissions from traffic, factories, domestic heating, cooking, and refuse burning are threatening the health of city dwellers, imposing not just a direct economic cost by impacting human health but also threatening long-term productivity. Governments, businesses, and communities face the daunting, yet urgent, task of improving their environment and preventing further air quality deterioration.

Urban Air Quality Management Strategy (URBAIR) aims to assist in the design and implementation of policies, monitoring, and management to restore air quality in Asian metropolitan areas. Government and industry representatives, local researchers, non-government organizations, international and local experts met at several workshops and working group meetings in Jakarta, Mumbai (Bombay), Kathmandu and Metro Manila to review air quality data and design action plans. These plans take into account the economic costs and benefits of air pollution abatement measures. Many of the costs stem from increased incidence of pollution-related illness and reduced life expectancy. The former is valued in terms of medical care costs and lost daily wages, as well as expenses undertaken to prevent illness. The latter is more difficult to evaluate in economic terms. The cost of increased morbidity is based on "value of statistical life" estimates. This study addresses alternative methods for valuing health damage and mortality.

This report details the steps in an air quality management system. It has been used in the preparation of URBAIR city-specific reports and is intended for use as a companion for these and other city-based air quality databases. Planners and engineers may refer to it for technical assistance and to create an action plan to control air pollution. It provides details on air quality modeling, choices of abatement measures and how cost-benefit analysis is used to choose appropriate measures. Finally, it summarizes the components of an action plan.

The concept of an air quality management system (AQMS) has the following components:

- air quality assessment;
- environmental damage assessment;
- abatement options assessment;
- cost-benefit analysis or cost-effectiveness analysis;
- abatement measures selection (action plan); and
- optimum control strategy.

Assessment. Air quality assessment, environmental damage assessment and abatement options assessment provide input to the cost-benefit or cost-effectiveness analysis, which is also based on

established air quality objectives (i.e. guidelines, standards) and economic objectives (i.e. reduction of damage costs). The analysis leads to an Action Plan containing abatement and control measures for implementation in the short, medium, and long term. The final result of this analysis is an Optimum Control Strategy.

An AQMS can only succeed if the following set of technical and analytical tasks can be undertaken by the relevant air quality monitoring authorities:

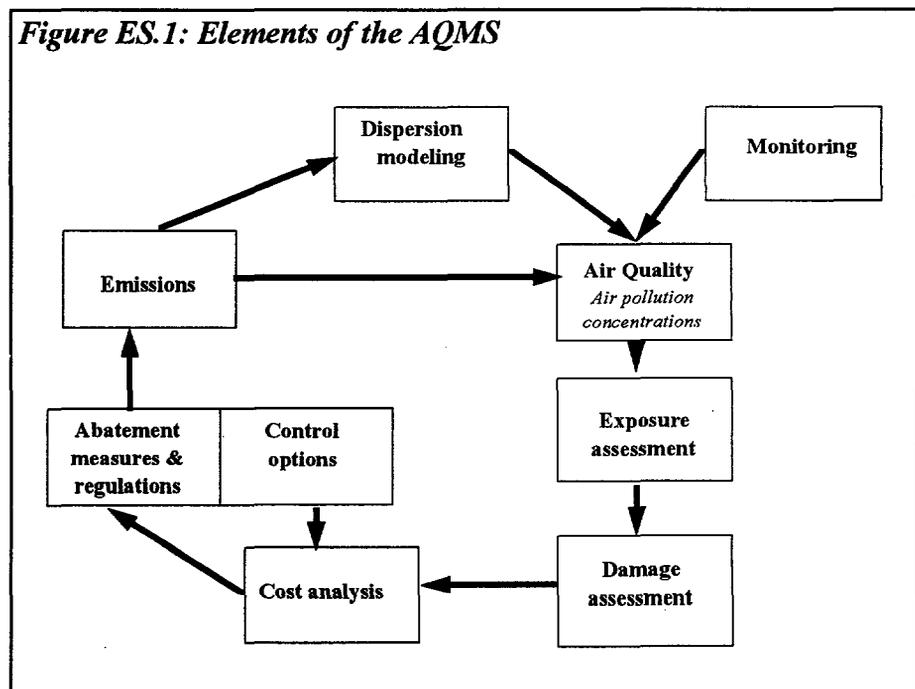
- inventory of polluting activities and emissions;
- monitoring of air pollution and dispersion parameters;
- calculation of air pollution concentrations by dispersion models;
- inventory of population, materials and urban development;
- calculation of the effect of abatement and control measures; and
- establishment and improvement of air pollution regulations.

These activities, and the institutions necessary to carry them out, constitute the prerequisite for establishing the AQMS. Figure ES.1 represents a simple visualization of AQMS elements and the flow of information among them.

Action. Categories of actions include the following:

- abatement measures
 - improved fuel quality,
 - technology improvements,
 - fuel switching,
 - traffic management, and
 - transport demand management;
- improvement of database in monitoring and information system, emissions inventorying and dispersion/exposure modeling, damage and cost assessment, and institutional strengthening;
- implementing an investment plan; and
- awareness raising and environmental education.

Monitoring. A third essential component of AQMS is monitoring, or surveillance. Monitoring is essential to maintaining the



effectiveness of air pollution control actions. The goal of an Air Quality Information System (AQIS) is to ensure thorough and ongoing monitoring by keeping the authorities and the public informed about the short- and long-term changes in air quality; and assessing the results of abatement measures, and thereby providing feedback to the abatement strategy.

Most Asian cities monitor air quality infrequently. If countries have adopted national or other guidelines for air quality, they are rarely enforced due to inconsistencies in laws and weak institutions. Laws and regulations are essential instruments in the air pollution control process, but only with strict enforcement and institutions that are capable of regularly assessing air quality, pollution-related damage and its costs. The contents of air pollution laws and regulations, and policy instruments used to control air pollution are discussed in this *Guidebook*. Policy instruments range from simple command and control instruments that may be very effective in state-owned industries, to communication tools that expand awareness of air pollution problems and build social consensus on pollution control measures.

The last chapter of the *Guidebook* presents a five-step action plan to guide cities toward creating an AQMS specific to their circumstances. The action plan presents a list of abatement measures to improve air quality, prioritized according to cost effectiveness (or cost-benefit analysis), and feasibility. The plan also classifies measures according to the time required to implement them, and when they would become effective. The major parties involved in the formation and implementation of each measure are also identified. The most important steps for developing an AQMS for an urban area are listed in Table ES.1.

Conclusion. In the absence of abatement measures, increased pollution will pose a greater threat to the health and well-being of Asia's urban population, eventually impacting the prospect for further economic growth. In order to prevent the situation from deteriorating further, it is important to make air quality management a part of the development plan for all urban areas. Although the data currently available in most countries are sparse, it is possible to use them to come up with preliminary action plans that could go a long way in improving the air quality in urban areas.

Table ES.1: Steps in the development of an AQMS

Step 1: Assessment and Analysis of Options	
Assessment	<ul style="list-style-type: none"> • identifying sources, • quantifying sources, • monitoring air pollution, • assessing the exposure conditions, • identifying source-exposure relationships, • estimating relative importance of pollution sources, and • assessing environmental damage.
Analysis of options	<ul style="list-style-type: none"> • investigating short/long-term control options, • performing cost-benefit/cost-effectiveness analysis, and • developing a control strategy and investment plan.
Step 2: Air pollution control	
	<ul style="list-style-type: none"> • developing institutions/ regulations/enforcement mechanisms, • raising awareness and environmental education, and • implementing an investment plan.
Step 3: Surveillance	
	<ul style="list-style-type: none"> • establishing an Air Quality Information System.

1. INTRODUCTION

HISTORY OF URBAN AIR POLLUTION AND ITS ABATEMENT

For centuries, urban air pollution has posed a problem for city dwellers. The earliest manifestation of pollution may have been the smoke produced by burning poor quality coal in relatively cold climates in Northern Europe. This caused high sulfur dioxide (SO₂) and particle exposure, sometimes with serious health impacts. England has an early history of smoke abatement, with Parliamentary Acts against coal burning issued as early as the 13th and 14th centuries. The Industrial Revolution introduced point sources of larger emissions from various processes. The most important of these was the burning of coal for energy production, resulting in SO₂ and combustion particles (smoke).

Coal burning in small and large sources was generally allowed to continue without required abatement well into the 20th century. Elevated stacks were the only mode of pollution abatement. Large emissions of SO₂ and smoke particles overloaded the atmosphere during temperature inversions in stable high pressure situations with stagnant air leading to notorious air pollution episodes (see Table 1.1)* The 1952 London episode was the worst, resulting in an estimated 4,000 deaths in five days. This prompted more stringent air pollution acts in England and in other countries, starting the modern history of air quality management.

Although the components of air pollution have changed over the years, with industrial sources now including toxic gases, coal remains an important source of air pollution. In addition, vehicular traffic sources have expanded rapidly in the last three decades. Traffic activity in urban

Table 1.1: Notable air pollution episodes in the last century

Location	Date	Pollutants	Deaths
London, England	Dec 9-11, 1873	SO ₂	650
London, England	Jan 20-29, 1880	SO ₂	1,176
Meuse Valley, Belgium	Dec 1-5, 1930	SO ₂	63
		Up to 100 mg/m ³	
Donora, PA USA	Oct 26-31, 1948	SO ₂	20
		Up to 5 mg/m ³	
London, England	Nov 26-30, 1948	SO ₂ (particles)	700
Poza Rica, Mexico	Nov 24, 1950	H ₂ S	22
London, England	Dec 5-9, 1952	SO ₂ (particles)	4,000
		Up to 4 mg/m ³	
London, England	June 3-6, 1955	SO ₂ (particles)	1,000
		Up to 2 mg/m ³	
New York, USA	Nov 24-30, 1966	SO ₂ (particles)	168

Source: Cochran et al (1992).

* **Note:** Except where indicated, tables, figures and boxes were originated by the authors; and dollar figures refer to 1992/93 U.S. dollars.

areas of industrialized western nations has witnessed a four- to five-fold increase over the last 30 years. In developing nations, this increase has been ten-fold or more. Prime examples of urban air pollution are the smog in London and photochemical smog in Los Angeles and Mexico City. Partial closing of cities in Europe and North America due to elevated levels of air pollution are common today.

The effects of air pollution on humans, the ecosystem, monuments and buildings have long been recognized. Relationships between air pollution emissions and exposure are now better understood through studies of atmospheric dispersion, chemical reactions, and deposition of pollutants. The importance of indoor air pollution in total exposure has also been established. While air pollution problems have become serious, their management including assessment, control, and surveillance has also become more sophisticated.

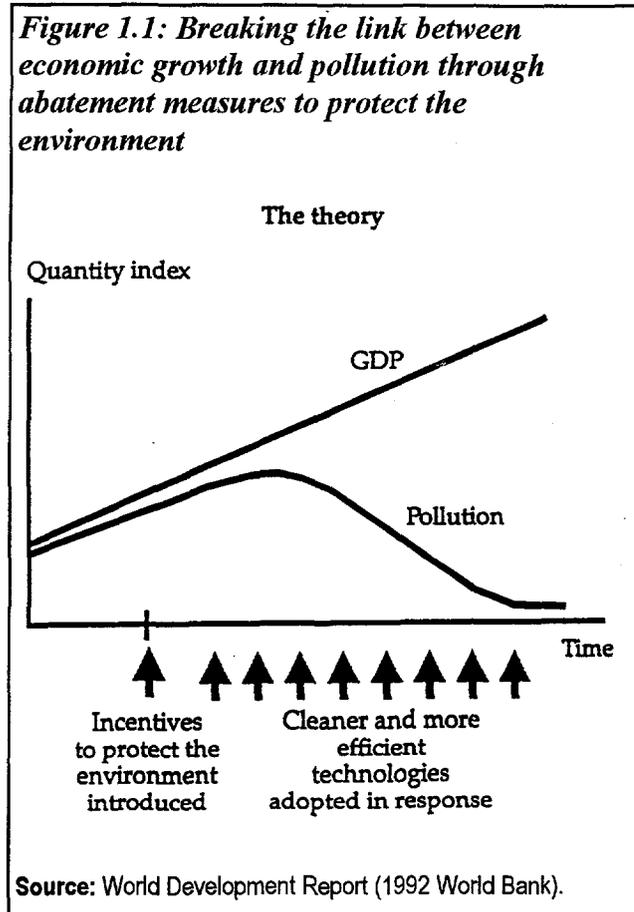
Simple and sophisticated techniques are available to detect various types of pollution compounds. Abatement techniques to reduce emissions at the source have also been developed and put to widespread use. Electrostatic precipitators, fuel desulfurization, and catalytic converters are examples of control processes that have been introduced on a large scale in industrial nations. Air quality improvements have been achieved as a result of annual expenditure on pollution abatement policies equivalent to 0.8-1.5 percent of gross domestic product (GDP) since the 1970s; about half of this was public expenditure.

There are costs associated with both the damaging effects of air pollution and its abatement. Knowledge of damage and abatement costs starts the process of developing an optimal control strategy for air pollution management.

The introduction and use of environmentally friendly or less damaging practices and technologies in many industrialized countries have decoupled pollution from economic growth, a process indicated in Figure 1.1.

A report by the Organization for Economic Cooperation and Development (OECD, 1991) describes some of the air pollution-control achievements in OECD countries since 1970. Figure 1.2 shows reductions in emissions of sulfur oxides, particles, and lead, as OECD averages. In Japan, improvements have been even more remarkable. However, some air quality problems are worsening. Nitrogen oxide (NO_x) emissions are increasing, largely because of more vehicular pollution. This affects urban and regional air quality by increasing acid deposition and the occurrence of tropospheric ozone. Globally, carbon dioxide (CO_2) emissions are on the rise, and have proven difficult to curb.

Developing countries have taken increasing steps to protect their environment,



although few, if any, can afford the large-scale investments in cleaner air and water made by the OECD countries in the 1970s and 1980s. The lesson that problem avoidance is cheaper than either retro-fitting of technology or clean-up of polluted sites has also been well argued and accepted.

Therefore, developing countries need to adopt the most cost-effective approaches to the most urgent problems. These involve setting incentives and targeting expenditures to promote clean technologies and practices in industry, transport, energy, and urban management.

AIR POLLUTION PROBLEMS OF MEGACITIES IN DEVELOPING COUNTRIES

Cities in developing nations are increasing rapidly in size and diversity. Increasing emissions from vehicular traffic, industry, domestic heating (in temperate climates), cooking, and refuse burning all pose potential risks for large air pollution exposures. The rapidity of economic development combined with the lack of emission controls, makes Asia's megacities prone to more serious air pollution problems than similar cities in industrialized nations.

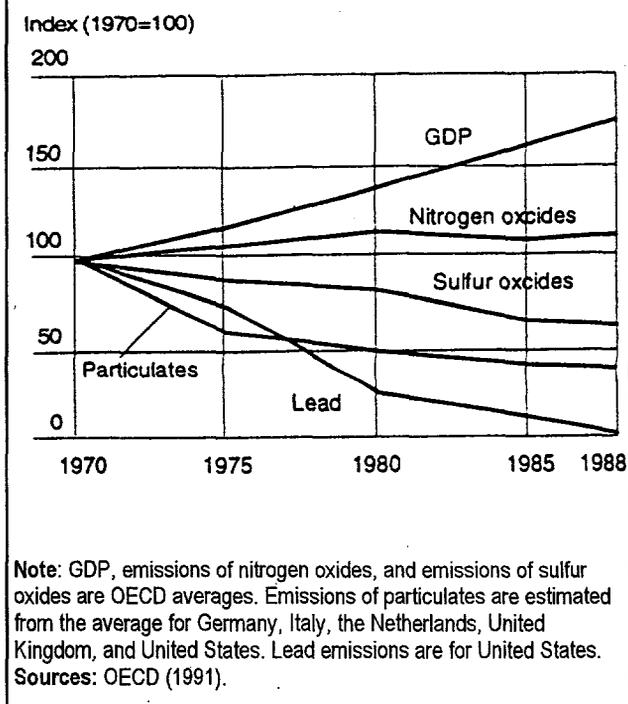
Air pollution management requires the establishment of national or local laws, and institutions to assess pollution levels and enforce the laws. Reliable information on a city's air pollution sources and its actual air quality are prerequisite to air quality management. Institutions capable of collecting and analyzing such data and information must be developed. Since there are competing options for air pollution control, many of them requiring substantial capital investments, it is crucial for management to be cost effective.

The following factors determine the nature of the air pollution problem in Southeast Asian cities:

- primary—mixture of dominant emission sources and type and quality of fuel used, and
- secondary—size of the populated area affected by the emissions, and topography and climate of the area.

Source mix and fuel quality determine the amount and composition of emissions. City size, topography, and climate, influence the pollutant concentration level through dispersion (dilution), and the formation of secondary pollutants through chemical reactions in the atmosphere. The degree of secondary pollutant formation is also a function of the source mix.

Figure 1.2: GDP and emissions in OECD countries



The air pollution situation in large Asian cities, including Bangkok, Beijing, Mumbai, Calcutta, Delhi, Jakarta, Karachi, Manila, Seoul, and Shanghai, has been described in *20 megacity report* (WHO/UNEP, 1992). In addition, URBAIR has studied conditions in Kathmandu Valley, Jakarta, Metro Manila, and Greater Mumbai (World Bank Technical Paper nos. 378, 379, 380 and 381). Several conclusions have been drawn from these studies:

- All these cities have a serious suspended particulate matter (SPM) problem;
- Beijing, Seoul, and Shanghai have serious-to-moderate SO₂ problems;
- Bangkok, Jakarta, and Manila have moderate lead (Pb) problems;
- Jakarta has a moderate carbon monoxide (CO) problem;
- No cities have a NO_x problem, however, levels are rising; and
- Beijing and Jakarta have a moderate ozone (O₃) problem.

URBAIR GUIDEBOOK FOR AQMS DEVELOPMENT

URBAIR is an initiative to develop strategic management frameworks to improve urban air quality in major Asian cities. URBAIR helps local governments, industries, and community groups to develop a city-specific AQMS. Thus far, five metropolitan regions are participating in the program: Colombo, Mumbai, Jakarta, Kathmandu Valley, and Metro Manila.

Since air pollution management in many Asian cities is at a preliminary stage, there is a need to develop comprehensive action plans (Phase I of URBAIR). In preparing such action plans, URBAIR working groups have identified the major pollutants in each city, their sources, and their health and economic impacts. Air quality models have been evaluated and adapted to the data available for these cities, and monitoring needs identified. Future investments are suggested as part of the action plan. The results of the URBAIR process have been discussed at city workshops. Based on the input received at the workshops, action plans have been finalized and Terms of Reference developed for preparing comprehensive AQMS for each city under the guidance of local working groups (Phase 2).

This *URBAIR Guidebook* provides a framework for the development of an AQMS. The results of the URBAIR process, including specific action plans for the four cities, based on air quality and health damage assessments, and cost-benefit analysis, are presented in separate city-specific reports for Kathmandu Valley, Jakarta, Metro Manila, and Greater Mumbai (World Bank Technical Paper nos. 378, 379, 380, and 381).

2. AIR QUALITY MANAGEMENT SYSTEM

An AQMS has the following components:

- air quality assessment,
- environmental damage assessment,
- abatement options assessment,
- cost-benefit analysis or cost-effectiveness analysis,
- selection of abatement measures, and
- optimum control strategy.

Assessments of air quality, environmental damage and abatement options are inputs into a cost-benefit analysis (CBA), or a cost-effectiveness analysis (CEA). CBA and CEA are also guided by established air quality objectives (i.e. guidelines, standards), and economic objectives such as reduction of damage costs. The final result of such analysis is an optimum control strategy in the form of an action plan, with prioritized abatement measures.

DEVELOPING AN AIR QUALITY MANAGEMENT SYSTEM

The most important steps in the development of an AQMS are presented in Table 2.1. An AQMS has two main components—assessment and actions. Assessment includes analysis of options. A third essential component is surveillance or monitoring which is essential to ensure the effectiveness of air

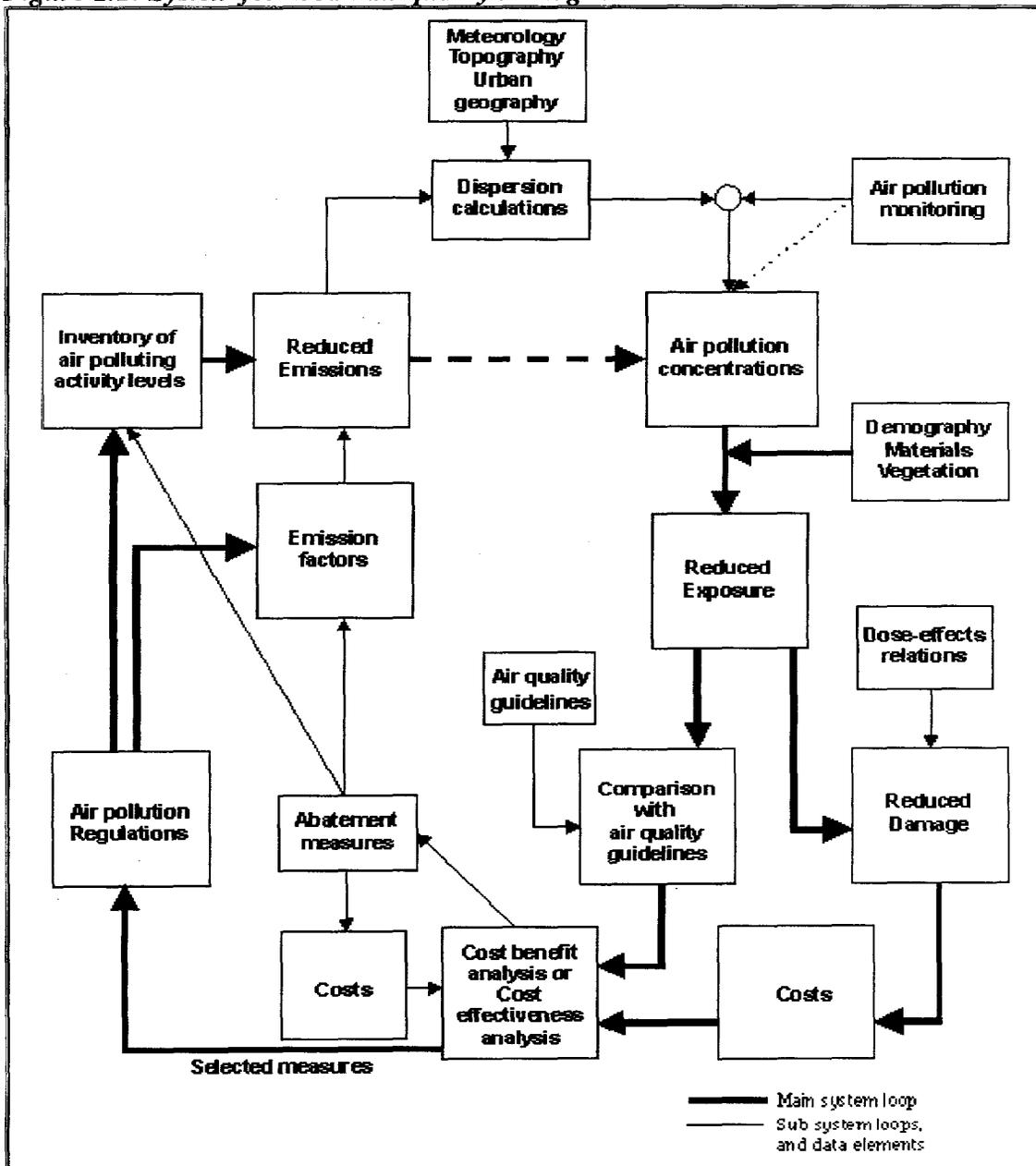
Table 2.1: Steps in the development of an AQMS

Step 1: Assessment and Analysis of Options	
A. Assessment	<ul style="list-style-type: none"> • identifying sources, • quantifying sources, • monitoring air pollution, • assessing the exposure conditions, • identifying source-exposure relationships, • estimating relative importance of pollution sources, and • assessing environmental damage.
B. Analysis of Options	<ul style="list-style-type: none"> • investigating short/long-term control options, • performing cost-benefit/cost-effectiveness analysis, and • developing a control strategy and investment plan.
Step 2: Air Pollution Control	
	<ul style="list-style-type: none"> • developing institutions/regulations/ enforcement mechanisms, • raising awareness and environmental education, and • implementing an investment plan.
Step 3: Surveillance	
	<ul style="list-style-type: none"> • establishing an Air Quality Information System.

pollution control actions. The goal of the Air Quality Information System (AQIS) is to ensure thorough, ongoing monitoring by keeping the authorities and the public informed about the short- and long-term changes in air quality; assessing the results of abatement measures; and thereby providing feedback to the abatement strategy. Efficient institutions are required to perform the tasks related to an AQMS.

Figure 2.1 shows a complete representation of an AQMS. The flow, top to bottom, follows the same steps as the AQMS—from monitoring and dispersion modeling, to exposure and damage estimates, to cost-benefit (or cost-effectiveness) analysis of available abatement options.

Figure 2.1: System for urban air quality management



Cost-benefit analysis is based on a comparison between the costs of abatement and reduced damage. An abatement strategy may also be based on a cost-effectiveness analysis, defined as the least cost means to achieve stated air quality goals. In all cases, an abatement strategy should be based on analysis of the cost of each abatement measure versus reduced damage costs, or on an analysis of cost for each measure of air quality/exposure improvement. In its most complete form, an AQMS requires personnel, skills, and equipment in many institutions in several technological and scientific fields. Only a few cities in the world have a system that is sufficiently comprehensive to establish optimum control strategies. Megacities in developing countries may require decades to establish a complete AQMS. In the development phase, intermediate strategies for controlling present air pollution problems should be devised. Such intermediate strategies must make optimal use of existing data. There are three developmental phases in an action plan.

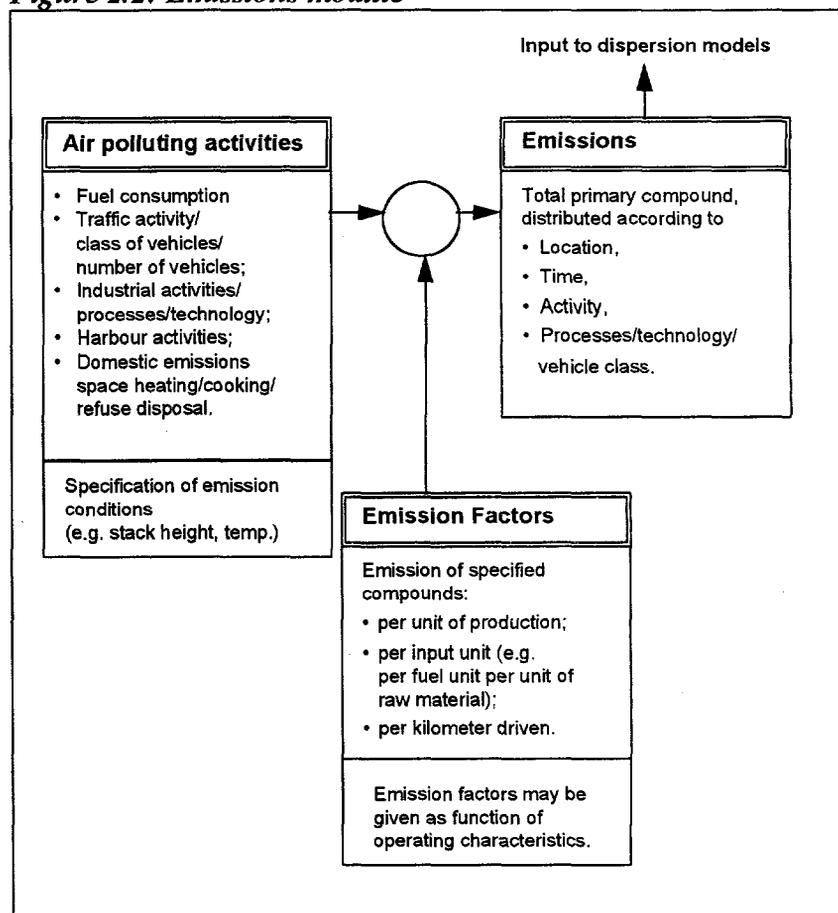
- Phase 1. Immediate action. Strategy for immediate control of the most urgent problems.
- Phase 2. Intermediate action. Strategy for control in an intermediate time scale (about 5 years), based on current development trends.
- Phase 3. Long-term action. Strategy for control over a long-time scale (more than 10 years), based on long-term projections.

AIR POLLUTING ACTIVITIES, SOURCES, AND EMISSIONS

An emissions inventory contains a list of relevant air pollutants in the area, broken down by activity sector, for example, traffic, industry, construction (see Figure 2.2). The inventory is usually geographical, based on the locations of industries, major roads and population distribution. Depending on the level of detail of activity data, emissions per sector are further divided into emissions per process, technology, class of vehicles or other factors and as a function of time. Input data requirements include the following:

- fuel consumption—types and qualities of

Figure 2.2: Emissions module



Note: Based upon location of sources, population distribution (geographically), and urban geography—activity zones (industrial, residential, commercial).

- fuel, processes (transport, domestic, industrial);
- traffic activity—vehicle classes, traffic data on major roads;
 - industrial sources—type, location, production, emissions, emission conditions (stack height, temperature, etc.);
 - other sources—refuse burning, domestic and commercial emissions, harbor activities;
 - population data—geographic distribution within the urban area;
 - emission factors—amount emitted per unit of production, per input unit (raw material), per kilometer driven, per fuel unit.

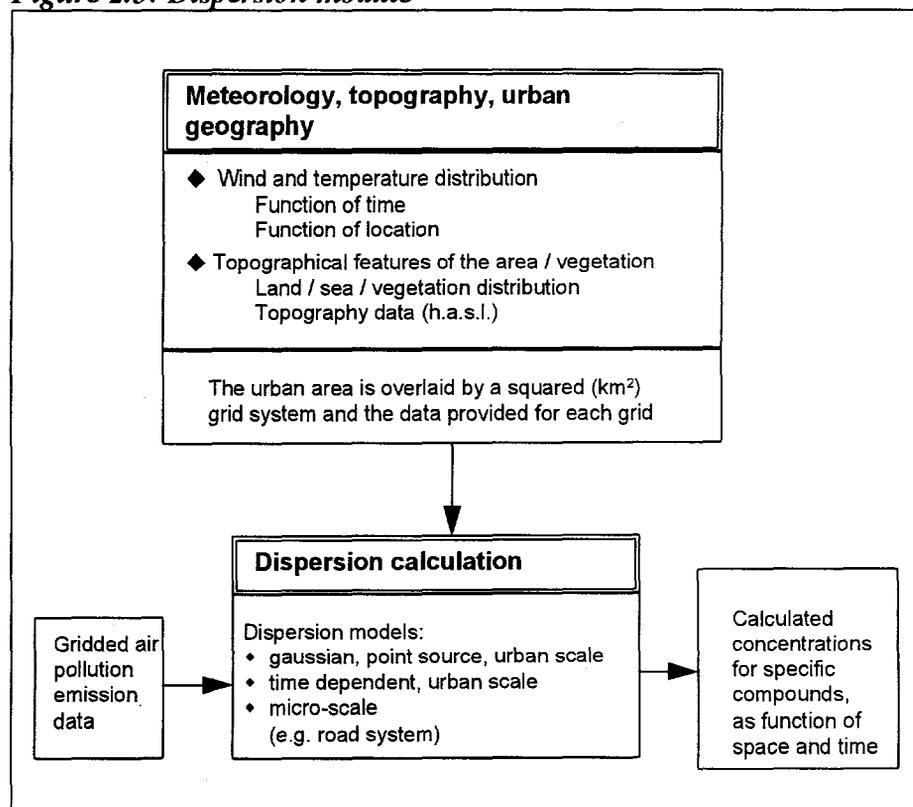
An emissions module calculates the spatially distributed (gridded) emission amounts. For example, emissions can be distributed within a square-kilometer (km^2) grid system, based on the location of sources, population distribution, and urban activity zones. The gridded emissions distribution provides input to dispersion models for calculating air pollution concentrations in the urban area by time and location. It also provides a basis for calculating the effects of specific abatement measures on air quality. The emissions module may be in the form of a computerized database.

DISPERSION CONDITIONS AND MODULES

Dispersion modules provide the ability to calculate air pollution concentrations in urban areas as a function of time and location. For primary pollutants (i.e. non-reacting compounds), modules can calculate contributions to local concentrations from each activity or technology sector. The elements of a dispersion module are illustrated in Figure 2.3.

The input data required for emission dispersion calculations include data on meteorology, topography, emission characteristics of the sources, and data from the emissions module. Basic meteorological data are wind speed and direction presented

Figure 2.3: Dispersion module



as time series (hourly averages) or as climatological statistics (wind roses, annual or seasonal). Air temperature and its variation at different altitudes is also an important parameter. Topography and the presence of water bodies, land, or vegetation, influence wind and dispersion conditions and, in turn, pollution concentrations. Results from the dispersion calculations can be as detailed as the relevant input data, i.e. the emissions and meteorological/dispersion data.

AIR POLLUTION EXPOSURE AND DAMAGE ASSESSMENT

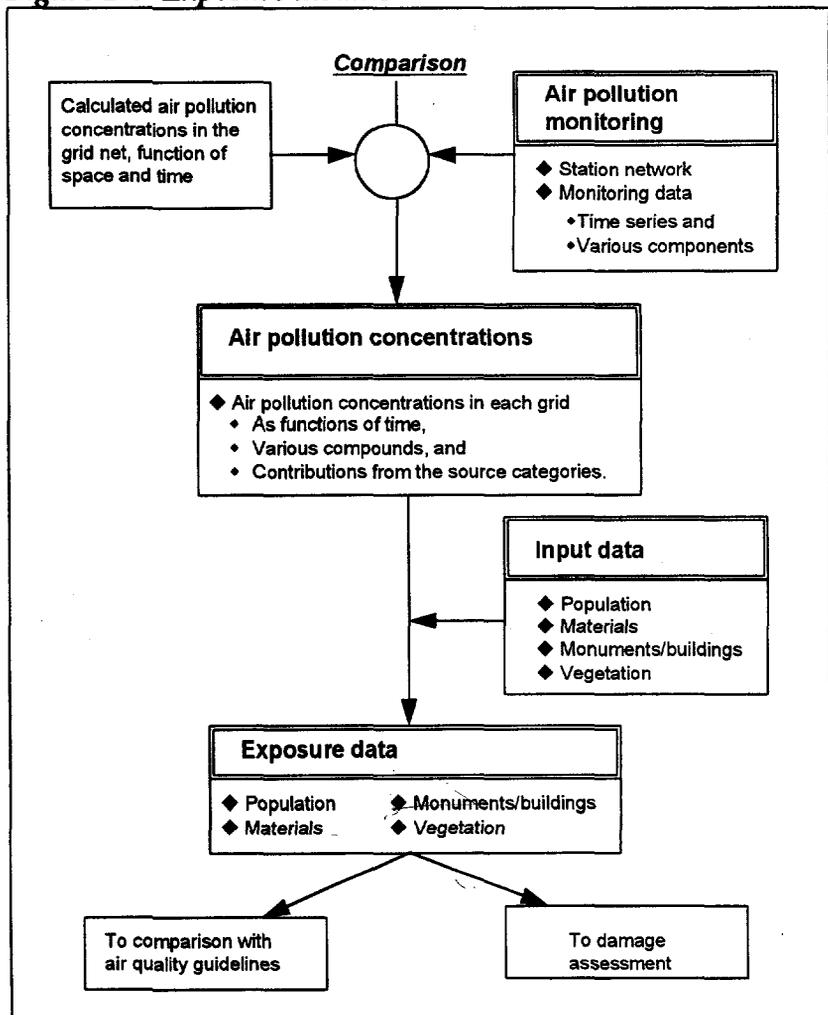
Exposure modules (Figure 2.4) provide data on the impact of air pollution on human health and damage to ecosystem, buildings and material. The exposure, or impact, is defined as the product of the local air pollution concentration (e.g. within a grid square), and the number of objects within that location (e.g. people, buildings). A simple equation would be as follows:

$$Exposure = Population \times Concentration$$

This calculation determines the number of people exposed to concentrations above permissible guidelines, where and how often this exposure occurs. This provides a population exposure distribution for each studied compound for each abatement scenario.

The concentrations may be calculated as averages over differing periods (annual, monthly, daily, hourly), depending upon the compound in question, and the averaging time specified in the air quality standard or guideline. For compounds that have acute effects, like SO₂, ozone (O₃), and carbon monoxide (CO), hourly averages are important, while for pollutants such as total suspended particulates (TSP), lead (Pb) and persistent organic compounds, long-term averages (month, year) are of greater interest.

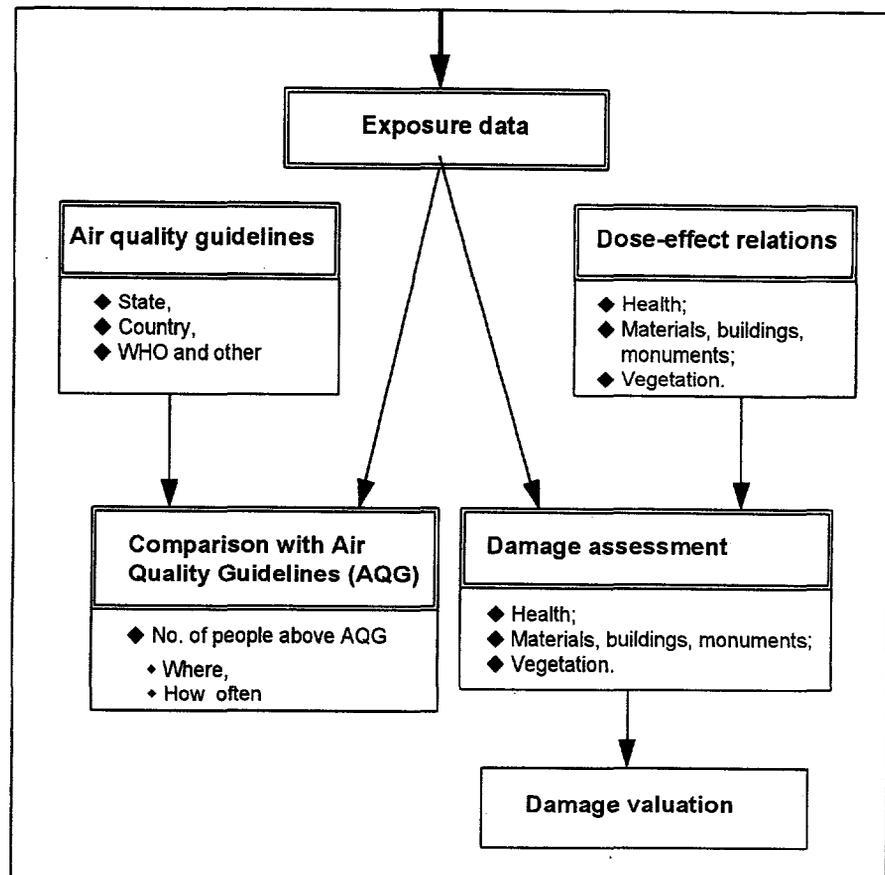
Figure 2.4: Exposure module



Categories of damage include health impacts; deterioration of materials, buildings, monuments; impact on vegetation; and higher production costs for firms needing clean air. For assessment of damage in physical terms, it is necessary to have dose-effect relationships and exposure distributions for people, objects, buildings, monuments and vegetation between isopleths (Figure 2.5). For health damage assessment, dose-response relationships are used to identify the impact of pollution levels of several different pollutants (such as particulates, PM₁₀, lead, SO₂, ozone, and NO₂) on various aspects of public health. Air pollution-related premature death, respiratory hospital admissions, emergency room admissions, restricted activity days, cases of chronic bronchitis, asthma attacks, respiratory symptom days, and lower respiratory tract infections in children can all be estimated.

Methods for monetary assessment of damage include the valuation of productivity loss, defensive or averting expenditures, and willingness to pay to avert damage, market or nonmarket derived.

Figure 2.5: Damage assessment module



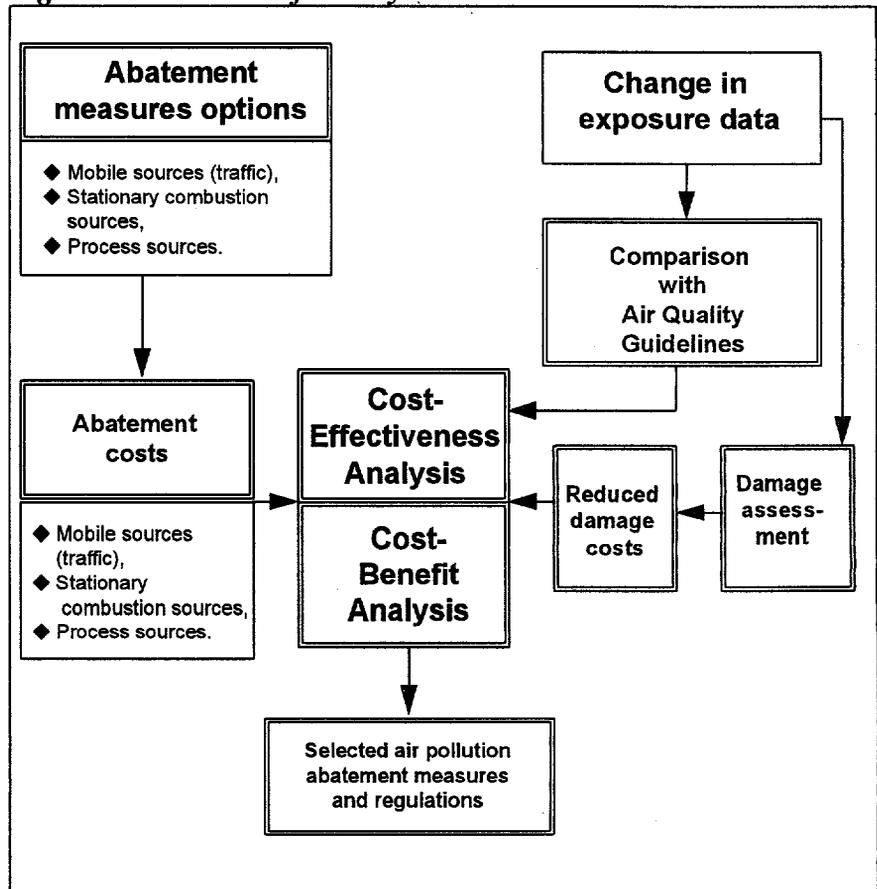
COST-BENEFIT ANALYSIS AND COST-EFFECTIVENESS ANALYSIS MODULE

The goal of cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) is to investigate and identify the best set of measures. In CBA, the costs of a set of measures are compared to the benefits; for example, reduced environmental damage would be calculated in monetary terms. Because the monetary estimation of reduced environmental damage (a benefit) is usually not accurate enough to compare to costs of achieving such an outcome, CEA is often used as an alternative. In CEA, benefits like reduced environmental damage are not monetized. Standards

are set for emissions or concentrations, and the set of measures which meets such standards at the least cost is selected (Figure 2.6).

Both methods must analyze three kinds of costs: investment, operation and maintenance (O&M). The discount rate is an oft-debated topic concerning CBA and CEA (discussed in Chapter 6). The discount rate serves to convert estimated costs (and in CBA, also the benefits) over various years into one discounted number.

Figure 2.6: Cost-benefit analysis module



3. AIR QUALITY ASSESSMENT

Air quality assessment is an integral part of an AQMS. Data collected under the air quality assessment are used for evaluating current pollution impacts, as well as costs and benefits of control options. This chapter describes measures to identify critical air pollution problems and possible short-term control options.¹

Air quality assessment includes an initial identification of pollution sources through monitoring and observation. This is followed by quantification of sources and monitoring of the most important pollutants. The aim of assessment is to provide relevant data in terms of spatial and temporal resolution. It details the key polluting compounds, the amount of pollution contributed by various sources and population exposure (Table 3.1).

Assessment involves inventorying sources and modeling air quality. Modeling has two parts: pollution concentrations and exposure of the population and other sensitive objects. In addition, when making plans for long-term air quality management, it is important to project long-term trends in air quality.

Developing an assessment program. Many cities have air quality assessment and management programs. Pre-existing air quality assessment programs should be compared to the recommendations made here and modified, as necessary, to suit local air pollution problems and management objectives. The time schedule for improving air quality assessment depends upon available equipment, trained staff, and financial resources. It is recommended that cities make efforts to simultaneously improve monitoring and modeling.

Types of data to be collected. The following broad categories of data are needed in air quality assessment:

- measured concentrations of air pollution from representative sites, for all key pollutants, for relevant averaging times (hour, day, month, year);

Table 3.1: Air quality assessment data

spatial resolution:	• km ² grids, or in specific receptor points.
temporal (time) resolution:	• hour, day, month, year.
compound resolution:	• key pollutant compounds (e.g. SPM, SO ₂).
source contributions:	• amount of pollution contributed by various sources.
exposure distribution:	• fractions of the population experiencing pollution levels above specified values.

¹ Parts of this chapter are based on *Handbook for Urban Air Improvement 1991* (L. Butterwick et al., 1992), cited with permission from the Commission of the European Communities.

- emission data from all significant sources for all key pollutants, spatial and temporal variation, emission conditions (stack height, etc.);
- relevant measured meteorological data for the dispersion of emissions;
- topographical data (isolines for height above sea level); and
- population data including number of residents for each referendum district and age distribution.

MONITORING AIR QUALITY AND DISPERSION CONDITIONS

The following components or steps are essential to the establishment of an air quality monitoring and assessment program:

- selection of pollutants,
- averaging times,
- mobile and stationary monitoring,
- monitoring techniques,
- network design and citing of stations,
- data collection and storage,
- quality assurance,
- financial and manpower requirements, and
- meteorological data needs.

Selection of pollutants

Urban areas have several hundred air pollution compounds in a typical source mix (traffic, industry, fossil and biogenic fuel combustion, and refuse burning). Most of the pollutants are volatile and nonvolatile organic compounds. The World Health Organization (WHO) has developed air quality guidelines (AQG) for 23 of these compounds or compound groups—16 inorganic and 7 organic. The WHO list of air quality guidelines can be found in Appendix 4, Table 4A.2.

The first priority selection of pollutants for monitoring should be based on the WHO AQG list. The second priority are those additional pollutants for which guidelines have not yet been set, but which are known to be harmful and are produced by major industries in the city. A set of pollutants that sometimes exceeds, or is expected to exceed, guidelines should be chosen for the long-term monitoring system. Other specific pollutants known to be in the city's atmosphere at an unknown level should be selected for a special, short-term assessment program to establish their level and variations. Pollutant fact sheets for SO₂, NO_x, SPM, CO, O₃ and PAN, benzene, PAH, formaldehyde, VOC, Pb and cadmium (Cd) are provided in Appendix 1. The fact sheets describe the pollutant, its sources and impacts. The following pollutants are recommended for inclusion in an air quality monitoring program:

- Suspended particles, measured as:
 - PM₁₀ and PM_{2.5},

- Lead,
 - CO,
 - SO₂,
 - nitrogen oxides (NO and NO₂), and
 - volatile organic compounds (VOC) measured as integral sum of many compounds and each photochemically active compound separately.
- Compounds dependent on the specific source mix in the city and may include the following:
 - specific compounds/elements within the SPM fractions, (such as PAH) and the separate compounds of this group and acid sulfates, and
 - VOCs such as benzene, toluene, xylene, aldehydes.

Averaging times of monitoring equipment

A major criterion for selecting monitoring methods is the averaging time of the method.

Averaging times range as follows:

- hour or less (requires monitors with continuous measuring sensors);
- few hours to a few days (typically 24 hours, integrating, active samplers with subsequent analysis of the collected samples in a laboratory); and
- several days to several weeks (integrating active samplers or passive samplers with subsequent analysis).

Averaging times vary according to selected compounds, but must be compatible with the objectives of the AQMS. For any one compound, different averaging times may be selected for monitoring sites, based upon the following criteria:

- averaging times suggested by the local, pollutant-specific air quality guidelines or standards;
- known or expected time scale of temporal variations of the compound; and
- need to separate among more than one significant source of the pollutant.

Fixed versus mobile monitoring sites

Monitoring instruments can be easily installed in vehicles to provide powerful monitoring facilities. There is a tendency, however, to assume that one such facility can substitute for several fixed stations. Experience shows that this is not the case, and that mobile and fixed stations serve very different purposes.

Fixed stations provide a 24-hour, 365-days measurement record at one location. Diurnal and seasonal influences on concentrations are included in average values and can be discerned using time-revolved data. Such information is optimum for determining compliance with air quality

standards and identifying long-term trends in ambient air quality. Problems arise with fixed stations when local source types or strengths change. For example, a new road scheme may influence the measurements of Pb, CO, and NO_x at a particular fixed station, but these trends are specific to that site and not representative of the entire area. This problem can be minimized by good network design (discussed below), but cannot be entirely eliminated.

Mobile stations typically consist of vans or caravans that are used for days or weeks at a fixed site, but can also be used to gather samples while in motion, assessing pollution from traffic or other sources. Mobile stations are normally used for troubleshooting. If people complain, or there is reason to suspect that a given area has abnormally high pollutant concentrations, the mobile station may be used to gather monitoring data without much delay. This is because it usually does not require the lengthy set-up period that is common in setting up fixed stations. In addition, one mobile station can be used to sample a number of sites (about six) in a sequence designed to statistically represent all times of day and seasons of the year. This involves daily sampling at each site. While this may be more economical than fixed stations, the data generated may be inferior to the data from fixed stations.

Monitoring techniques

The *Monitoring Methods Fact Sheets* (see Appendix 2) provide detailed information on the most commonly used traditional and new monitoring techniques for key pollutants including SPM, NO₂, SO₂, O₃, CO, VOC, benzene, PAH, Pb, and Cd. The following monitoring techniques may be used:

- continuous monitoring for “on-line” data;
- semi-continuous; and
- integrating samplers, active or passive, involving subsequent laboratory analysis.

There is a general trend away from laboratory-based methods toward fully automated monitoring stations. In an air quality assessment program, automated and laboratory techniques may be combined. The choice of equipment is influenced by the following factors:

- program objectives,
- cost,
- available personnel,
- existing laboratory and computer facilities, and
- power and shelter availability at monitoring sites.

Network design and siting of stations

Network design and siting of stations differ according to the specific aims of the monitoring. If the aim is to monitor compliance with air quality standards, a particular sampling protocol and site location are used. If the aim is to evaluate risk to human health through population exposure estimates, the second approach—selective location of sampling site—should be preferred. If the

monitoring takes place as part of an AQMS, it must be able to accomplish the following objectives:

- provide data for actual exposure to air pollutants in residential and hot-spot locations;
- provide data usable for controlling and modifying dispersion models; and
- monitor changes in air quality resulting from pollution abatement actions.

There are two primary ways of designing a monitoring system network. First, sampling sites are located close to intersection points on a geometric grid superimposed on the city. This approach is used in Berlin, Germany and other cities. Care should be taken to adjust the site location where the grid intersection is close to a specific source. This method leads to a large number of sites, and makes it possible to construct isolines of air pollution concentrations based solely on measurements. Second, sampling sites are located selectively at sites considered to be representative of more defined exposure situations or source activities. Examples of such sites may be residential areas in various parts of the city, industrial or traffic sites, and extra-urban background sites (of particular interest for ozone monitoring).

The second approach is generally preferred, especially when dispersion modeling is used as part of the assessment procedure. It provides measured concentrations that indicate the exposure in residential areas and hot-spot locations, and provides data for comparison with, and possible adjustment to, the dispersion model. With proper selection and location of measurement sites, it is possible to use the comparison between measured and model-calculated concentrations to check emissions data for specific sources.

To fulfill AQMS objectives, it is recommended that at least two continuous monitors be operated in the city at the specific sites for measuring the compounds listed in Table 3.2.

In addition, a number of sites with integrated active or passive samplers for SPM (PM₁₀, PM_{2.5}, TSP, NO₂, SO₂) should be established,

depending on city size and source mix, distributed among sites characterized as urban centers, residential areas, and traffic or industrial hot spots.

Table 3.2: Siting monitoring stations

Site category	Compound
City center residential	• SPM (preferably PM ₁₀), NO and NO ₂ , O ₃ , and SO ₂ (in cities with sulfur dioxide problem)
Traffic-exposed hot spot	• SPM (preferably PM ₁₀), NO and NO ₂ , CO
Industrially-exposed hot spot	• SPM (preferably PM ₁₀), SO ₂ (in cities with sulfur dioxide problem)
Extra-urban background	• O ₃ , (NO _x and NO ₂)

When selecting monitoring sites, the following tools are necessary:

- simple scaled map showing locations of urban central districts, residential and industrial areas, dense traffic, the main road system, and large industrial plants and complexes;
- preliminary emissions inventory to assist in identifying the most polluted areas and locations removed from major sources;
- preliminary dispersion modeling to identify more closely those areas that warrant investigation;

- low-cost preliminary monitoring study (for example, diffusion tube samplers for NO₂ can be used at very low cost to provide spatially-detailed data on the distribution of NO₂; this may be used to identify a smaller number of representative locations for fast-response continuous samplers);
- spatial scale of variability of the pollutant (CO, very high close to major roads; and peroxyacetyl nitrate, high spatial uniformity).

Data collection and storage. Only when monitoring data are readily available to the users can they be used efficiently. Procedures for data collection and storage differ for automatic monitors and integrating samplers. For both it is necessary that the final product of the procedure be stored on electronic data files, linked to a software database with provisions for easy display and presentation. The software must include data processing capability (statistics programs) so that both time series and data statistics (average/frequency distribution, exceeding of guidelines, standard deviation, etc.) can be easily presented.

Procedure for automatic monitors. The monitors should be linked on-line to electronic loggers, then transferred by modem at selected time intervals (per hour, per day) to the database in a central laboratory. Provisions must be made for correcting the data in connection with quality control procedures.

The frequency with which the analyzer's output is logged-in depends on the pollutants' variation with time and logger capacity. A logging frequency of 5-60 seconds is recommended: 5 seconds for hot-spot locations (traffic sites, industrial sites), and closer to 60 seconds for sites removed from immediate impact. The averaging procedure should be done at the logger to save memory capacity at the central computer. Data transferred to the central computer should be the average value of the 5-60-seconds, together with the maximum value of the basic time unit (5-60 seconds).

Procedure for integrating instruments. Samples from integrating instruments (typically 8-24 hour samples) as filters or liquids, are typically transferred to the laboratory once a day or once per week. After the subsequent analytical procedures, the resulting concentration data must be transferred into the database, coupled to similar data software programs as the data from the automatic instruments for processing and presentation.

Quality control and quality assurance

Data quality must be assured through the application of quality control and quality assurance procedures. Quality assurance is not synonymous with quality control. Quality control is the system of activities to provide a quality product; quality assurance is meant to protect against failures of quality control. A quality assurance program comprises a system of activities that makes certain that measurements meet defined standards of quality with a stated level of confidence.

Quality control usually includes checks performed during normal internal procedures (e.g. periodic calibrations, duplicate checks, split samples). Quality assurance refers to more occasional activities, such as on site system surveys and periodic evaluation of internal quality control data. In this text, quality assurance is used for both quality assurance and quality control.

Following is a brief summary of the important principles of quality assurance. For a more thorough overview one may refer to the GEMS/AIR methodology reviews (UNEP/WHO, 1994).

Site location. Ensure that the monitoring site is representative of the general neighborhood. The system administrator should record past and foreseen changes in land use, construction, nearby sources, traffic changes and regulation, or any other factors that may alter the criteria that are used to establish a station.

Inlet system integrity. Make sure that the inlet system, through which the sample air is drawn to the instruments, is constructed in a way that will not change the sample air as it passes through the system. Residence time should be short. No absorption, desorption, or reaction must take place at the surface, and no bends should be sharp enough to cause particulates to impact.

Instrument performance and calibration. The choice of methods to be used, whether actual analyzers and samplers, or laboratory equipment, depends on considerations such as pollutant specificity, interference, response time, ease of operation, calibration procedures, availability of service and spare parts, and cost. Laboratories that are experienced at providing such services may provide valuable advice. The instrument must follow specifications for linearity of response, response time, interference, and calibration drift.

The equipment should be maintained and operated according to the manufacturer's specifications. Regular performance checks and calibration are necessary. Thorough performance checks should be conducted once or twice a year, preferably in the base laboratory. Instrument calibration should be regularly checked. Inspection frequency depends on the drift specifications, instrument environment, and other factors. Calibration gases are available for most pollutants.

There are two main modes of supply: (1) pre-analyzed, certified cylinders of compressed gas mixture purchased from a quality supplier, and (2) permeation tube systems. In both cases, it is important that the supplied gas mixture or permeation tube be traceable to an absolute calibration point such as a certificate issued by a qualified institution. High quality dilution equipment should be used in the actual calibration procedure. It should be maintained according to specifications, and routinely calibrated. One of the best quality checks is carried out through an inter-laboratory comparison in which a standard sample is circulated to several laboratories for analysis. Inconsistencies in the laboratory's work become clear if it reports results that do not correspond closely to the true value of the sample.

Data validation. Entries into preliminary data files must be validated before they are accepted as permanent data. Validation is done in two steps: (1) modifying data according to the results of subsequent instrument calibration checks, and (2) inspecting the time series of the data to look for spurious data or peaks that are not found in nearby, similar sites. This does not imply that such data should be automatically deleted, but errors may be detected by such inspection. Suspicious data may be flagged, checked, and corrected.

Financial and manpower requirements

Financial and manpower requirements vary among countries and cities. Major costs are categorized below.

Initial site costs. Includes factors such as capital cost or rent, necessary modifications of the site, cost of the inlet system, and air conditioning, if required.

Air monitoring instruments. Costs of typical instruments are provided in the Fact Sheets in Appendix 2. The cost of back-up instruments (if purchased), meteorological instruments, and calibration equipment such as a permeation tube system and precision gas blender, must also be considered. Instruments used continuously for monitoring may need to be replaced every five years.

Operating costs. Include electricity consumption, travel between stations, calibration gases, permeation tubes, laboratory chemicals, filter papers and selective filters for analyzers, instrument repair and spare parts.

Personnel. Two trained personnel are a minimum for all-year monitoring in a small city. They service and calibrate instruments and carry out quality assurance procedures. A larger network or bigger selection of compounds requires more than two staff members. If there is appreciable laboratory work, technicians are needed to work under the supervision of a trained chemist. It is impossible to make exact predictions of staff requirements before the network's frequency of sampling and substances to be measured have been determined. Typically, an urban network of six sites, measuring a selection of compounds, requires one or two people for on-site instrument maintenance and sampler changing, and two people in the laboratory for analytical work and quality assurance.

Meteorological data needs

Meteorological data are needed to facilitate the manual interpretation of spatial and temporal variations of measured air quality data. Such data must be measured simultaneously with air pollution data. They are also necessary inputs for dispersion model calculations of pollution concentrations. Important meteorological parameters include the following:

- wind speed and direction;
- parameters describing atmospheric turbulence and stability, such as temperature profiles (measurements at two or more heights, or direct turbulence measurements);
- mixing height; and
- ground air temperature.

Such data should be available on an hourly basis, for a 12-month period of average meteorological conditions. The height of observations may vary from 10 to 50 meters above ground. The number of measurement sites depends on the city's topographical complexity. The sites must be chosen to represent the undisturbed meteorological conditions of the area.

The following observations should be noted if measured data are being manually interpreted:

- Wind direction indicates whether a given source is influencing a sampling station at a particular time.

- Wind direction and speed data enable an evaluation of whether trends in concentrations are due to meteorological factors rather than changing emissions.
- For sites on the periphery of a city, wind direction will indicate whether the air sample has traversed the city or is about to enter it.
- Data on vertical temperature structure will help recognize periods when abnormal pollutant concentration may occur.

EMISSIONS INVENTORIES

An emissions inventory is a compilation of all air polluting emissions in an area. The inventory includes pollutants (e.g. SO₂, NO_x, particulate matter), source (e.g. industry, traffic, domestic), and/or energy carrier (e.g. oil type, gasoline, wood). It also specifies the location of each source and time variation in the emissions. An emissions inventory serves the following functions:

- providing spatially-resolved source strength data on each pollutant for dispersion modeling,
- predicting environmental impact,
- helping in urban and regional planning activities,
- supporting the design of air monitoring networks,
- contributing a basis for evaluating emission trends, and
- assisting in the formulation of air quality management policies.

The construction of a complete, high-quality, emissions inventory is time-consuming and, depending on its complexity, can take many months or even years. Before embarking on the inventory, decisions should be made on what pollutants to include, the extent of spatial and temporal resolution, and data requirements based on the degree of sophistication to be employed in estimating emissions.

In recent years, several institutions have developed procedures for compiling emissions inventories, including nomenclature, source categorization and emissions factor compilation. These include the USEPA (USEPA, 1985),² IIASA (Amann, 1992), WHO (Economopoulos, 1993) and the European Commission (Bouscaren, 1992). The European Commission, through the European Topic Center of Air Emissions of the European Environment Agency, offers a software tool for compiling an emissions inventory. For a rapid compilation of a first estimate, IIASA and WHO citations may be used.

To compile an emissions inventory for urban areas, it is important to include the position of sources (i.e. to get the spatial distribution of the emissions in the urban area with a resolution of not more than one kilometer). The use of a coordinate system is suggested. GIS-based software tools which include the spatial component are available for this purpose. The following section describes the steps in constructing an emission inventory.

²

For a compilation of the emissions tools available from the USEPA, refer to the EPA Clearinghouse for Inventories and Emission Factors (AIR-CHIEF).

Categorizing pollutants

In order to create an emissions inventory, pollutants may be divided into three categories.

1. Those which should be inventoried, and for which data are readily available. Pollutants in this category are SO₂, oxides of nitrogen (NO_x), particulates, CO, and Pb.
2. Those which should be inventoried, but for which data are available only with difficulty. This category includes VOCs, specific hydrocarbons such as polynuclear aromatic hydrocarbons (PAHs) and benzene, and cadmium.
3. Secondary pollutants are formed in the atmosphere rather than emitted directly, and can be attributed quantitatively to precursor sources only as a result of complex numerical modeling methods. Ozone and peroxyacetyl nitrate (PAN) are included on this category.

A city that does not have an inventory should begin with category (1) and proceed later to category (2). The processes affecting secondary pollutants are so complex that attempting source apportionment for pollutants like ozone or PAN requires detailed monitoring data and highly sophisticated numerical chemistry and diffusion models.

Constructing an inventory

Constructing an inventory requires information on the source strength of all emitters within specified geographic areas. In some instances, such information may be relatively easy to obtain. For example, the operator of a chemicals plant may already possess detailed records of measured stack emissions. Other cases may be more difficult. The owner of a large building heated by fuel oil is unlikely to know the magnitude of its SO₂ emissions. However, from knowledge of the amount of fuel burned and its sulfur content, a fairly accurate estimate of SO₂ emissions can be made. In the case of NO_x and hydrocarbon emissions from the same boiler, the estimate is less precise as it is based on emissions from similar boilers elsewhere and cannot readily incorporate local factors such as boiler's condition.

There are five stages in calculating an emission inventory:

1. establishing a list of point, area, and mobile sources;
2. contacting each point source operator to obtain quantitative process and emissions data;
3. compiling data on activity levels for area and mobile sources, such as number of vehicle kilometers and speed, number of household boilers, monthly heating oil use for a district;
4. reviewing data to evaluate its suitability and developing alternative strategies or activity level indicators as necessary; and
5. processing the individual source and activity level data to provide a spatially-desegregated source inventory.

Categorizing sources

There is no single way to develop an emissions inventory. Decisions need to be made on the extent to which the information is refined into categories. One of the first points at which this occurs is when source types are subdivided into relatively homogeneous groupings. Table 3.3 shows a typical breakdown of source categories. Stationary sources may be treated as either significant point sources or as components of an area source. An electricity generating station will be a substantial source of emissions and data will be collected for this one specific source. A domestic boiler for heating one house is not itself significant, but becomes important when added to other boilers in a city suburb. The emission from such a source is estimated from fuel consumed in the area for the purpose of domestic heating, a statistic which can often be obtained from fuel suppliers. Another example is wood burning at small bakeries or street vendors. Individually they may not consume much wood, but collectively they may be an important source. Information on total wood consumed by the bakeries may be obtained from suppliers.

Table 3.3: Source categorization

Mobile Sources	
1. Motor vehicles	3. Off-road vehicles
<ul style="list-style-type: none"> • petrol (leaded) • petrol (unleaded) • diesel • LPG 	4. Railways
2. Aircraft	5. Marine (not always relevant to urban environment), Ships/Pleasure craft
	<ul style="list-style-type: none"> • outboard • inboard • inboard diesel
Stationary Sources	
1. Waste combustion	6. Petroleum and solvent sources:
<ul style="list-style-type: none"> • municipal incinerators • industrial incinerators • sewage sludge incinerators 	<ul style="list-style-type: none"> • oil refineries • petrochemical plants • bulk storage of petroleum products • preparation of solvents • use of solvents
2. Electricity generation	7. Other industrial sources
<ul style="list-style-type: none"> • coal fired • oil fired • gas fired 	<ul style="list-style-type: none"> • metal smelters, foundries and refineries • cement works • glass works • sulfuric acid plants • sulfonation plants • fertilizer works • nitric acid plants • other chemical industry
3. Fuel consumption: industrial	8. Miscellaneous sources:
<ul style="list-style-type: none"> • coal • oil • gas (LPG) • natural gas 	<ul style="list-style-type: none"> • gas leakage • utility engines (e.g. lawnmowers) • unconfined fires • other commercial operations (e.g. printworks or scrap yard for lead)
4. Fuel consumption (commercial):	
<ul style="list-style-type: none"> • solid fuel • oil • gas (LPG) • natural gas 	
5. Fuel consumption(domestic):	
<ul style="list-style-type: none"> • coal • smokeless fuel • wood • oil • gas (LPG) • natural gas 	

Collecting data from sources

Questionnaires are often used for data collection. Appendix 3 has sample questionnaires for collecting point source information. Information sources include the following:

Major point source emissions:

- national pollution regulatory agencies,
- regional and local pollution regulatory agencies,
- regional and local planning authorities, and
- plant operators.

Area sources:

- regional and local planning authorities,
- census authorities,
- chambers of commerce,
- regional and local pollution regulatory agencies, and
- fuel suppliers.

Mobile sources:

- national highway authorities,
- regional and local highway authorities,
- regional planning agencies,
- fuel suppliers,
- railway operators,
- airport operators,
- ship operators, and
- port and marine authorities.

Determining emission factors

Emission factors are an important element of inventory development. These relate pollutant emissions to a measure of activity level: for a car, grams of NO_x per kilometer driven; for a boiler, grams of NO_x per kilowatt fired, and for a nitric acid works, grams of NO_x per ton of nitric acid produced. In instances where source strength measurements are not available, it is necessary to estimate emissions (*E*) from measure of activity (*A*), and emission factor (*F*):

$$E = A \times F$$

In the case of SO₂ emissions, it is necessary to know the sulfur content of the fuel. Emissions of SO₂ are then given by:

$$E = V \times S \times P \times 2$$

where: *V* = amount of fuel (tons per year); *S* = percent sulfur; *P* = proportion of sulfur emitted as SO₂, and 2 is the factor required to convert sulfur to SO₂.

Emission factors have been determined for a very wide range of industrial, commercial and domestic activities, and tabulated values may be carefully used to estimate emissions. Comprehensive tabulations have been prepared by the U.S. Environmental Protection Agency (USEPA 1985), WHO (Economopoulos, 1993), and by the European Commission (Bouscaren, 1992). In some instances, appropriate emission factors are not available and it is necessary to conduct the necessary research for coming up with estimates.

Choosing spatial and temporal resolution

Although it is feasible to construct an emissions inventory without source categories and spatial distribution, a detailed approach is more useful. Spatially distributed data are valuable, especially for dispersion modeling, urban and regional planning, and monitoring network design. Various levels of spatial desegregation are possible, depending on the resources available. Experience suggests that, for most purposes, a km²-grid approach is sufficient.

Emissions are also temporally variable. Some sources such as the brick industry may be operated only in the off-monsoon season. For major point sources, temporal variations can be discerned from information supplied by the operators. For area sources, such emission changes cannot readily be discerned from fuel delivery statistics, and other approaches are needed. One approach is the "degree-day" principal that relates the temperature-dependent emission rate [$E(T)$] to the annual average emission rate (E_o). Such predictive equations, as shown following, are to some extent area-specific:

$$\begin{aligned} E(T) &= E_o [0.33 + 0.11 (14.5 - T)] \text{ for } T \leq 14.5^\circ\text{C} \\ E(T) &= 0.33 E_o [0.33 + 0.11 (14.5 - T)] \text{ for } T > 14.5^\circ\text{C}. \end{aligned}$$

DISPERSION MODELS

Dispersion models have two important functions in urban air quality management: (1) models predict air quality in regions where it is not possible to carry out air sampling, and (2) calculated concentrations using emissions from different groups of sources are used by policymakers when assessing different emission control strategies. Emissions are dispersed and diluted in the atmosphere before reaching people or air pollution samplers (receptor points). Air quality modeling seeks to combine knowledge of pollutant source strengths (i.e. emitted quantities per unit time) with meteorological data to estimate concentrations at the receptor point. Models have varying degrees of sophistication and accuracy is rarely better than plus or minus 20-30 percent of the actual value, unless the model is "tuned" by use of pollution monitoring data (stochastic modeling).

Types of dispersion models

Air quality models are used to establish a relationship between emissions and air quality. Typical spatial scales, and related sources of pollution in urban areas, are shown in Table 3.4.

Table 3.4: Spatial scales of air pollution

Location	Spatial Scale	Pollutant	Source
Local	10 - 100 m	SO _x , NO ₂ , PM ₁₀ /TSP, CO	Elevated point source; low-level area sources; nearby auto traffic
Urban	10 - 40 km	SO _x , NO ₂ , PM ₁₀ /TSP, Photochemical oxidants	Multiple point sources; low-level area sources. Auto traffic, industrial processes
Regional	100 - 1000 km	SO _x , PM ₁₀ /TSP, Secondary Pollutants	Industrial area, densely populated area, urban area, transportation system

Meteorological data and knowledge of physical and chemical reactions in the atmosphere, are used to calculate the air concentrations of one or more pollutants as a function of time and space.

Types of data required for dispersion models include the following:

Emission and source data:

- source location, geographical co-ordinates,
- source dimensions, height and exit diameter,
- exhaust gas exit temperature and velocity (or total volume flow rate),
- mass flow of air pollutant from the source, and
- time dependence of pollutant emissions, duration and frequency as well as diurnal and seasonal variations.

Wind and dispersion data:

- hourly average wind speed and direction,
- description of atmospheric turbulence and stability (to estimate dispersion),
- mixing height,
- height of inversion layers,
- ambient air temperature (for plume rise calculations), and
- joint frequency distribution of at least the first three meteorological parameters.

Deterministic models are based on solutions of the diffusion equation. Models vary in size and complexity based on source characteristics, type of pollutants to be estimated (primary, inert, secondary, gas, or particles), area size, topographical features and budget.

Steady-state models calculate a fixed concentrations distribution, varying in space for a given meteorological situation. The following are examples of steady-state models:

- gaussian point source models for estimating impact from single stacks,
- multiple source Gaussian models for point and area sources in urban areas, and
- simple area source models based on an input/output (flux) consideration, where concentrations are inversely proportional to wind speed.

Time-dependent models. In time dependent models, all input parameters can be functions of time; the concentration output is also dependent on time. Examples include:

- box models for urban areas for estimating the flux of pollutants across boxes where sources, dispersion, deposition and transformation are taken into account;
- grid models for solving the diffusion equation numerically in a grid, largely used for solving specific problems, including photochemical processes (Eularian approach); and
- lagrangian (puff trajectory) models where puffs of pollutants are advected along the wind trajectory and where diffusion, transformation and deposition take place.

Table 3.5 identifies models that describe spatial concentration distributions resulting from different meteorological conditions and dispersion phases. Observed concentrations at measuring stations are used to validate the calculated (model) description of emission and dispersion. Measurements may also be used to improve the accuracy of calculated concentration fields when they are treated statistically along with results of dispersion models.

Table 3.5: Air quality models developed for different groups of sources

Type of source	Dispersion phase	Spatial scale	Model characteristics
Single stack	1. Momentum phase 2. Building phase 3. Dispersion phase a. looping b. coning c. fanning	Stack diameter, Building height, L = 10-100 m, Transport: 1 km	Plume rise formula (Briggs), Gaussian plume formulae. Time- and distance- dependent dispersion parameters σ_y and σ_z
Highway	1. Car-made turbulence 2. Building phase 3. Dispersion phase	Car dimension, Building height, L = 20-100 m, Transport: 1 km	Gaussian highway model Time- and distance- dependent σ_y and σ_z
Urban scale Multiple sources	Stationary and homogeneous dispersion conditions	10-40 km Vertical: 50-100 m	Superposition Principle - Single stacks
Reactions in the atmosphere producing oxidants			Complex time dependent photochemical models
Local and urban scale sources	Wind and dispersion varies with time and in space	1-40 km	Gradient/transport Lagrangian approach for the local scale and Eulerian approach for the urban scale
Regional scale	Mesoscale Processes Long range transport	10-1000 km Vertical: 1 km 1000-5000 km	Knowledge about weather systems on a cyclonic scale
Global scale	Atmospheric structure on a global scale	Zonal average vertical: 1 km. Time scale: 12 hr	Photochemical models in the high atmosphere

AIR POLLUTION EXPOSURE

Assessing the effects of air pollution on a city and its people is complicated. For stationary objects (buildings and vegetation), it is necessary to combine the geographic distribution of air

pollution concentrations with the corresponding geographic distribution of population, built environment and vegetation. Various techniques are used to assess individual and population air pollution exposure. These include the following:

- personal samplers to measure actual individual exposure;
- calculating long-term average exposure by combining residential distribution with calculated or measured spatial distributions of long-term average pollutant concentrations; and
- calculating short-term (hourly) and long-term (annual) population exposure distributions by combining knowledge of an individual's movements in the area (by diary method), with calculated distribution of short-term average pollutant concentrations.

These techniques help to estimate population exposure to outdoor ambient air pollution. However, indoor air pollution exposure may also be a very important part of an individual's total exposure. This is especially true in the rural areas of many Asian countries where indoor cooking with unvented stoves is the norm. Indoor air pollution is also important in many urban areas. Indoor exposure can be measured by using personal monitors. It is not accounted for in the second method, but may be accounted for in the first and third method, provided data on indoor air concentrations are available. Each of these three methods is discussed below.

Personal sampling

Personal sampling allows the measurement of actual individual exposure to pollution. This however is expensive, time consuming and requires a large field study. Following are examples of pollutants that can be measured using personal sampling:

- CO, hourly average concentration can be measured; practical limitation is only one to a few days of sampling;
- Particles, 8- to 24-hour averages can be measured; analysis of major elements such as lead is included; practical limitation is a few days to a few weeks of sampling; and
- NO₂, VOCs, averages over a few days to a few weeks; long-term average exposure can be established.

Practical and financial considerations limit such a measurement campaign to a maximum of 10–100 people for perhaps 10–20 sampling periods. Personal sampling can also be utilized as part of a health effects research study, where individuals are studied for both exposure and health effects; and to estimate the total population exposure distribution, provided a suitably representative set of individuals is selected reflecting residential, commuting, and day-time location and activity patterns.

Calculating long-term population exposure based on residential addresses

This method was used for the URBAIR exposure assessments in Kathmandu Valley, Jakarta, Metro Manila, and Greater Mumbai (World Bank Technical Papers Nos. 378, 379, 380 and 381).

Long-term population exposure based on residential addresses is calculated in the following way:

- Establish the distribution of residents in the study area, preferably within each square of a grid network; and
- Calculate long-term average concentrations for each grid square using, for instance, a multi-source Gaussian climatic-type model.

This method does not require a large effort, especially in cases where an emissions inventory and dispersion model have already been established. It presents the residential population exposure to annual average TSP concentrations in Manila.

Calculating additional exposure in hot-spot locations. It is possible to extend this method, in a statistical manner, to include “hot-spot” exposure of populations along major roads and in industrial areas.

- Calculate how many commuters, drivers, others spend how many hours on the road each day.
- Estimate the number of people who live in areas with significantly elevated concentrations from nearby industrial emissions.
- Establish concentrations representing typical conditions on main roads, and industrial areas (Table 3.6).

Table 3.6: TSP concentrations and exposure on the roads

	While commuting (2 hr.) ($\mu\text{g}/\text{m}^3$)	Rest of day (22 hr.) ($\mu\text{g}/\text{m}^3$)	Average ($\mu\text{g}/\text{m}^3$)
High exposure	570	150	185
Medium exposure	300	120	135
Low exposure	220	90	100

Source: World Bank Technical Paper 380 (1997).

This method was used to estimate roadside exposure in the Metro Manila and other cities in the URBAIR studies. An example of a calculation of annual average population exposure distribution for Manila is explained here. The average on-the-road TSP concentration (annual average) was estimated to be $350 \mu\text{g}/\text{m}^3$, based on traffic and TSP data in Table 3.7. The number of individuals exposed on or near the main road networks is estimated in Table 3.8. Although approximate, these estimates are of a realistic order of magnitude. Exposed population is categorized as drivers/ policemen, commuters, and residents near roads.

Drivers/policemen. Exposure for drivers and policemen is $350 \mu\text{g}/\text{m}^3$ for 8 hours during the day and $150 \mu\text{g}/\text{m}^3$ for 16 hours. The average daily exposure is thus $220 \mu\text{g}/\text{m}^3$. Adding policemen and ‘other’ drivers, an estimated

Table 3.7: Estimated on-the-road TSP concentration (annual average) as a function of AADT (vehicles/day)

AADT on Manila Main Road Network		Estimated on-the-road TSP concentration ($\mu\text{g}/\text{m}^3$)
AADT	km	
120-140,000	11	570
100-120,000	6	500
80-100,000	16	430
60-80,000	30	360
40-60,000	69	290
20-40,000	120	220
<20,000		150

Source: World Bank Technical Paper 380 (1997).

300,000 'road workers' are exposed to high road concentrations for several hours each day.

Commuters. There are 17.7 million person-trips daily. Traffic activity on the main road network is 50 percent of total traffic. Each person takes an average of 3-4 trips per day. Thus, approximately 2-3 million people commute on the main road network in Manila every day, spending a total of 1-2 hours per day "on the road." The exposure calculation shown in Figure 3.1, uses an estimate of 2.4 road commuters, distributed equally between high, medium and low road exposure.

Table 3.8: Total number of persons exposed

	No. of vehicles	No. of drivers on road daily	No. of persons exposed
Jeepneys	50,000	2.0	100,000
Buses	5,000	2.0	10,000
UVs	200,000	0.5	100,000
Trucks	50,000	0.5	25,000
Tricycles	20,000	1.0	20,000
Total	325,000		255,000

Source: World Bank Technical Paper 380 (1997).

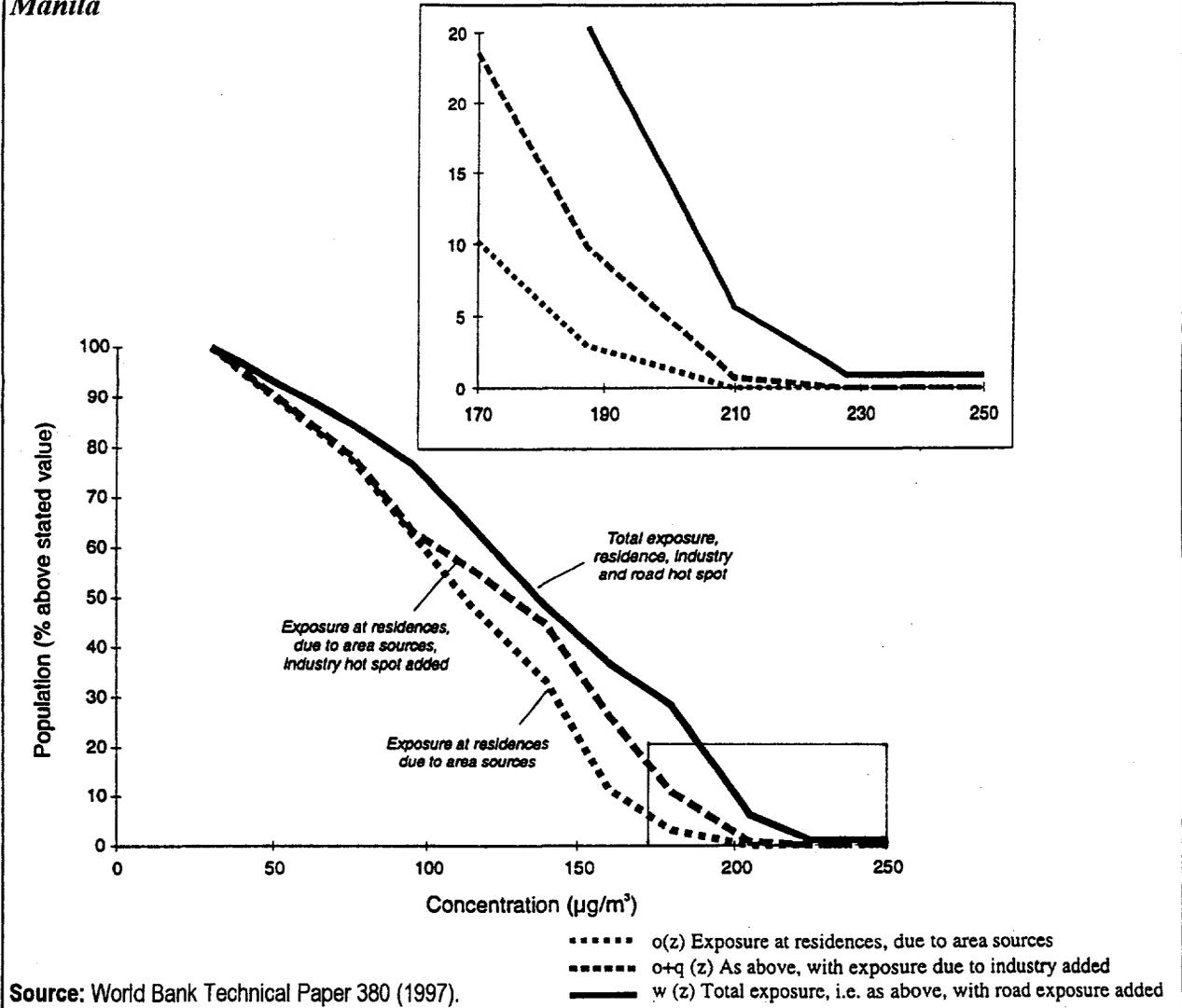
Roadside residents. Main roads with less than the annual average daily traffic (AADT) of 40,000 are 130 km in length. The length of main roads with residents alongside are 50 percent of this length (65 km) with 50 percent roadside house coverage. Calculating 10 residents per 10 meter roadside, there are an estimated 65,000 roadside residents. The resulting modifications to the population exposure distribution of Manila are shown in Figure 3.1.

Diary method

In addition to the use of personal monitors, long-term population exposure can also be assessed by using dispersion models in combination with diaries. By opting for this method, researchers are not restricted by the availability of monitoring and sampling methods in the choice of pollutant compound and averaging time. The diary/dispersion model method provides the best assessment of exposure. The diary method involves the following steps:

- Several hundred city dwellers, representing various population groups, areas of residence, occupations, commuting practices, etc. are selected.
- These individuals keep daily diaries, detailing their movements and time spent at different locations throughout the day.
- Researchers calculate hourly average concentrations at a number of "receptor points" in the urban area, including the center points of the km² grids, the locations given in diaries, and selected hot spots.
- Population exposure distribution for selected pollution compounds and average times is calculated by constructing an "exposure model." This model combines the calculated concentration time series at selected points with the location data from the diaries, the residential distribution, and other time and location data.

Figure 3.1: Calculated annual average population exposure distribution for TSP in Metro Manila



AIR QUALITY GUIDELINES AND STANDARDS

Many countries have set air quality "limit values." These may be presented as national standards or recommended air quality guidelines (WHO AQG). Standards are legally binding whereas guidelines are often interpreted as long-term planning goals for acceptable air quality. Before adopting standards, AQG values must be considered in the context of prevailing exposure levels and other local environmental, social, economic, and cultural conditions.

Limit values are selected based on scientific research on a pollution compound's actual effects, usually presented in criteria documents. The most complete AQG document has been produced by the WHO Regional Office for Europe (WHO, 1987). It provides guideline reference

material for 23 air pollution compounds, concentrating on the health effects of those pollutants. Table 3.9 lists the WHO AQG values, as well as summary tables of standards from various countries, for cadmium, CO, lead, NO₂, ozone, SO₂, SPM, and VOC. Comments from the WHO document, "Air Quality Guidelines for Europe," regarding the nature of the guidelines, are cited in Appendix 4. When setting the numerical values in the WHO AQG, the following criteria were considered:

- lowest-observed-adverse-effect level (LOAEL),
- protection factor,
- averaging times,
- consideration of sensory effects, and
- carcinogenic endpoint.

PROJECTING LONG-TERM TRENDS IN AIR QUALITY

It is difficult, sometimes impossible, to make long-term projections about air quality. The level of economic development, technological progress and social awareness impact future environmental conditions. In the interest of long-term planning and preparedness, however, it is crucial that rudimentary projections be made. Often such projections are no more than indicators of what may result if no changes were made to the present (baseline) situation. These baseline conditions and future trends are the main inputs for an AQMS to reduce air pollution to an acceptable level in the medium and long term. Dispersion models are used to calculate future air pollution estimates. Emission distribution estimates for future scenarios and estimates of future population and materials distribution are necessary inputs for such estimates.

These two input databases determine the projected exposure situation, which forms the basis for assessing future damage costs and selecting abatement strategies. Such projections should be provided for the following scenarios:

- Medium-term (5-10 years) scenarios follow past and present trends.
- Long-term (10-20 years) scenarios take into account probable trends, including
 - development and introduction of new technologies in the region,
 - economic development (or growth), and
 - the enforcement of current and anticipated air pollution regulations.

AIR QUALITY INFORMATION SYSTEM

In order to ensure that an AQMS is having the desired impact, it is important to not only continuously monitor air quality, but to widely disseminate the monitoring results. An air quality information system (AQIS) has several significant uses. Air quality management authorities use it to enforce laws and regulations, issue permits, and develop strategies and policies. Polluters (i.e. industries) can use it to monitor the impacts of their activities. The public can refer to air quality information to understand the effects of each individual's activities (traffic, cooking, refuse

Table 3.9: Summary of WHO air quality guidelines (AQG)

Substance	AQG	Averaging time	Components
Organic			
1) Acrylonitrile	None		Carcinogen ^a , (1 µg/m ³ presents a 2 x 10 ⁻⁶ lifetime risk)
2) Benzene	None		Carcinogen ^a , (1 µg/m ³ presents a 4 x 10 ⁻⁶ lifetime risk)
3) Carbon disulfide	100 µg/m ³	24 hours	
4) 1,2-dichloroethane	0.7 mg/m ³	24 hours	
5) Dichloromethane	3 ng/m ³	24 hours	
6) Formaldehyde	100 µg/m ³	30 minutes	
7) PAH	None		Carcinogen ^a , (1 µg/m ³ presents a 1 x 10 ⁻⁶ lifetime risk)
Inorganic			
1) Arsenic	None		Carcinogen ^a ; (1 µg/m ³ presents a 3 x 10 ⁻³ lifetime risk)
2) Asbestos	None		Carcinogen ^a ; (1 fiber/m ³ presents a 10 ⁻⁶ -10 ⁻⁵ lifetime risk of developing lung cancer, and a 10 ⁻⁵ -10 ⁻⁴ lifetime risk of developing mesothelioma)
3) Cadmium	1-5 ng/m ³ 10-20 ng/m ³	1 year (rural) 1 year (urban)	
4) Carbon monoxide	100 mg/m ³ 60 mg/m ³ 30 mg/m ³ 10 mg/m ³	15 minutes 30 minutes 1 hour 8 hours	
5) Chromium	None		Carcinogen ^a ; (1 µg/m ³ presents a 4 x 10 ⁻² lifetime risk)
6) Hydrogen sulfide	150 µg/m ³	24 hours	
7) Lead ^b	0.5-1.0 µg/m ³	1 year	
8) Manganese	1 µg/m ³	1 year	
9) Mercury	1 µg/m ³	1 year	
10) Nickel	None		Carcinogen ^a ; (1 µg/m ³ presents a 4 x 10 ⁻⁴ lifetime risk)
11) Nitrogen dioxide	400 µg/m ³ 150 µg/m ³	1 hour 24 hours	
12) Ozone & other	150-200 µg/m ³	1 hour	
13) Photochemical oxidants	100-120 µg/m ³	8 hours	
14) Radon	None [≥100 Bq/m ³]	[1 year]	Carcinogen ^a ; (1 Bq/m ³ presents a 0.7-2.1 x 10 ⁻⁴ lifetime risk [recommended level for remedial action in buildings])
15) Sulfur dioxide	500 µg/m ³ 350 µg/m ³ 125 µg/m ³ 50 µg/m ³	10 minutes 1 hour 24 hours 1 year	
16) Particulate matter ^c	150-230 µg/m ³ 60-90 µg/m ³	24 hours 1 year	
17) Vanadium	1 µg/m ³	24 hours	

a A linear one-hit extrapolation model has been used to calculate the lifetime cancer risks.

b According to the revised WHO AQG for Europe, the AQG for lead has been lowered from the 0.5-1.0 µg/m³ range to 0.5 µg/m³.

c The revised WHO AQG for Europe indicates that there is no safe level of particulate matter. Effect-response should form the guideline.

Source: World Health Organization (1987).

burning), change attitudes, the effects of the pollution and the measures introduced by the authorities. An AQIS can ultimately be used in concert with all the players above for air pollution forecasting and alert measures during pollution episodes

Elements of an AQIS database:

- measurement and monitoring data, as time series, for each monitoring site,
- emissions inventory, and
- air pollution concentration data from dispersion models, presented as concentration fields (calculated concentrations in each square in a km² grid system or calculated concentrations representing each road link and other hot spot locations).

Features of database presentation software:

- graphs depicting previously measured time series for one or more components at each monitoring site; this could be continuous recording data such as from a NO_x monitor, or 24-hour average data from integrating measurement methods such as pararosaline method for SO₂;
- on-line presentation of most recent measurements on computer monitors; and
- calculation and presentation of concentration statistics—monthly or annual averages, frequency distributions, maximum values, instances where AQG have been exceeded.

Not all cities can develop an AQIS that performs all these functions, in a short-time period. A simple and straightforward AQIS has the following features:

- timeliness of data (able to present the previous month's data);
- efficiency (working together of insitutions involved in monitoring, chemical analysis, modeling, and public reporting);
- accessibility (easy access to data for analysis, enforcement, and reporting by involved government agencies); and
- public reporting (polluters and the public-at-large should have access to the most up-to-date monitoring data, even if at a more aggregated level than the pollution control authorities).

Computer-based AQIS can use software that provides possibilities for on-line graphic presentation of monitoring data. One sophisticated one-line AQIS, called ENSIS, has been developed in Europe and used in the 1994 Winter Olympics in Norway. A description of this system is given in Appendix 6. While the degree of sophistication apparent in ENSIS may exceed the capacity and budgets of many developing countries, it remains a good example of an advanced and client-oriented AQIS.

4. ENVIRONMENTAL DAMAGE ASSESSMENT

This chapter presents procedures to assess air pollution damage and methods to place a monetary value on these damages. Although it may not be possible to measure all the costs of air pollution with precision, even approximate estimates may help to increase support for pollution control measures. Thus, this chapter presents methods to place a dollar value on air pollution damage, especially damage to human health. Air pollution imposes serious health-related social costs in the form of illness (morbidity) and premature death (mortality). Increased expenditure on medical care, loss of productivity, and pain and suffering are all components of air pollution's social costs. Other more physical impacts of air pollution include damage to the ecosystems on which humans depend for their livelihood; damage to the physical infrastructure and dirtying of facades and other physical material.³

GENERAL PROCEDURE FOR ENVIRONMENTAL BENEFIT/DAMAGE ASSESSMENT

The following steps should be taken to assess the economic benefits and costs of changes in air quality.

1. *Identify the population and stock/assets at risk due to pollution* by creating a simple matrix as shown below in Table 4.1. The population-at-risk may be all the residents of a polluted area, or a fraction thereof, such as elderly people or people with a chronic respiratory affection. The stock-at-risk refers to the area (m²) of exposed steel or zinc, or the area (hectares) of wheat or rice in a polluted area.

Table 4.1: Example of an impact matrix of common air pollutants (local outdoor pollution)

	SO ₂	TSP	NO _x	CO	O ₃
Human health					
Mortality	x	x	n/a	x	x
Morbidity	x	x	x	na	x
Materials					
Steel	x	na	(x)	na	na
Masonry	x	na	(x)	na	na
Soiling	na	x	na	na	na
Ecosystem	x	na	x	na	x

x = impacts.

(x) = impacts expected but not empirically substantiated.

na = no known impacts.

³

The damage assessment in this chapter is confined to local impacts; regional or global impacts such as acidification, global warming and stratospheric ozone depletion are not included. Also, indoor pollution is not included.

2. *Determine the number of people and objects that are exposed to ambient pollution that exceeds standards or guidelines.* This provides a first indication of the extent of benefits/damages. The amount by which standards are exceeded provides additional information (see previous chapter's discussion, Air Pollution Exposure).
3. *Identify relevant dose-response functions* that relate ambient levels of pollutants to impacts on specific assets or certain aspects of health. For many pollutants, the severity of health impacts is directly correlated to the concentration of pollutants. Different levels of pollutant concentrations result in differing degrees of symptoms.
4. *Calculate marginal physical impact* by multiplying the population-at-risk and/or the stock-at-risk with the impact per unit of pollution in the reference scenario.
5. *Determine monetary values per unit of physical impact* with calculations depending on the type of impact. Impacts on productive processes (e.g. crop production) can be valued with market prices. Health and ecological impacts and those on nature cannot be directly valued with market prices.
6. *Calculate the monetary value of benefits/damage* due to the change in air pollution by multiplying marginal physical impact (4) with the monetary unit values (5).

The following sections outline the procedures used to assess health damage (steps 3 and 4, above) discuss monetary valuation techniques. Both topics are discussed in greater detail in Appendix 4.

HEALTH DAMAGE ASSESSMENT

Epidemiological roots of dose-response functions

There is substantial evidence from developed countries of strong correlations between exposure to ambient air pollution concentrations and health risks (Dockery et al, 1993; Pope et al 1995; Schwartz, 1991; Ostro, 1994). Three types of studies have been used to establish causal relationships between air pollutants and health outcomes: (1) clinical studies, based on human volunteers in carefully controlled experiments; (2) toxicological studies, in which effects on animals are extrapolated to humans in risk assessment studies; and (3) epidemiological studies that examine how the incidence of specific health outcomes vary with variations in ambient air pollution levels.

Compared to clinical and toxicological studies, carefully done epidemiological studies provide the most reliable measure of health conditions under normal human exposure conditions.⁴ Although expensive and time-consuming, such studies can capture both acute as well as chronic health effects. Most epidemiological studies are either cross-sectional studies that correlate variations in air pollution levels across spatial areas with incidences of health endpoints, or time

⁴ A recent US epidemiological study covered 6 cities over a 15-year period (Dockery, et al, 1993).

series studies that correlate daily variation in mortality and morbidity with air pollution concentrations on the preceding days.

Given the absence of epidemiological studies when assessing health impacts in developing countries, results from epidemiological literature from industrialized countries are typically used. Dose-response functions generated by these studies are applied to ambient pollutant levels to get estimates of selected health effects. Estimates in the United States, United Kingdom, and elsewhere link mortality to SPM and respiratory illnesses from lead, SO₂, ozone, and other pollutants (Ostro, 1994).

Forms of dose-response functions

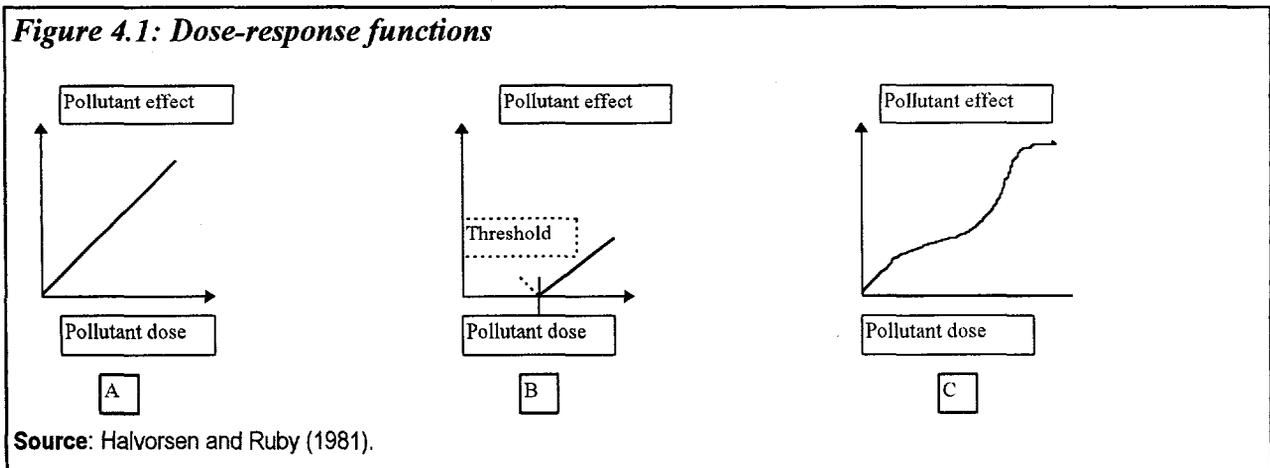
In its simplest form, a dose-response function takes the following linear form:

$$dH_i = \beta POP_i * dA, \text{ where}$$

where dH_i = change in population risk of health effect (i); β = slope of the dose-response function; POP_i = population at risk of health effect i ; and dA = change in level of air pollutant under consideration.

Once the relevant β is estimated, the health impact (dH_i) of a change in ambient air pollution levels (dA) on a given population (POP_i) can be estimated. The POP_i variable may include the entire population of a city, or it may only focus on a particularly vulnerable subgroup. Whereas children are particularly vulnerable to lower respiratory tract infections from particulate matter and lowered Intelligence Quotient (IQ) ratings from lead, adult males are particularly vulnerable to elevated blood pressure from lead.

The slope, or the first derivative, of a dose-response function at prevailing pollutant levels measures the physical impact per unit of pollution. Figure 4.1 below shows three functional forms often used in dose-response studies. Graph A represents a linear relationship between the dose of the pollutant and the number of people exhibiting symptoms of adverse health effects. Graph B represents the “hockey stick” dose-response function: the pollutant has no impact below a certain threshold level and a linear effect at concentrations above this concentration. Graph C



presents the sigmoid dose-response function. According to this function, very low doses of pollutants impact only the health of sensitive individuals—such as children, the aged or infirm—while the majority of the population is affected above a higher but less well-defined threshold. This type of dose-response function is assumed to be the closest representation of the health impacts of pollution.

Implicit assumptions in dose-response functions

When applying a dose-response function, the change in the concentration level of a specific pollutant (dA) is usually hypothetical. Often, analysis is done assuming that ambient concentrations are lowered to meet national standards, or WHO AQG. Alternatively, an arbitrary 10 percent or 20 percent reduction is assumed. In operational terms, the first approach is useful to highlight the magnitude of current air pollution damages. The second approach is useful for comparing incremental costs with incremental benefits when analyzing feasible cost-effective air quality control strategies.

The implicit assumption behind specified air quality standards is that there are no significant adverse health effects below the specified standards. Analysts often assume that levels below the WHO AQG are safe for human health, and that reducing a pollutant that is already in compliance with an established standard would have no further health benefits. However, epidemiological studies in industrialized countries are questioning the validity of thresholds (Box 4.1). For instance, recent studies indicate that there are no safe levels for lead in the atmosphere.

When dose-response estimates from industrialized countries are applied to populations in developing countries, the following assumptions are often made.

- *Baseline health status is the same in industrialized and developing countries.* Poorer sanitary conditions make people more susceptible to adverse health outcomes. Although it may not be incorrect to assume that the general level of health in developing countries is worse, it is difficult to assess if the dose-response function will be steeper for a pollutant in a developing country, unless dose-response functions are estimated specifically for that country.
- *On average, people have similar weights.* The average weight for an individual in the United States is assumed to be 70 kilograms, higher than the average weight in many

Box 4.1: Is there a threshold below which exposure is safe?

Epidemiological studies increasingly indicate that there is really no “scientifically defensible” threshold for criteria pollutants that is safe for all people. Instead, a series of thresholds for different sensitive populations exist. As stated by a former EPA administrator “in a heterogeneous population it is unlikely that, for any pollutant, there will be a single scientifically defensible threshold applicable to all people. Instead, there will be a series of thresholds for different sensitive populations and a threshold of zero for some people.”

Source: Reilly, W.K. (1981).

developing countries. A Bangkok study (USAID 1990) adjusts for this by assuming an average body weight of 54 kilograms.

- *Distribution of causes of death are the same as the industrialized countries.* A 1997 study (Cropper et al, 1997) found that less than 20 percent of all deaths in Delhi, India are attributable to cardiovascular and respiratory disease, as compared to 50 percent in the United States. This lead them to conclude that even if people in Delhi reacted (physiologically) in the same way as those in the United States, the impact on total mortality, of a reduction in particulate matter, will be lower in Delhi than in the United States.
- *Levels and duration of exposure.* People in developing countries generally spend a lot more time outdoors either working, traveling in vehicles and living in homes that are not air conditioned. As a result, they are exposed to higher concentrations over a longer period of time. The problem is exacerbated by the fact that the ambient concentration levels are much higher than in industrialized countries. Both these factors could combine and cause an underestimation of benefits if dose-response estimates are transferred.

Another limitation of using dose-response functions in any country is that they do not account for complex physiological reactions from exposure to several pollutants simultaneously. That is, respiratory illness may be an outcome of simultaneous exposure to particulate matter, SO₂ and several other pollutants in ambient air. Current dose-response functions do not capture such complex causal relationships.

In spite of the caveats outlined above, dose-response functions are highly useful in estimating the health impact of pollution in developing countries. Dose-response functions being estimated for developing countries, such as in Chile and India, have been shown to correspond well with those from industrialized countries.

MONETARY VALUATION OF HEALTH IMPACTS

Assessing the damage that pollution causes to human health is both important and controversial. Although it is clear that pollution-related illness results in financial and non-financial welfare losses, valuing this loss in monetary terms is uncertain and difficult. Estimating the monetary value of the risk of excess mortality is often the most difficult part of health damage assessment. The lack of dose-response functions or willingness-to-pay (WTP) data for developing countries makes the task even harder. Yet, such estimates are essential in order to calculate the costs and benefits of various air pollution abatement strategies.

Economic theory of valuing health effects

The respiratory disease and other health impacts of air pollution can be divided into: (1) sickness or morbidity, some cases of which may involve hospitalization, and (2) premature deaths, or mortality. Once these physical health impacts are estimated, then the next step involves imputing monetary values to those health impacts. This step gives us the economic benefits of reducing air pollution. From an economist's perspective, the correct measure of the value of a reduction in a

health risk is given by the individual's willingness to pay. A measure of WTP captures the value an individual assigns to measurable health effects, as well as less tangible effects such as physical and mental discomfort. But there are few studies that estimate WTP from data in developing countries.

In the absence of adequate WTP studies in developing countries, more direct measures are needed to value morbidity and mortality. The two approaches that are most commonly used in valuing health benefits for developing countries are: (1) the cost of illness approach for morbidity, and (2) the human capital approach for mortality. Both of these, as well as the WTP approaches to valuing morbidity and mortality, are discussed below.

Economic valuation of morbidity effects

The cost of illness approach. Morbidity is commonly valued by the cost of illness approach that incorporates direct costs of medical treatment as well as lost income due to the illness. To use a simple example, an individual who earns US\$50 a day suffers a respiratory infection that causes him to stay off work for 4 days. Suppose the costs of medicines and consultation with a doctor is US\$20. The cost of this incidence of illness can be valued at $[\text{US\$}50 \times 4] + \text{US\$}20 = \text{US\$}220$. Two points to note are that it is not relevant if the costs were borne by the individual or by the government (the expense is seen as a cost to society), and the above figure is an underestimate because it does not assign any monetary value to pain and suffering.

Studies in the United States have also found that the cost-of-illness figures provide a lower bound on morbidity, when they are compared with WTP studies (Berger 1987). It is not unreasonable to assume that this may also be true for developing countries. However, there is anecdotal evidence that people in developing countries visit doctors less than in industrialized countries, and hence estimated treatment costs should be adjusted accordingly. Also, self medication and use of indigenous medicines, both prevalent practices in developing countries, are harder to translate into direct costs.

Although the cost of illness approach only provides lower bound values, it has several advantages. The data required for this approach can be obtained with moderate ease in most countries (Box 4.2). The estimates can also be easily communicated because they are based on

Box 4.2: Valuation of morbidity costs

Shin et al. have used information from a USAID study of Bangkok and Ostro dose-response equations to place an economic value on morbidity costs of exposure to particulate matter. Estimated work loss days (WLD) and restricted activity days (RAD) are based on the relationships between exposure to particulates, and numbers of WLD and RAD respectively. Looking at figures for 1989, the estimated WLD were 26.46 million; the RAD for the same year, after accounting for WLD, were 24.78 million. Multiplying WLD by the average daily wage rate of US\$10 ($\text{US\$}1.25 \times 8$ hours) gives an economic value of US\$264.6 million (1989 USD). For RAD, Shin et al. assumed an average wage loss of 50 percent which gave an economic value for RAD at US\$123.9 (1989 USD). Thus, total morbidity cost for Bangkok was estimated at US\$390 million in 1989.

Sources: Shin (1997), Ostro (1983), and USAID (1990).

costs that people easily understand.

Primary data on incidence and duration of illness can be obtained from health centers, hospitals, and departments of health—or else estimated from dose-response functions. Similarly, the costs of treatment can be obtained from local public and private health systems, or estimated based on the observed costs in other countries. For example, treatment costs in the U.S. are given in the left column of Table 4.2. These costs have been used in other studies by adjusting the U.S. health costs downward by a factor equal to the ratio of average daily wages. Another basis for adjusting U.S. health costs is the ratio of at least one easily measurable health cost, such as the cost of a doctor consultation. These two conversion factors are shown in Table 4.2 as a basis for estimating high and low estimates of health treatment costs in India. This table gives, in the right columns, unit cost estimates for several symptoms, which can be the basis for benefit-cost calculations.

Willingness-to-pay approach. A more theoretically sound measure of health damage is an estimate of the individual's willingness to pay to avoid the illness. There are two ways in which WTP can be estimated. It can be inferred from an individual's averting behavior, or from an explicit expression of what the individual is willing to pay to avoid the illness (contingent valuation).

- *Averting behavior approach:* This approach is based on the notion that the time and money an individual spends to avoid exposure to air pollution or to avoid illness is indicative of a lower bound value she attaches to avoiding illness. The common techniques people adopt to avoid exposure to air pollution include staying indoors or in air conditioned environments, using face masks as in Delhi and Metro-Manila, and moving to suburban or "cleaner" areas of residence. There are however certain limitations in this approach. The costs of face masks are usually very low, and the discomfort people experience from wearing the masks are not reflected in the price of masks. It is also difficult to estimate productivity losses, if any, incurred by people choosing to stay indoors or by moving out to the suburbs and spending more time commuting. Therefore, even assuming perfect data availability, we would only get very conservative estimates with this approach. However, data availability is an issue which makes estimating various types of averting behavior very difficult. Even though country-specific costs of masks, air conditioners, and moving can be identified, it is much harder to ascribe an economy-wide level of those costs that are attributable to air pollution.
- *Contingent valuation approach:* Contingent valuation involves individual survey questionnaires designed to elicit individual valuations of goods and services that are not traded in markets. The contingent valuation approach can capture many impacts of air pollution not measurable with market prices. In the United States, contingent valuation has been used to value serious respiratory diseases (bronchitis, chronic obstructive pulmonary diseases), as well as more minor ones (coughing, irritated eyes, headache). In this approach, individuals are asked how much they would be willing to pay to avoid a certain symptom or illness.

Table 4.2: Calculating health treatment costs and VSLs in India

Measure	US Data	Conversion Factor		India Data		Unit	Approach
		lower estimate based on ration of per capita incomes	higher estimate based on ratio of doctor fees	lower	higher		
Average Wage per year per day				481.97 1.93	481.97 1.93	US\$ per year US# per day	annual wage from CSO 1992 daily wage=annual wage/250 working days
Value of a Statistical Life Human Capital Approach				4,208.24		US\$ per death	Net present value = wage 1992 discounted by interest rate r= 0.05 over 10 year assumed additional lifespan
Compensating Wage Approach	3,000,000.00	0.0133			40,017.21	US\$ per death	Value of life derived from cnsensus accepted by the USEPA and used in legal settlements, scaled down by ration of India/US GDP
Respiratory Hospital Admissions	6,306.00	0.0133	0.0333	84.12	210.20	US\$ per case	hospital cost
Emergency Room Visits	178.00	0.0133	0.0333	2.37	5.93	US\$ per case	emergency treatment costs
Sum				86.49	216.13	US\$ per case	
Restricted Activity Days				1.93	1.93	US\$ per day	daily wage
Minor Restricted Activity Days				0.96	0.96	US\$ per day	daily wage adjusted by half
Respiratory Symptoms	5.35	0.0133	0.0333	0.07	0.18	US\$ per day	treatment cost
Lower respiratory illness in children (<17 yrs)	5.32	0.0133	0.0333	0.07	0.18	US\$ per case	treatment cost
Asthma attacks	29.84	0.0133	0.0333	0.40	0.99	US\$ per case	treatment cost
Asthma Exacerbation	29.84	0.0133	0.0333	0.40	0.99	US\$ per case	treatment cost
Chronic Bronchitis	132.00	0.0133	0.0333	1.76	4.40	US\$ per case	treatment cost
Chest Discomfort	5.97	0.0133	0.0333	0.08	0.20	US\$ per case	treatment cost
Eye Irritation	5.97	0.0133	0.0333	0.08	0.20	US\$ per case	treatment cost
Non-fatal Heart Attacks	28,334.00	0.0133	0.0333	377.95	944.47	US\$ per case	treatment cost
Hypertension	442.00	0.0133	0.0333	5.90	14.73	US\$ per case	treatment cost
IQ Loss	1,147.00	0.0133	0.0333	15.30	38.23	US\$ per point	treatment cost
Other Non-Quantified Health Effects	5.97	0.0133	0.0333	0.08	0.20	US\$ per case	treatment cost

Exchange rate: US\$1=Rs. 30; Lower estimate—per capita GNP_{India}/per capita GNP_{USA} in 1992 US\$ equals 310/23,240=0.0133 (World Development Report 1994)

India-US Medical Service Cost Ratio: Upper bound -Ratio of Doctor's visit in India to doctor's visit USA, in US\$

Inflation of India Rupee from 1988/89 to 1991/92: 34.5% (from TATA Service Ltd (1992), Statistical Outline of India, Dept. of Economics and Statistics)

Average indian Annual Wage in 1992 US\$: Wage₁₉₈₈ (=Rs.10,752) adjusted for inflation and exchange rate (Wage₁₉₉₂=US\$481.97) from Central Statistical Org. (1992) Statistical pocket Book: India, 1992; Average India Daily Wage in 1992 US\$: Wage₁₉₉₂/250 working days = US\$1.93

Net Present VSL: Wage₁₉₉₂ discounted by interest rate @ = 0.05 for a period of 10 years

Source: Brandon and Hommann (1995).

Early WTP studies did not bring income constraints to the respondents' attention, as a result of which the WTP estimates obtained were very large. Recently, more carefully done studies take into account the size of income. A 1987 study (Dickie et al, 1987) found that respondents dramatically changed their original bids when confronted with budget implications. Respondents reduced their original bids of US\$355.10 for avoiding one day of coughing to US\$1.39. The same study reported that in the United States, the mean WTP to avoid one day of coughing was US\$1.39 (1984 USD) and US\$4.35 (1984 USD) for avoiding one day of headache. On an average, this study also found that WTP estimates to avoid one day of symptoms related to respiratory illnesses exceeded the corresponding averting behavior estimates by 5 to 10 times.

In order to obtain information about a respondent's recent illness episode and associated costs, the following contingent valuation survey question was asked in Taiwan:

Suppose you were told that, within the next few days, you would experience a recurrence of the illness episode you have just described for us. What would it be worth to you—i.e. how much would you be willing to pay—to avoid the illness episode entirely?

Remember that you are paying to eliminate all your pain and suffering, your medical expenditure, the time you spent visiting the doctor or clinic, your missed work, leisure or daily activities. Bear in mind, if you pay to completely avoid being ill this time, you have to give up some other use of this money. For example, you may reduce your expenditures for entertainment or education.

(Alberini et al, 1995)

Administering surveys of this nature tends to be expensive for large samples, and this is not widely done. The Taiwan study cited above did show, however, that for some countries, it is valid to use the "benefits transfer" approach by which costs estimated for one country, such as the United States, can be adjusted and applied to another country, such as Taiwan. By using a conversion factor of the ratio of average household income in Taiwan to average household income in the United States, the Taiwan values fell within the 95 percent confidence interval estimated by WTP survey. However, benefits transfer should be used with caution because the conversion factor adjustment may not be appropriate for all developing countries.

Economic valuation of mortality effects

The value of premature death caused by air pollution is based on establishing the value of a statistical life (VSL). Two broad alternative approaches are used to estimate VSL: the human capital approach (which values an individual's life according to the net present value of his/her productivity) and the WTP approach (which measures the value society places on individual distinct from an individual's wage-earning capacity). The first of these approaches tends to give lower values than the second.

Human capital approach. This approach is based on the economic productivity of an individual, and uses the individual's discounted lifetime income as a measure of lost production due to premature mortality. The assumption underlying this approach is that the value of an individual is

based on what he produces which, in turn, is reflected in his earnings. It is similar to the cost of illness approach that was discussed earlier as a method to value morbidity. In the absence of WTP estimates in many countries, this approach provides an amenable methodology for obtaining country specific data and in valuing loss in productivity.

Calculating the number of life years lost is a crucial part of valuing premature mortality. A World Bank study in Santiago, Chile, estimated an average loss of 12.9 discounted productive years, assuming that the distribution of deaths due to air pollution was identical to the distribution of deaths from pneumonia, and that people who died prematurely from air pollution would have lived as long as others in their age group (see Sanchez, 1994 for details of the calculations). Another study in India based its calculations on the assumption that people who died prematurely due to air pollution would have normally (in the absence of air pollution) lived 10 years longer (see Cropper et al, 1997).

The life years lost are multiplied by the average wage rate in the country to get the value of a premature death. Based on an average annual wage rate of US\$3,482, the Chile study estimates the value of a premature death from air pollution at US\$45,000. It is important to note that many studies do not include costs of illness when calculating value of premature mortality from exposure to air pollutants. In reality, however, people who die from respiratory diseases often suffer periods of prolonged illness. Including the costs of illness would give analysts a more accurate estimation of costs of death from air pollution.

Willingness-to-pay approach. The principle underlying WTP is the belief that in market economies, the social cost of a change in economic outcomes is measured by the sum of individuals' WTP for that change. Unlike human capital approaches that measure tangible changes in productivity, WTP measures capture many intangible aspects (e.g. pain, suffering, discomfort). An appropriate valuation of a marginal reduction in risk of dying from air pollution-related respiratory disease is the amount people are willing to pay to marginally reduce that risk. There are two basic methods used to measure WTP for reducing mortality risks.

- *Compensating wage differential:* In the compensating wage differential approach, the basic assumption is that other things being equal, workers in riskier jobs must be compensated with higher wages than workers in safer jobs. The differential in wages reflects what the individual is willing to give up if he moves to a safer job, therefore it is a measure of the value placed on increased safety. This information can be used to estimate VSL. A wage premium of US\$100 may be required to attract individuals to undertake a job with a 1-in-10,000 chance of increased mortality. This is an implicit value for a statistical life of US\$1 million. Compensating wage studies in the United States show VSL estimates ranging from US\$1.9 to US\$10.9 million (1990 USD). Box 4.3 presents an example of the use of the wage differential approach.
- *Contingent Valuation:* As described in the previous section on valuation of morbidity, the second approach to ascertain WTP consists of asking people directly what they would be willing to pay for reduced risk of increased mortality. Contingent valuation studies in the United States have estimated VSL ranging between US\$1.2 and US\$9.7 million (1990 US\$).

Although it would be preferable to use wage differential estimates from country specific studies, these are not available for most developing countries. The common approach in most studies has been to use estimates from industrialized countries. As cautioned by Cropper (1997),

Box 4.3: Wage differential approach for Bangkok

A 1993 World Bank study in Thailand discusses the possibility of obtaining back-of-the-envelope estimates of wage differentials for Bangkok. For the 149,000 construction workers in the city in 1992-93, it is estimated that the wage premium is 15 to 20 percent compared to wages in less risky industries. Since approximately 200 workers were assumed to die per year on the job, death risks were estimated to be 13.4 per 10,000. Assuming an average wage of US\$3,000 per year, construction workers would earn US\$450-600 premia, and the VSL could range between US\$336,000 to US\$448,000 per year.

Source: *Thailand: Mitigating Pollution and Congestion Impacts in a High-Growth Economy*, World Bank (1993).

most compensating wage differential studies measure compensation of mortality risks for individuals who are, on average, about 40 years of age. If we assume that an individual is productive until 65 years of age, we are valuing about 25 life-years lost. Deaths from exposure to air pollution typically occur at a later age than 40 and, therefore, imply fewer life-years lost. Adjustments must be made in applying these estimates to deaths related to air pollution exposure.

In the United States, VSL obtained from WTP studies are typically 5 to 10 times higher than those obtained by the human capital approach. One useful approach to valuing mortality in developing countries would be to use the human capital approach as a lower bound estimate. WTP estimates from the United States could be projected to developing country data for obtaining an upper bound estimate. Box 4.4 below gives us an example of valuing mortality in Delhi. Many less tangible health effects (e.g. physical and mental discomfort) are not quantified in the literature. Therefore, what we have are at best lower bound values of health effects. An important point that merits repetition is that all valuation attempts only capture partial benefits. Efforts to value health effects of air pollution do not capture lifestyle changes or physical and mental discomfort that are subclinical in nature, or some of the more chronic intangible effects. For instance, children may not be allowed to go out and play because of poor air quality, affecting their quality of life, physical activity and implications for long-term well being; and poor air quality may cause eye irritations that affect ability to read. These types of impacts are not quantified by the techniques introduced above.

OTHER DAMAGE ASSESSMENT

There are potential adverse effects of air pollutants on buildings, on crops and vegetation, and on a city's aesthetic values (affecting its potential for tourism). Direct costs for cleaning soiled buildings can be assessed in a fairly straight-forward manner. Similarly, the costs of repairing and maintaining damaged buildings can also be assessed and valued. However, damage to buildings of historic and cultural significance are more difficult to value. The costs in this case not only include financial costs, but also probable irreversible losses to the cultural heritage of the city, which are difficult to quantify and value. Apart from the loss of intrinsic value inherent in unique cultural monuments/property, there may be adverse impacts on tourism. WTP/contingent valuation studies conducted on a case-by-case basis can provide a rough estimate of damage to

Box 4.4: Valuing life: The case of Delhi

Cropper et al in their study have used the human capital approach in order to get a rough approximation of the value of life-years saved by reducing particulates in Delhi to meet the WHO AQG levels. Foregone earnings are used for a lower-bound estimate and projections of the value of life from U.S. studies for an upper bound estimate.

First, the number of life-years lost due to air pollution need to be estimated. The study estimates that approximately 2,712 deaths would be avoided if TSP were reduced to meet the WHO AQG. If the age distribution of these deaths is approximately the same as for total mortality, the air quality improvement would result in 727 fewer deaths over the age of 65 (26.8 percent), 1,348 fewer deaths among those between ages 15 and 64 (49.7 percent) and 637 fewer deaths under the age of 14 (23.5 percent). Using estimates of life expectancy at each age for India, this implies a total of 79,516 life-years lost.

The average annual income in manufacturing in Delhi is approximately US\$500.58. Assuming an annual interest rate of 5 percent and that individuals are not productive in the workplace until age 14, the present value of life-years lost due to pollution exposure based on foregone earnings comes roughly to US\$14,893,422 (1991 USD), as a lower-bound estimate.

Another study (Rosen 1988) has shown that value of life estimates based on WTP are approximately five times the value obtained using foregone earnings. Applying this figure to our example, our upper bound estimate of the value of life years lost comes to US\$74,467,111. This is the value of the life-years that would have been saved if pollution levels in Delhi had been reduced to meet the WHO AQG levels.

Source: Cropper et al (1997); Rosen (1988).

cultural monuments. Table 4.3 presents some methodologies to evaluate non-health effects of air pollution.

Productivity losses to vegetation and crops can be assessed if we know the area of vegetation that could potentially be affected. If reliable dispersion models are not available, a rough approximation would need to be made about the area likely to be affected. Damage to commercial vegetation is relatively easy to value, based on estimated crop yield loss and the selling prices of the crop. Direct costs of chemicals and other measures used by farmers to prevent or reduce damage from air pollution can also be obtained. Damage to noncommercial

Table 4.3: Methodologies to evaluate non-health effects of air pollution

Effects other than health effects	Valuation methodology
• Soiling (households and firms)	Direct costs of laundering, repainting, cleaning.
• Physical damage to buildings, monuments	Direct costs of repair or replacement; contingent valuation.
• Amenity values — e.g. decreased visibility of mountains	Contingent valuation.
• Vegetation / agriculture	Productivity losses.
• Consequences for tourism	Contingent valuation.
• Reduction in economic activity by closing down plants or schools due to poor air quality, or banning motorized traffic, etc.	Productivity losses.

Source: Freeman (1979).

vegetation (e.g., forests that are rich in biodiversity) are much harder to value.

The MEIP Economic Valuation study of Bombay uses hedonic pricing techniques to value the effects of air quality on property value (Box 4.5). The basic assumption behind this approach is the notion that air quality is part of a bundle of attributes that a consumer buys when it purchases (or rents) a residence, and other factors held constant, price (or rent) differentials reflect the differences in air quality among spatial locations.

Box 4.5: Economic valuation of impact on property values— hedonic pricing approach

The MEIP study regressed price of rentals in Bombay on variables related to:

- location (distance from central business district),
- characteristics of residential units (type, number of rooms, age of house), and
- ambient air quality measures.

Finding: Market rents declined with increases in suspended particulate matter.

Assumptions under a hedonic price approach:

- free market in equilibrium,
- complete information, and
- large number of buyers and sellers.

Caveats: There are at least two caveats that warrant attention. First, the rent control act in Bombay implies that rental values are under market rates, and therefore the estimates are gross underestimates. Second, it is difficult to separate health implications from aesthetic and property values.

Source: K. S. Parikh et al (1995).

5. TECHNICAL MEASURES

It is important to analyze the costs and benefits of technical and policy measures that combat air pollution. Three steps precede such analysis:

1. identifying possible technical measures to reduce emissions,
2. assessing the costs of each identified measure, and
3. assessing the benefits of each identified measure.

This chapter covers the first and second of these steps; Chapter 6 deals with the third step. In order to list technical options information must be available on the types and sources of pollutants. Further, a database of possible technical measures and their characteristics is also critical. This chapter may be seen as a database of measures. It aims to provide a brief but useful overview of appropriate measures. Because some of the data on costs of measures are tentative, they should be used with care. Guidelines on the use of such data are also provided.

DATA STRUCTURE AND GUIDELINES FOR USE

The choice of technical measures depends upon type of pollutant addressed, source and the measure's cost-effectiveness (tons of emissions abated per unit of costs). The following categories of information are used for describing an abatement measure.

Specific emissions addressed. Abatement measures are chosen based on the type of emission. Under this heading, a brief statement of the impact of a particular emission and its spatial characteristics—for example, if the impact is felt at the roadside (from traffic), ambient (metropolitan level) and regional (long-distance dispersion)—should be included. As this study is restricted to impacts within cities, emission of CO₂ and chlorofluorocarbons (CFCs), which have global impacts, are not included.

Measure provides the name, or a very brief description of the chosen measure. Definitions are technical, and there is no reference to policy instruments that may promote implementation.

Effectiveness indicates the extent of reduction in the emission.

Viability comments on constraints and requirements for the introduction of the measure, or on its non-environmental benefits. Such constraints and requirements may be set by circumstances outside the scope of environmental planning. An example of an outside constraint is an energy

policy that is not integrated with the environmental policy. An example of a non-environmental benefit is an increase in traffic safety resulting from the environmental inspection of vehicles.

Costs provides an indication of the related expenditures. If relevant, savings are also mentioned.

Comment/reference presents additional comments and provides sources for the information.

How to use the database. The database has three sections: measures addressing mobile sources, stationary combustion sources, and a miscellaneous category that includes measures to reduce/end process emissions. Each section contains a brief description of pollutants and sources, anticipating the emissions inventory to be set up in the specific cities. Thus, given the source and pollutant, possible measures can be identified. In case of process emissions, only general costs have been identified. A list of appropriate measures, including an assessment of costs involved, requires a detailed knowledge of process emissions sources at the plant level.

MEASURES TO REDUCE EMISSIONS FROM TRAFFIC SOURCES

Air pollution due to mobile sources

Pollutants. The main air pollutants emitted by cars, motorcycles, trucks, and buses are CO, NO_x, VOC, particulates, lead, and SO₂. In addition, PAH (polycyclic aromatic hydrocarbons), either volatile (a component of VOCs) or as a component of suspended particles are also emitted. According to their visual appearance, specific suspended particles and VOC are referred to as black smoke and white smoke.

Diesel engines in buses and trucks emit black smoke (suspended particles containing PAH). White smoke consists of atomized lubricating oil from mixed-lubrication motors used in motorcycles and three-wheel vehicles. Both black and white smoke emissions are caused by poor maintenance and off-specification motor adjustment, transient loading of motors in congested traffic and poor fuel quality (low volatility, low cetane number).

Scientific data such as dose-response relationships on environmental damages caused by black and white smoke do not exist. Such information may be derived from data on the effects of suspended particles.

Lead originates from TEL (tetra ethyl lead) found in leaded gasoline. It accumulates in roadside dust which, when swirled (secondary emission), exceeds standards for maximal allowable lead contents.

CO emissions from idling automotive engines are very large in congested traffic. In addition, they increase sharply due to the maladjustment of engines. Although CO is rapidly dispersed in comparison with other pollutants mentioned above, emissions may be large enough to exceed standards for concentration at the roadside level.

SO_2 originates from sulfur in diesel oil used for automotive purposes and from fuel oils used in industries.

NO_x is a collective term used to refer to two species of oxides of nitrogen: nitric oxide (NO) and nitrogen dioxide (NO_2). NO_x , like SO_2 , contributes to soil acidification.

VOC is a collective term for various organic compounds. Benzene, a carcinogenic compound, and one of the constituents of VOC, is released through gasoline use. In urban areas, vehicles are a major source of both NO_x and VOC pollution. NO_x and VOC may react photochemically with each other, producing ozone, and causing a major environmental problem. Under sunny and stagnant weather conditions NO_x and VOC cause photochemical smog.

Measures to reduce/cease emissions. Measures appropriate for emission abatement are listed in Tables 5.1, 5.2, and 5.3. These measures are not mutually exclusive. For example, the introduction of catalytic devices for control of automotive exhausts requires a switch to unleaded fuels. The following systemic problems are not included in these tables:

- traffic management systems,
- introduction of urban rail transportation systems,
- road construction, and
- physical planning and land-use planning.

Traffic management

Traffic management refers primarily to measures that address traffic congestion. These range from installing traffic signals, introducing one-way roads and improving parking facilities, to coordinating different transportation modes, such as introducing separate bus lanes. Successful traffic management reduces congestion and thus emissions by diminishing idling of vehicles, accelerating and decelerating and fuel consumption.

Conversely, the removal of bottlenecks also leads to increased traffic flow, greater kilometers traveled and, hence, increased emissions. In order to prevent such an outcome, a restricted-access policy might be implemented: curbing parking in specific zones, road-pricing systems or levying toll at the entry of specific zones (Birk, 1992). A few cities, including Athens and Mexico City, are attempting to control episodic pollution during stagnant weather by restricting the use of vehicles on those days. For example, only vehicles with odd license numbers are allowed on the road on certain days, alternating with those with even license numbers.

Table 5.1 Emission reducing devices

Measure	
Application of three-way catalytic converters	
Specific emission addressed:	Tail-pipe emissions (CO, VOC, NO _x and lead) of ignition-motor powered vehicles (gasoline/four stroke).
Effectiveness:	Catalytic converters can lead to a 90% reduction in tail-pipe emissions of CO, NO _x and VOC. They must be used in conjunction with unleaded gasoline.
Viability:	Maintenance and inspection schemes, and the supply of unleaded gasoline (in case of standards enforcing the use of catalysts) are essential. Cars equipped with catalysts are sold on the world market. Problems arise when indigenous car manufacturers are not able to produce cars that satisfy standards.
Costs:	Extra purchasing costs of a car equipped with a three-way catalyst, and a fuel control system is up to US\$400 per car (pre tax). These devices are common in many parts of the world where cars powered by four-stroke engines are used.
Comment::	Application of three-way catalysts requires electronic motor management and well-adjusted motor controls. Improved fuel efficiency is an important benefit. Reference: Allemand, 1990.
Application of oxidative catalytic converters (oxidation catalysts)	
Specific emission addressed:	Tail-pipe emissions of CO, VOCs and lead from ignition-motor powered vehicles, including auto-rickshaws and motorcycles powered by mixed-lubrication motors. Emissions of NO _x are not addressed.
Effectiveness:	Catalytic converters can lead to a 90% reduction in tail-pipe emissions of CO, NO _x and VOC. Converters must be used in conjunction with unleaded gasoline.
Viability:	Maintenance and inspection schemes, and supply of unleaded gasoline (in case of standards enforcing the use of catalysts) are essential. Cars equipped with catalysts are sold on the world market. As compared with three-way catalytic converters, oxidative catalytic converters impose fewer restraints on vehicle manufacturing. Engines require fewer modifications.
Costs:	Extra purchasing cost of vehicles equipped with these open-loop control systems (oxidation catalysts) is US\$200 per car or motorcycle.
Comment::	There have been temporary mandates for such a device (Europe 1985-1992) in case of medium and small vehicles. In many parts of the world, three-way catalysts are currently required for all categories of four-stroke, gasoline-powered, cars. The use of catalytic (oxidation) devices to reduce emissions from motorcycles and mopeds powered by mixed-lubrication engines is limited to a few countries, such as Switzerland and Austria. Reference: Allemand, 1990.
Carbon canister (carbon filter)	
Specific emission addressed:	VOC emissions due to diurnal evaporation of gasoline in tank and fuel system.
Effectiveness:	80% of evaporation emissions.
Viability:	Cost is the main limiting factor.
Costs:	Each canister adds US\$100 to the cost. Some of this cost is compensated by savings from reduced fuel loss.
Comment::	These devices are used in areas where stringent levels for ambient ozone are in effect (California, Australia). They are being considered in Europe. Reference: CONCAWE, 1987; Allemand, 1990.

Table 5.2: Improving fuel quality

Measure	
Reduction of sulfur content of diesel fuel	
Specific emissions addressed:	SO ₂ emissions from road traffic (diesel powered vehicles).
Effectiveness:	Proportional to the decrease of sulfur content.
Viability:	If diesel oil is from indigenous sources, the refineries probably have to build capacity for hydro-desulphurization of oil products. This may require monitoring the sulfur content of marketed diesel fuel.
Costs:	Depend on local fuel-market conditions (among them the type of crude oil processed in local refineries and refinery lay-out), and on initial and required sulfur content. Some of the additional cost is compensated by benefits from longer lasting exhaust systems.
Comment:	Current sulfur content of European diesel oil is 0.2 wt percent. There are plans to decrease this maximal allowable content to 0.05 percent.
Banning lead in gasoline	
Specific emission addressed:	Lead from gasoline powered vehicles (lead in roadside dust).
Effectiveness:	100 percent reduction.
Viability:	Requires replacement of TEL by alternative octane boosters (oxygenates).
Costs:	Depend on local fuel-market conditions.
Comment:	Unleaded gasoline is required if the use of catalytic emission-control devices is mandated.
Using better quality, e.g. more volatile, diesel fuel	
Specific emission addressed:	Black smoke from heavy diesel powered vehicles, such as buses, in congested traffic.
Effectiveness:	No data available. Depends on a range of other variables, such as tuning and maintenance of motors.
Viability:	Requires the monitoring of marketed diesel.
Costs:	Depend on local fuel-market conditions.
Comment:	Considered for Bangkok. Reference: Tharby, 1992; Hutchison and van Paassen, 1990.
Introducing buses that use CNG (compressed natural gas) as a fuel	
Specific emission addressed:	Black smoke from buses in congested traffic and routine emissions of TSP, NO _x , SO ₂ , CO.
Effectiveness:	No data available.
Viability:	Requires a separate system for CNG supply, new bus fleets, and increased inspection and maintenance of buses.
Costs:	Relate to technical alteration of engines and fuel systems, increased inspection and maintenance, and an infrastructure for the supply of CNG. These costs may be partly offset by low CNG costs.
Comment:	The use of CNG in diesel powered vehicles is not a proven technique. The proven alternative is to use high quality diesel fuel.
Introduction of LPG as fuel	
Specific emission addressed:	Lead, smoke, NO _x , SO ₂ , CO and VOC.
Effectiveness:	LPG does not contain lead and sulfur (order of magnitude of emissions reduction is 25 percent).
Viability:	Use of LPG in cars equipped with spark-plug ignited engines is common in several countries. Assuring the safety of such cars, specifically of the LPG fuel tank, and the logistic system, remains a problem.
Costs:	Depend on local fuel-market conditions.
Comment:	Forbidden in Indonesia for safety reasons. Used in Bangkok by half the fleet of three-wheeled tuk-tuks. Reference: Birk, 1992.

Table 5.2: Improving fuel quality

Measure	
The use of "low-smoke" lubricating oil	
Specific emission addressed:	White smoke from two-stroke engines (two- and three wheel vehicles).
Effectiveness:	Although it is known to be effective, no data are available.
Viability:	Control of sales of lubricating oils at retails.
Costs:	The price of such oil (marketed in Western Europe) is double the price of lubricating oil currently used in Southeast Asia.
Comment:	Private communication with Shell Oil Co.
Mandating the use of "smokeless" lubricating oil (polyisobutene)	
Specific emission addressed:	White smoke from two-stroke engines (two- and three wheel vehicles).
Effectiveness:	100 percent reduction.
Viability:	Control of sales of lubricating oils at retailers.
Costs:	Higher than low-smoke oils.
Comment:	Mainly Japanese development.

Table 5.3: Improving tuning/motor adjustments

Specific emission addressed: Black smoke, white smoke, NO_x, VOC, CO	
Measure:	Increasing inspection and maintenance of all vehicles.
Effectiveness:	May be up to 50 percent, depending on statistical distribution of maladjustments. If combined with a scheme for safety inspection (road-worthiness), traffic safety benefits are substantial.
Viability:	Requires either legislative or economic incentives, and training of garage car workshop personnel.
Costs:	Depending on local wages and availability of workforce.
Comment:	Various studies highlight the contributions of only small numbers of vehicles - old, worn out, off-adjusted - to emissions, both in cities without cars equipped with sophisticated exhaust-control devices and in other areas such as California Reference: McGregor & Weaver, 1992; Fujita et al, 1992).

Transport infrastructure

Mass transport systems such as underground rail transport, light rail transport systems (streetcars), and electric buses (trolley buses) have considerable environmental benefits. However, considering the time needed for preparation and construction, environmental benefits may only become visible over a long period of time. The investment costs of introducing such mass transportation are orders of magnitude larger than introduction of technical devices for pollution control (Birk, 1992), but the environmental benefits, such as increased urban efficiency and improved real estate values, are larger as well.

Investment in infrastructure also addresses the demand for transport. Traffic Demand Management (TDM) operates from the viewpoint of managing the demands for various modes of transport in an integrated way. Hong Kong and Singapore are areas where TDM is applied successfully, as described in Box 5.1.

Box 5.1: Singapore and Hong Kong: air quality benefits of transport demand management

Singapore: Fourteen years of direct road pricing through Area Licensing Schemes have significantly reduced congestion and helped to control the growth in vehicle use in central Singapore. Because the initial charge was determined without benefit of prior survey research, the results were unexpected, with an initial reduction in morning peak traffic considerably greater, at 70 percent, than intended. The reduction in traffic has settled down to about 44 percent, with an increase of 22 percent in traffic speeds.

Hong Kong: All three transport demand management schemes that were tested achieved substantial changes in road use, with a reduction in peak-time car traffic of between 20 percent and 24 percent. Survey evidence showed that a significant proportion of drivers would change the time of their journey. Off-peak car travel would increase by between 17 percent and 24 percent, with only a 3 percent increase in the demand for public transport. About 40 percent of car trips were unaffected by road pricing (because they took place outside either the area or the time subjected to charges); it was estimated that around 40 percent of drivers would “stay and pay;” 9 percent changed their mode of travel-switching to walking, cycling or public transport; and 5 percent changed their time of travel.

All three schemes produced a reduction in fuel consumption of between 6 percent and 9 percent, reductions in CO emissions of between 14 percent and 17 percent, in lead and NO_x of around 6 percent and hydrocarbons of around 3 percent.

Source: Butterwick et al (1992), pp. 182-183.

MEASURES TO REDUCE EMISSIONS FROM STATIONARY COMBUSTION SOURCES

Air pollution due to stationary combustion. The chemical composition of a fuel determines the type of pollutant that will be released when the fuel is combusted. An exception is NO_x which is formed from oxygen and nitrogen, both compounds in the air. The rate of NO_x production is affected most by the construction and operation of boilers, furnaces and other combustion equipment. A main parameter is the combustion temperature; higher flame temperatures lead to greater rates of NO_x production.

SO₂ is formed by a combustion of sulfur, a minor constituent of fuel. The amount of SO₂ emitted is directly related to the sulfur content of the fuel.

TSP (including PM₁₀) pollution originates from the non-combustible matter in fuel (coal, fuel oil) or, in the case of malfunctioning combustion equipment, from soot production. TSP is a carrier of heavy metals, and PAH.

PAHs are present in fuels and also arise from incomplete combustion of heavy hydrocarbons (constituent of heavy fuel oils and coal).

VOC and CO also result from incomplete combustion. As compared with traffic sources, stationary combustion is a minor source of CO and VOC. Cooking on unvented or other stoves, without adequate ventilation, results in indoor air pollution, and is a substantial threat to health. CO and carcinogenic soot are the main pollutants.

Controlling NO_x and SO₂. Measures for reducing NO_x are listed in Table 5.4 and for controlling SO₂ in Table 5.5. Control measures are grouped according to the type of pollutant they address. Such measures can be divided into four categories:

- removal of pollutants from flue gases (end-of-pipe techniques),
- improving fuel quality (sulfur content) and eventually switching to the use of less polluting fuels (natural gas),
- adjustment of combustion conditions, and
- energy conservation measures.⁵

Table 5.4: Measures to control NO_x

Measure	
Adjustment of burners (Low-NO_x firing techniques)	
Specific emission addressed:	NO _x .
Effectiveness:	20-50 percent reduction in NO _x .
Viability:	Large combustion sources.
Costs:	Investments of 1000 - 6000 US\$/MWe, depending on specific technique.
Comment:	Reference: Kokkinos, A. et al, 1992.
DeNO_x SCR (Selective Catalytic Reduction) equipment (flue gas treatment)	
Specific emission addressed:	NO _x .
Effectiveness:	80-90 percent reduction in NO _x .
Viability:	Very large combustion sources.
Costs:	Dependent on application.
Comment:	Reference: Kokkinos, A. et al, 1992.
Switching to gaseous fuel	
Specific emission addressed:	NO _x from coal or oil combustion.
Effectiveness:	Up to 50 percent reduction in NO _x .
Viability:	Depends on availability of indigenous natural gas or import of LNG.
Costs:	Energy prices determine costs.
Comment:	CO ₂ emissions are also reduced.

⁵ These measures are usually taken primarily for economic reasons; emission reduction due to a decrease in fuel consumption is usually a premium, not an objective. The local energy policy - taxes and subsidies, indigenous energy sources - is a main factor explaining the extent of energy consumption or conservation.

Table 5.5: Measures to control SO₂

Measure	
Using lower sulfur fuels	
Specific emission addressed:	SO ₂ due to combustion of fuel oils.
Effectiveness:	Reduction in SO ₂ emission is proportional to the sulfur content of fuel.
Viability:	Monitoring imports and indigenous fuel oil producers may require the establishment of an inspection system. If fuel oils are supplied by local refineries, construction of (residual) hydro-desulphurization (RDAs) capacity may be needed. In case of large combustion plants, flue gas desulfurization (see below) is an attractive alternative to using low sulfur oils.
Costs:	World market sulfur premium is an indicator. In Western Europe the cost of reducing sulfur levels from 3.3 percent (wt) to 1.5 percent (wt) is US\$50-70 per ton fuel oil .
Comment:	Current practice in many countries.
Switching from coal or fuel oil to natural gas	
Specific emission addressed:	SO ₂ , NO _x , Fly-ash.
Effectiveness:	A 100 percent reduction in SO ₂ , if natural gas contains no sulfur. 50 percent reduction in NO _x .
Viability:	Requires construction of transport infrastructure.
Costs:	Depending on investments in infrastructure and gas purchase.
Comment:	Also results in reduction of CO ₂ , due to the low carbon content of natural gas in comparison with liquid or solid fuels.
Flue gas desulfurization	
Specific emission addressed:	SO ₂ .
Effectiveness:	90-98 percent
Viability:	Large (>100 MWth) combustion sources, primarily.
Costs:	Order of magnitude of investments US\$150/kWe (throwaway process for a power plant of 500 MWe capacity). Investment costs of regenerative processes (production of sulfur or sulfuric acid from SO ₂) is about double. Reference: Vataavuk, 1990.
Comment:	Flue gas desulfurization is a current practice in electricity production in Japan, US, and Europe. Various types of desulfurization plants are offered on the market The choice depends on the characteristics of the fuel and other local conditions. Fly-ash emissions are reduced when wet scrubbers are used. Reference: Vataavuk, 1990; see also Dalton et al, 1992.
Dry sorbent injection of lime: To capture SO ₂ , lime is introduced into the furnace where it reacts with SO ₂ and produces gypsum. this gypsum along with the extra lime, that has been converted to gypsum, and fly ash are removed from flue-gases simultaneously.	
Specific emission addressed:	SO ₂ .
Effectiveness:	A 50 percent reduction in SO ₂ .
Viability:	Small (<100 MWth) combustion sources, primarily
Costs:	US\$10-20/kW _e .
Comment:	Reference: Muzio & Offen, 1987.
Sorbent injection	
Specific emission addressed:	SO ₂ and NO _x from atmospheric fluidized bed combustion (AFBC).
Effectiveness:	Depends on specific operation (amounts of SO ₂ binding materials).
Viability:	Small industrial boilers (10-100 MWth). This technique is not yet commonly used.
Costs:	Similar as in the case of Dry Sorbent Injection.
Comment:	

Controlling Particulate Matter. The choice of technology depends upon the diameter of the particles. Without information about specific emission sources it is not possible to indicate which of the techniques listed in Table 5.6 would be appropriate, nor is it possible to indicate the costs. For a description of the techniques and procedures to estimate costs, see Vataavuk (1990). Two techniques commonly used in large combustion plants—coal-fired electricity production—are listed in Table 5.6. Measure for non-specific pollutants is shown in Table 5.7.

Table 5.6: Measures to control particulate emissions

Measure	
Electrostatic filters	
Specific emission addressed:	SPM diameter 10 - 0.1 micron (10^{-6} m). All type of industries including coal-power plants.
Effectiveness:	Up to 99.9% reduction. Residual concentrations of TSP in waste gases are less than 50 mg/m ³ .
Viability:	Commonly used in coal-fired electricity plants.
Costs:	Energy consumption: 0.3- kWh/1,000 m ³ . Investments (per 1,000 m ³ /h treated) order of magnitude larger than cyclones.
Comment:	Reference: Vatauvuk, 1990.
Fabric filters	
Specific emission addressed:	TSP up to diameter 0.01 micron (10^{-6} m).
Effectiveness:	Up to 99% reduction.
Viability:	Used for power plants and industries.
Costs:	Typical investments range from Dfl 25 to 5 (per cubic meter), with flow rates varying between 1,000 to 100,000 m ³ /hour (excluding ducting costs).
Comment:	Reference: Vatauvuk, 1990.

Table 5.7: Measures that are not pollutant specific

Measure	
Increasing stack height	
Specific emission addressed:	All flue-gas pollutants.
Effectiveness:	Only reduces ambient concentrations, not emissions.
Viability:	Low cost option for dispersion of pollution.
Costs:	Depend on various factors and local construction costs.
Comment:	Reference: Vatauvuk, 1990.

MEASURES TO REDUCE PROCESS EMISSIONS

Air pollution due to non-combustion processes. Process emissions constitute a residual category of emissions—non-combustion emissions from stationary sources. A number of pollutants fall into this category including NO_x, SO₂, VOC, CO, TSP. Pollution due to processes is often analyzed by economic, technological sectors. Table 5.8 gives an overview of selected processes and corresponding typical pollutants. The processes mentioned in the table also involve fuel combustion, however, related emissions are not indicated in the table.

Process emissions also include small industrial sources and emissions due to small craft shops. Examples are painting activities, dry cleaners and automobile repair shops. The extent to which small businesses contribute to ambient concentrations should be assessed in the emission inventories. The list in Table 5.9 does not account for emissions from small businesses and focuses solely on measures relevant in industrial cases.

Table 5.8: Examples of major sources of process emissions.

Sector	Process	Typical pollutants
Fertilizers	Sulfuric acid	SO ₂ , SO ₃
	Nitric acid	NO _x
Organic chemicals	Various processes i.e. storage & distribution	Various VOCs, among them aromatics, alkenes*
Primary metal	Iron and steel	TSP, CO
	Non ferrous	SO ₂ , Fluorine, TSP containing heavy metals
Refineries	Loading/storage/fugitive	VOC
Gasoline distribution	Loading and breathing of storage tanks	VOC
Cement production	Cement kiln	Dust, TSP
Ceramics (brick & tile)	Calcining	SO ₂ , NO _x , TSP
Textile industry	Mills	TSP
Waste combustion	Combustion	Various

*Non-point emissions (flanges, leaks and other).

Table 5.9: Measures addressing specific pollutants

Measure
Using triple-contact process in production of sulfuric acid (H₂SO₄)
Specific emission addressed: SO ₂ and SO ₃ .
Effectiveness: 95 percent reduction in SO ₂ and SO ₃
Viability: Expensive compared with other SO ₂ -control measures (see above).
Costs: US\$3,000 per ton abated (total annual costs). Reference double contact process.
Comment: Emission factor for triple-contact process 0,1 kg/ton H ₂ SO ₄ . Reference: Thomas R., 1988.
Introduction of selective catalytic reduction (SCR), or improved nitric acid production processes
Specific emission addressed: NO _x from nitric acid production.
Effectiveness: 80% reduction
Viability: Techniques are available.
Costs: Total annual costs of SCR are US\$4,000 per ton abated, from a 1980 type of plant in the Netherlands (see below).
Comment: Emission factor in the Netherlands in 1980, 7.3 kg/ton Nitric Acid produced. Current factor of new plants (without SCR)— 1.4 kg/ton.
Internal floating roofs in storage tanks (to reduce loading emissions)
Specific emission addressed: VOC emissions from storage & distribution of volatile organics (including gasoline).
Effectiveness: Up to 90% reduction in VOC emissions.
Viability: Techniques available.
Costs: Depend on economics of scale, and value of prevented loss of organic compounds.
Comment:
Program to control fugitive and other poorly defined VOC emissions in various industries processing organics (refineries, chemical industry, plastic processing)
Specific emission addressed: VOCs.
Effectiveness: Depending on program.
Viability: unknown
Costs: Variable, depending upon the situation.
Comment:

Measures addressing TSP. A range of technologies is available to tackle TSP emissions. Particle size is the main parameter for choosing a technology. Without any information about specific emission sources it is not possible to indicate which of the techniques listed in Table 5.10 would be appropriate, nor is it possible to provide approximate costs. For a description of the techniques and procedures to estimate costs see Vatavuk (1990). The first and second techniques listed below are commonly used in large combustion plants (coal-fired electricity production). The third, appropriate electrostatic and fabric filters for small particles, are used in many process industries (cement manufacturing, primary metals and other).

Table 5.10: Measures addressing TSP emissions

Measure	
Cyclones	
Specific emission addressed:	Emissions of particulate matter (and atomized liquids). Ranging from large particle size to 2 micrometer.
Effectiveness:	Up to 100 percent reduction (depending on particle size distribution).
Viability:	Are used in virtually all industries.
Costs:	Equipment relatively simple (no moving parts). Requires fan. Consumption of energy: 0.25 - 1.5 kWh/1000 m ³ . Indication of investments (without ducts and construction): US\$500-1000 per 1000 m ³ /h.
Comment:	Reference: Vatavuk, 1990.
Wet scrubbers. This a collective term for a wide variety of equipment.	
Specific emission addressed:	Particulate matter and gaseous emissions.
Effectiveness:	Up to 100 percent reduction.
Viability:	Depends on specific situation.
Costs:	Costs are variable and generally high.
Comment:	Reference: Vatavuk, 1990.
System of waste collection	
Specific emission addressed:	Particulate matter from local refuse combustion.
Effectiveness:	Depends on enforcement capabilities.
Viability:	Depends on specific situation.
Costs:	Even an estimation of order of magnitude requires more information about amounts of refuse and the spatial distribution of waste production.
Comment:	Uncontrolled burning of refuse is an important source of SPM. Reference: Mitchell, 1991.

6. ANALYSIS OF COSTS AND BENEFITS

Cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) are analytical methods to select a “best set” of policy measures (Mishan, 1988). A cost-benefit framework allows us to rank air pollution control measures in order of the net social benefits each measure confers. The calculation of net social benefits requires estimation of marginal benefits from each control measure, as well as the estimation of the marginal costs of introducing various control options. In order to conduct a comprehensive cost-benefit analysis, both the costs and benefits from each control option, whether technical or policy, need to be identified, quantified and valued in monetary terms (to the extent possible). The comparison of benefits and costs reveals whether or not a measure is worth undertaking. Cost-benefit comparison across measures helps to rank them in such a way that the measure with the largest net social benefit is selected.

The benefits of an environmental policy measure consist of reduced environmental damages. However, the calculation of total benefits of a policy measure requires the following four steps:

1. estimated reduction in emissions at source,
2. estimated reductions in ambient concentrations as a result of reductions in emissions,
3. estimated reduction in exposure to pollutants, and
4. assessment of increased health benefits.

In the final analysis, economic values of health benefits are compared with the monetary costs of measures. Although a complete cost-benefit analysis is theoretically possible, benefits can often not be accurately assessed. This is primarily because comprehensive and reliable data are not always available; and some impacts of air pollution are not easy to quantify, due to particular uncertainties in dose-effect relations and monetary valuation methods. For example, it is difficult to place an economic value on premature loss of human life, deterioration of cultural monuments, or loss of biodiversity. When a full cost-benefit analysis is not feasible because benefits cannot be estimated, a cost-effectiveness framework is often used.

Cost Effectiveness Analysis. The principal difference between CBA and CEA is that in CBA both the costs of air pollution reduction measures, and their benefits (i.e. reduced air pollution damage) are expressed in monetary terms. In CEA, only the costs of measures are considered, whereas the benefits are expressed in physical terms, such as reduced emissions or reduced concentrations. The primary objective of CEA is to attain a given pollution reduction goal at the least cost. An analyst considering a CEA would ask the following questions:

1. What pollutants require priority attention in the city (with consideration of sector contributions)?
2. By how much do the ambient concentrations of these pollutants need to be reduced in order to meet specified goals or standards?
3. What are the available least cost options to reduce pollutants to these levels?

In CEA, the benefits (i.e. the monetized reduced environmental damages) are not estimated, but restrictions are set to emissions and/or concentrations of one or more pollutants. For each set of measures it is then determined whether the restrictions are met and at what cost. The set that meets the restrictions at lowest cost is selected.

CEA and CBA under fixed budgets. In case of a fixed budget for air pollution reduction, the procedures for both CBA and CEA are slightly different. In undertaking CBA, that set of measures is selected which does not cost more than the budgeted amount, and which has the largest benefit/cost ratio. In CEA, that set of measures is selected whose costs do not exceed the budget, and which best meets the guidelines or goals for a certain pollutant, beginning with the least cost measure.

Distributional aspects of CBA and CEA. Both costs and benefits have distributional aspects. It is possible that the persons or institutions who pay a large part of the costs are not the same as those who enjoy the benefits. CBA theory states that, at least hypothetically, those who enjoy the benefits should be able to compensate those who pay the costs, so as to reach a situation in which everyone is better off than before. While in principle it is possible to correct for such distributional effects, in practice this is not often done because the ratios of utility and monetary costs are not well known for various income groups. Such assessments are also complicated by the fact that those who initially pay the costs may then pass them along to other groups. For example, a firm that pays the costs of emissions reduction may raise the prices of its products, passing on the cost to consumers. It may, however, be politically relevant to make an assessment of the distribution of costs over the various income groups.

Estimating costs for CEA and CBA. Environmental policy measures have costs. Due to differences in wages and prices, such costs vary among countries and cities. Therefore, all cost estimates must be made separately for each city. Investment, and operation and maintenance (O&M) costs are part of the application of an environmental policy. Investment costs are typically made at beginning of the period after the enforcement of the measure, while O&M costs run over a longer period. To avoid the problem of estimating future inflation, all cost estimates should be done in constant values.

COST-EFFECTIVENESS ANALYSIS

If there is only one target posed for a type of emission (e.g. the total SO₂ emission should be reduced by 20 percent), the procedure of putting together a least cost set from the measures is relatively straightforward. The following steps should be taken.

1. Calculate the discounted cost stream for each of the measures.
2. Estimate emissions reduction resulting from each measure.
3. Calculate the costs per unit of reduction from the ratio of (1) and (2).
4. Select the measure which has the least cost per unit of reduction. These steps can also be expressed as:

(a) Suppose there are n measures and discounted cost per unit reduction in pollutant is—

$$C_1, C_2, \dots, C_n \text{ where: } C_1 < C_2 < \dots < C_n$$

(b) The reduction associated with each measure is —

$$X_1, X_2, \dots, X_n$$

(c) The first t measures are chosen that satisfy the constraint —

$$X_1 + X_2 + \dots \geq T, \text{ where } T \text{ equals the target reduction.}$$

(d) The total cost across all of the most cost-effective measures required to meet the selected target is then —

$$C_1X_1 + C_2X_2 + \dots + C_tX_t = C$$

If there is more than one restriction (pollution reduction target), the derivation of a least cost set of measures becomes complicated. Linear programming techniques can be used. A simpler alternative is to gather many sets of measures, and calculate the cost and effectiveness of each set of measures. The set that satisfies the guidelines at the least cost is selected. Although each set consists of various measures, the measures in different sets may overlap.

COST-BENEFIT ANALYSIS

As mentioned above, cost-benefit analysis requires the estimation of the full benefit stream, something that is not required for CEA. When the discounted benefit stream of one or more measures is estimated, it is compared with the discounted cost stream.

The benefit/cost (B/C) ratio is a unit to assess if a set of measures is desirable or not. Only if the benefit/cost ratio exceeds the value of 1 is the set of measures worthwhile. In case of more sets of measures, one selects the set with the largest benefit/cost ratio.

$$B/C \text{ ratio} = \frac{\sum_{t=0}^n B_t / (1+d)^t}{\sum_{t=0}^n C_t / (1+d)^t}$$

Another unit that is often used is the internal rate of return (IRR). The IRR is that hypothetical discount rate at which the discounted costs equal the discounted benefits:

IRR is the rate at which

$$\sum_{t=0}^n B_t / (1+r)^t = \sum_{t=0}^n C_t / (1+r)^t$$

IRR should be above some minimal value (i.e. should exceed the official discount rate). Instead of the B/C ratio or the IRR, the difference between benefits and costs (B-C) can be used as the criterion. This difference is used when, within a fixed budget restriction, the goal is to achieve maximum pollution reduction benefit. When B/C exceeds 1, the IRR exceeds the official discount rate, and B-C is positive. But the package with the highest B/C ratio is not necessarily the one with the highest IRR, and the greatest difference B-C.

DISCOUNTING

Most people prefer to have money now rather than in the future. In economic terms, the same amount of money has a smaller utility in the future than it does in the present. Discounting is the process of adjusting the value of an amount of money in the future to its current value. If the discount rate is 8 percent, US\$100 now has the same value as US\$108 after one year and US\$116.64 after two years, etc. In other words, an amount of US\$100 to be obtained after one year equals US\$92.59 today. Typically, the costs (and benefits) of a policy measure are not evenly spread over time. Future costs are discounted using the following formula:

$$NPV = \sum_{t=0}^n C_t / (1+d)^t$$

where *NPV* equals net present value, C_t equals costs in year (t), d equals discount rate and n equals time horizon. Net benefits, with B_t equalling benefits in year t , are expressed by the formula:

$$NPV = \sum_{t=0}^n (B_t - C_t) / (1+d)^t$$

Time horizon (n) is the point in the future at which benefits are being calculated. The change in benefits after such a point should be insignificant.

Due to discounting, future costs expressed at current value fade away in the more distant future. If, for instance, $C_t = 100$ for all t , and if the discount rate is 8 percent, the current value of C_t is as shown in Table 6.1.

The value of the discount rate has both economic and political relevance. The higher the discount rate, the lower is the present value of costs faced far in the future. One may base the

discount rate on a bank interest rate (corrected for inflation) or on the rate of return on investments (also corrected for inflation).

Table 6.1: Discounting based on 8% rate

t (year)	C _t (cost in year)	Current value
0	100	100.00
1	100	92.59
2	100	85.73
8	100	54.03
16	100	29.19
32	100	8.52

INCREMENTAL COST OF ABATEMENT CURVE

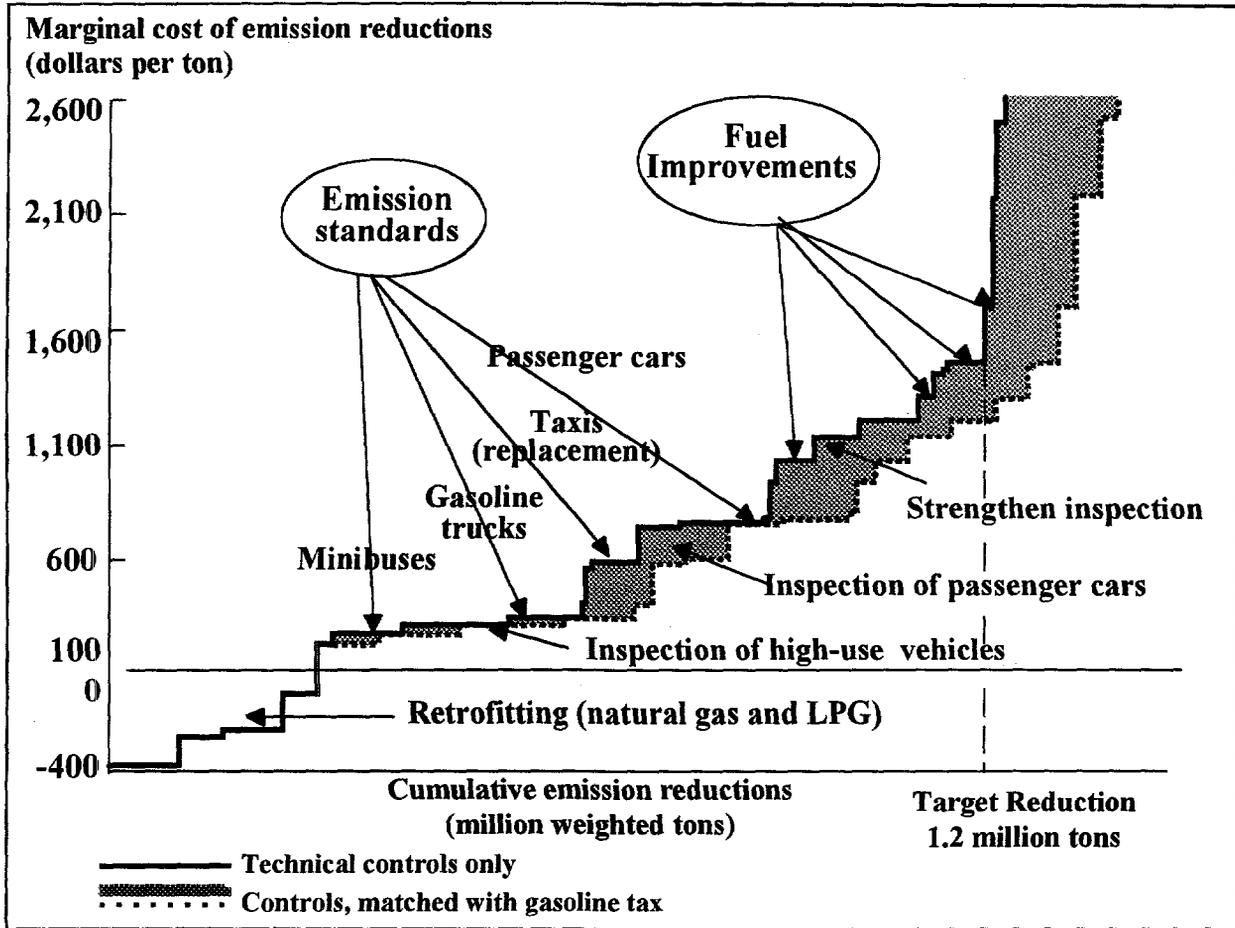
An extremely useful analytical and presentational tool that can be derived directly from cost effectiveness analysis is an incremental cost of abatement curve. This curve can also be called an abatement supply curve with the reduction in emissions on the horizontal axis and cost per ton of emissions abated on the vertical axis. The supply curve rises to the right, since greater abatement can be achieved as the unit cost of abatement rises.

Table 6.2 gives details from a incremental cost curve developed for Mexico City in 1992. Under the cost-effectiveness analysis, the costs and benefits of three groups of abatement strategies were analyzed. The benefits were expressed in tons abated, but not valued in economic terms. The three groups of options analyzed were: (a) options that promote the use of cleaner fuels (e.g., natural gas retrofits and fuel improvements such as unleaded petrol); (b) options that promote the use of cleaner transport technologies (e.g., vapor recovery, tighter emission standards, and increased inspections of vehicles); and (c) options that reduce overall travel demand or shift demand to less polluting travel modes (e.g., a gasoline tax).

On the left side of the curve — natural gas retrofits and vapor recovery—are the technical options that offer the cheapest emissions abatement. (In fact, these two are “win-win” options, in that they pay for themselves financially, not only economically.) The middle part of the curve shows that inspections of vehicles and the imposition of emissions standards are the next most cost-effective options to be pursued. Finally, starting at emissions reduction of about 700,000 tons, the imposition of a gasoline tax improves the cost effectiveness of the purely technical options.

The great value of this incremental cost curve is that it explicitly and clearly shows the results of cost-effectiveness analysis. It is useful both analytically, to show priorities for action, as well as presentationally, to illustrate to decision-makers and the general public the underlying logic of the action plan.

Table 6.2: Ranking measures to reduce traffic emissions in Mexico City



Note: Calculations are based on -0.8 elasticity of demand for gasoline.

Source: G. Eskeland, World Bank (1992).

7. POLICY INSTRUMENTS

In principle, environmental authorities may use a broad range of policy instruments to prevent and combat air pollution. In practice, however, the choice of instruments is limited by a number of factors, including the following:

- legal and institutional framework (although this framework may be changed if there is a strong preference for a specific instrument),
- technical feasibility,
- administrative feasibility,
- state of knowledge for use of the instrument,
- public support,
- economic costs,
- distribution aspects of costs, and
- influence on technological development.

Basic principles of environmental policy—*the polluter pays*, *prevention is better than cure*, *precautionary principle*, and the *stand-still-principle*—guide policy makers in their choice of an instrument. It is important that the selected instrument have no significant negative side effects within the environmental sphere or on other aspects of government policy. Social conditions and characteristics particular to a society must also be kept in mind. For example, in the rapidly growing cities of South and East Asia, economic activity is increasing steadily and this increase may offset a possible decrease in pollution per unit of output or consumption. Policy instruments that are effective in a less dynamic situation may not work in these parts of the world. Within these limitations, one can try to find the most effective or the most efficient instrument. An instrument that maximizes the effect (given a certain budget) or minimizes costs (given a certain environmental objective) should be chosen. The effect could include positive side effects.

Until recently, Western market economies had relied almost exclusively on "command and control" type of environmental policy. This kind of policy has had some successes, notably in the area of air and water pollution, but the limitations of this approach are becoming increasingly clear. Environmental problems have been transferred instead of being solved. A well-known example is the sludge from water purification plants that is often so heavily contaminated by substances like heavy metals that there is no productive use for it.

The strongest argument against command and control measures is that they are inflexible. The traditional way of dealing with polluters by prescribing measures or standards for each individual source is both inflexible and inefficient, because it results in higher costs of abatement than would result from more flexible market-incentive schemes. On one hand, the inflexibility leads to no incentive for existing sources to innovate to cleaner products and processes; on the other hand, new sources often find themselves in an unfavorable competitive position with regard

to existing sources because they have to comply with tighter standards. This is also an obstacle to innovation.

To a large extent, many of the disappointing results of command and control methods can be attributed to production growth. New environmental problems have emerged that had not been previously recognized. Further, policy makers are acknowledging that the so-called "target groups" of environmental policy could be involved more actively in its implementation. Additionally, the "re-discovery" of the market as a regulating mechanism has created a favorable atmosphere for a policy style that gives polluters the responsibility and the initiative for implementing imaginative solutions. Charges, tradable emission or production rights, liability, voluntary agreements, and instruments of communication contain these features to a larger extent than "command and control" instruments.

Another major trend in Western environmental policy is toward various kinds of integration which span in the following ways:

- across different parts of the environment (water, air, soil);⁶
- between environmental policy with other areas of government policy;
- over the entire life cycle of substances and products (the so-called "cradle-to-grave" approach, or "integrated chain management"); and
- across national borders especially in areas where the pollution has transboundary effects (global warming, stratospheric ozone depletion, acidification, marine and river pollution).

Isolated measures regarding single pollutants, products and parts of the environment, are no longer seen as the core of environmental policymaking. Regulations will continue to play an important role in environmental policy. However, they will have to be applied in a way to create opportunities rather than restrictions, and challenge the creativity and responsibility of individuals and firms. Instruments that create awareness and provide incentives to consume and produce in a more environmentally responsible way, will become increasingly important.

In the following pages of this chapter, we discuss the following categories: direct regulation, economic instruments, instruments of communication, and infrastructure and public services.

DIRECT REGULATION

Direct regulation refers to instruments that require authorities to intervene directly in the activities of individuals and groups in society. Generally, such instruments have a "command and control" character. In other words, they set prohibitions and obligations.

Direct regulations may be very effective in case of state-owned firms or monopolies. Energy firms in many Asian countries are an example. In such cases, compliance with environmental regulations may be quite straightforward; prescribing the fuel to be used, the combustion and flue gas purification techniques, or the maximum emissions per plant can be done by mandate. On the other hand, there are many cases where command and control policies are impractical. In Asia, for example, much of the indoor air pollution in both urban and rural areas comes from cooking

⁶ This integration is also present, for instance, in the Indian Environmental Protection Act of 1986.

with unvented stoves in homes that have poor ventilation. The fuel used is also of poor quality. However, cooking is an essential activity. Given the limited budgets of households, a ban on burning wood or waste to cook food should be accompanied by the provision of alternatives such as natural gas, electricity, and waste collection. Simple command and control regulation banning the use of unvented stoves or poor quality fuel would be unwarranted.

Direct regulation consists of two principal activities:

- (a) devising applicable guidelines, standards and regulations; and
- (b) monitoring and enforcing compliance with these guidelines, standards and regulations.

Devising applicable guidelines, standards and regulations

Standards set the quantitative limits within which actors are allowed to pollute. The primary aim of air quality standards is to provide a basis for protecting public health from adverse effects of air pollution and for eliminating, or reducing to a minimum, those contaminants of air that are known or likely to be hazardous to human health and well-being (WHO *Air Quality Guidelines for Europe*, 1987).

Environmental quality standards such as ambient air quality and emissions standards, may be expressed in terms of maximum allowable concentration for certain substances (or other indicators of environmental quality).⁷ Standards based on relatively short averaging periods (1, 8, or 24 hours) are better at accounting for peak concentrations than standards based on yearly average values.

Standards are based on the best technique available. The principle commonly used in the European Union countries is called BATNEEC (Best Available Technique Not Entailing Excessive Costs). However, for the most harmful emissions the guiding principle should be ALARA (As Low As Reasonably Achievable). The problem with fixed standards is that once met, there is no incentive to innovate and come up with cleaner technologies. In order to boost innovation, periodic tightening of standards may be necessary ("progressive" or "technology forcing" standards).⁸ It is important that changes in standards be known for some years in advance, so that polluters and their technology suppliers have the chance to make the necessary investments in research and development. In general, companies prefer standards to fines or charges for emitted pollutants because they have more room to negotiate with authorities on the adoption of standards.

Ambient standards/guidelines. Ambient air quality guidelines set levels at which no adverse health impact is expected. The guidelines also provide an estimate of a lifetime risk arising from those substances that have been proven to be carcinogenic (in case of WHO AQG) or harmful to human health in other ways. There are three types of ambient standards:

⁷ Air quality standards for various substances are presented in Appendix 4.

⁸ Tightening of standards is advisable only if it is felt that present standards are not stringent enough to provide lasting environmental protection.

1. target values (below which no significant damage can be expected);
2. reference values (which should be reached, as far as possible); and
3. limit values (which should not be exceeded).

Usually, ambient standards are not binding for individuals or firms. They can, however, be binding for (local) authorities. Most countries have some standards for ambient air quality. WHO also has standards for concentration of specific pollutants. For example, the WHO guideline for SPM is $120 \mu\text{g}/\text{m}^3$ (24 hours). Thailand's ambient air quality standard for the same is $100 \mu\text{g}/\text{m}^3$ (annually) or $330 \mu\text{g}/\text{m}^3$ (24 hours). In Thailand, the "Enhancement and Conservation of National Environmental Quality Act, 1992" assigns the National Environmental Board the task of prescribing ambient air quality standards.

Emissions standards state the maximum amount or concentration of air pollutants that may be emitted by a production unit, process, or product (e.g., electricity generation plant, waste combustor, vehicles). Often, product standards take emissions guidelines into account. They are usually expressed in terms of concentrations (e.g., in $\mu\text{g}/\text{m}^3$) in the flue gas. It is also possible to state standards as total amount per unit of time, or to relate them to an indicator of the input, throughput, or output of the production process (e.g., per ton).

A general advantage of emission standards is that they can be set to meet the objectives of environmental policy. For example, if TSP is a concern, tougher emission standards may be introduced for vehicles. On the other hand, emissions standards allow the polluter to use end-of-pipe treatment rather than cleaner core technology. Therefore, there is always a danger that pollution could be transferred from one medium to another, for example, from air to water or soil. In addition, if emissions-producing activities are expanding, standards have to be tightened in order to keep total emissions unchanged. Emissions standards can be uniform or differentiated.

- *Uniform standards* usually apply to products and production processes. There are standards for almost every production process from bakeries to chemical production. Uniform standards apply to all the entities that fall under a category, irrespective of size or amount of production. The costs of administration, monitoring and enforcement tend to be lower for the enforcement of uniform standards. They may also be less susceptible to lobbying or bribery.
- *Differentiated standards* account for the circumstances of an individual polluter (e.g., the costs of complying with them, or financial capacity), as well as the specific environmental conditions (e.g., local air quality, weather conditions and geographical position of the source).⁹ Differentiation is also possible between existing sources and newcomers.¹⁰ Differentiated standards are generally described in a license. Uniform standards are cheaper to apply, but differentiated standards tend to be more efficient, especially if there are substantial differences among marginal costs of pollution prevention or abatement for different polluters.

⁹ Regional differentiation of emission standards is common practice in Japan, the United States, and India. This differentiation may reflect both differences in air quality objectives between areas, and differences in actual air quality.

¹⁰ Such a differentiation between existing and new sources may act as a kind of "dirty protectionism", strongly backed by outdated industries to prevent more innovative competitors from entering the market. Cairncross (1991, p. 239) cites some examples from the United States.

Process standards relate to the conditions under which potentially polluting processes are being performed. They prescribe, for instance, the temperature at which certain combustion processes should take place, or the measures to prevent dust emissions.¹¹ Safety standards and professional skill requirements also belong to this category. Process standards are often easier to monitor and enforce because they do not require the measurement of emissions. On the other hand, they leave the polluter no choice among alternative emission reduction options.

Product standards, which apply to the producer, seller, or user of a product, determine maximum allowable content of certain substances in a product (e.g. lead in fuel); specify the obligatory composition or structure of a product (e.g. catalytic converters in cars); and/or prescribe the way in which a product should be packaged, stored, handled or disposed (transportation of natural gas).

Product standards may be effective if they are used in cases where emissions standards are either being exceeded, or cannot be imposed. However, if other emissions control techniques are available (e.g., flue gas desulfurization), a product standard (e.g., for the sulfur content of fuels) may be unnecessarily restricting. Product samples are often randomly checked, either before or after they reach the market, to ensure compliance with standards. If the environmental performance of a product is dependent on its maintenance and wear and tear, regular inspections must take place. This is the case, for instance, with motor vehicles. Small-scale industries in Asia may be perfect candidates for process and product standards. They represent all kinds of trades and crafts, in many cases they are semi-organized and operate on an informal, semi-legal basis. Their operations and products could be randomly monitored.

Monitoring and enforcing compliance

Regular monitoring is essential to enforce environmental quality and emissions standards. A large number of non-point and mobile sources (consumers, cars, small-scale manufacturing, agriculture) have replaced a limited number of point sources (large-scale industry, power plants, etc.) as the major contributor to many kinds of pollution. This has caused tougher monitoring and enforcement problems. Continuous measurement of emissions would be ideal, but is very expensive and therefore only used for large sources. Registration and verification of reported emissions also require considerable personnel and expertise. In Asian countries where traffic is a major source of pollution, setting standards for vehicular emissions is an important but not sufficient instrument. This is because the conditions under which the vehicle is tested for compliance often do not reflect the actual conditions under which it is used. Second, growth in the number of vehicles and the average distance driven may outweigh the emissions reduction per vehicle and per kilometer. Therefore additional measures would be required to control vehicular emissions, that may include providing expanded alternatives to the use of cars .

Enforcement is a crucial part of all kinds of direct regulation. To be effective, a regulatory enforcement agency requires expertise, technical equipment, and the support of a well functioning legal system. In addition, efforts must be made to minimize the agency's

¹¹ In this respect, one should not only think of production and transshipment processes. Demolition activities also cause severe dust emissions which may contain extremely dangerous substances like asbestos.

susceptibility to intimidation and bribery. Tools for enforcement include lawsuits, fines, and closures.

- *Lawsuits against trespassers* should not be the exclusive privilege of environmental authorities. Vigilant citizens and pressure groups can also play an active role in this respect. The Indian Environmental Protection Act of 1986, for instance, permits individuals to initiate legal action against an offender (Bowonder and Arvind, 1989).
- *Fines* against those who violate the laws is one way of ensuring compliance. Prompt fines and severe sanctions make it unattractive to break environmental laws. In addition, authorities may be able to confiscate the profits of firms that operate illegally. While they are important methods of direct regulation, fines must not undermine the financial capacity of a firm to invest in the necessary environmental protection measures.
- *Closures of firms* that breaks the law is the most radical sanction. Although effective, closure causes loss of capital and employment. It might be considered a temporary measure, until the firm complies with the rules.

Other direct regulations

Besides standards and licences, the authorities have other possibilities to intervene directly with the conditions under which potentially polluting activities take place.

Spatial planning and zoning can be used to minimize the potential for worsening air quality. Polluting industries should be located in areas that are not subject to air inversion or trapping of pollutants, and where prevailing winds blow toward relatively unpopulated areas. A minimum distance to the nearest built-up area, and an obligation to establish a green belt could also be prescribed for new plants. To minimize the volume and environmental impact of motor vehicle traffic, new businesses should preferably be accessible by public transport. If vehicular traffic is unavoidable, one should be aware of possible bottlenecks causing congestion and additional air pollution.

Traffic regulations can be used to avoid congestion and promote a smoother flow of traffic. A well-coordinated set of traffic light schemes, speed limits, right-of-way rules, one-way traffic, and stopping and parking prohibitions are part of a system of traffic regulations. Special traffic lanes and right-of-way rules may advance the average speed of public transport, thus enhancing its attractiveness.¹² The same is true for bicycles.

The main flows of traffic can also be directed away from residential areas. Measures may be taken that make it unattractive for car and truck drivers to enter residential areas or city centers enroute to other destinations. Traffic regulations require substantial enforcement efforts. Compliance may be ensured by making violation of the rules physically impossible. The construction of speed ramps, bollards (to prevent parking), and traffic sluices (to obstruct cars from driving on tramlines and bus lanes) are examples of such barriers.

¹² The increase in demand for public transport will often cause a need for additional equipment and personnel. This may add to the financial burden of the (mostly publicly subsidized) transport company, and thus to the burden of collective spending.

Environmental management plans and environmental audits may be required from firms. In India, the Environmental Protection Act of 1986 makes it mandatory to have environmental management plans, as well as hazard management plans for all new projects (Bowonder and Arvind, 1989, p. 187). This obligation could be extended to existing activities.

Compulsory environmental audits can refer to actual environmental concerns such as streams of substances and waste from the firm, or to the organizational aspects—tasks, responsibilities, procedures, and information systems. Preferably, the authorities should minimize the formal requirements for environmental management systems and audits to prevent inefficiencies. Firms should be given the opportunity to adapt their system to specific characteristics such as size and organizational structure. Larger firms may, for example, have a separate official for environmental affairs. In many cases, environmental management can be combined with quality management schemes and/or improvement in working conditions.

Alternative application of regulations. Direct regulation can be applied in a negative way such as by abolishing regulations that contribute to air pollution. A policy that requires the use of domestic coal for energy production purposes, instead of imported natural gas, is an example of a *negative* regulation that contributes to air pollution. Finally, emergency regulations may be required to prevent and limit damage to health and the environment in case of accidents and calamities. Certain authorities can be empowered to announce obligations and prohibitions in a state of emergency. Such regulations are a vital supplement to preventive measures, because risks can seldom be reduced to zero.

ECONOMIC INSTRUMENTS

Environmental charges

Environmental charges or taxes are the most common form of market-based instruments currently used to supplement more traditional direct regulation in many countries. Most countries have adopted the "polluter pays principle" as the foundation of their environmental laws and regulations. However, this principle has not yet been effectively implemented, primarily because the levels of pollution taxes or charges, combined with their level of enforcement, are too low to have much effect.

Pollution (effluent or emissions) charges can be highly efficient, but only if rates are set high enough to alter behavior. In many Asian countries, these charges are far too low. In China, charges tend to be lower than the operating costs associated with industrial pre-treatment. In such cases, the charge serves a simple revenue generating effect, and does not create a real incentive for pollution abatement. In contrast, if the charge is set at a high enough level to trigger abatement, the revenue generated could decline—unless the pollution base is growing due to regional economic growth. The level of the charge will determine the highest marginal cost of abatement a firm will be willing to pay. Above that level, it would be cheaper to pay the charge than to continue investing in abatement. As a result, the effect of a pollution charge must be monitored over time to determine if the ambient pollution target levels are being achieved. If not, the relevant charge levels or tax rates should be revised. Pollution charges or taxes are best levied

when monitoring, enforcement and competition are all in evidence. If competition is lacking, then firms can pass on higher costs without having an incentive to reduce pollution levels. If monitoring and enforcement of specific pollutants is costly or difficult, then the more blunt indirect market measures are easier, such as fuel or energy taxes.

Even though "optimal" taxes may be difficult to calculate or introduce in many countries, the use of pollution charges has three major advantages over direct regulation. First, pollution charges comply better with the "polluter pays principle." A polluter pays not only for emissions reduction measures, but also for the environmental damage caused by remaining emissions. Second, charges are, in principle, more efficient than uniform standards.¹³ This is because a profit-maximizing firm will reduce its emission (or any other quantity on which the charge is based) to the level where its marginal abatement costs equal the charge rate. A charge thus equalizes the marginal abatement costs among polluters. It also leaves the polluter more freedom to choose the optimal point in time for an anti-pollution investment, enabling him to take depreciation terms into account. Third, a charge provides a continuous incentive for the polluter to look for opportunities to further reduce the emissions. This may lead to innovations in more effective and/or efficient pollution control technologies. Standards do not contain this permanent incentive, unless they are periodically tightened.

Tariff differentiation is another kind of charge. It's impact is similar to a direct pollution charge. Tariff differentiation can be applied to excise duties and other taxes, and to goods and services supplied by public utilities such as energy and public transport. The differentiation may relate to product content (for instance, between leaded and lead-free fuels) or to the time of consumption. In February 1990, the Singapore government attempted to increase the use of unleaded gasoline by applying a differential tax that made unleaded petrol cheaper than leaded petrol by Singapore\$0.10 per liter. Combined with a steady reduction in the lead content of petroleum between 1981 and 1987, this led to a considerable increase in the use of unleaded gasoline. By the end of 1993, 57 percent of all gasoline sold was unleaded.

Governments may also levy a tariff on the use of a public utility or public transport at peak hours in order to shift use to other times of the day, thereby reducing peak emissions. This approach can be applied to electricity and traffic ("road pricing"). A successful system of road pricing has been operational in Singapore since 1975. Low-occupancy private cars pay a fee to enter the central business district between 7.30 and 10.15 AM. This scheme has stimulated the use of public transport and shared vehicles. It has proven to be both cost-effective and easy to administer. According to the World Bank, it offers a valuable model for other cities faced with the task of dealing with serious traffic congestion (Midgley, 1986).

Subsidies and tax credits

A subsidy on emissions reduction is the mirror image of an emission charge. It has the advantage of providing a lasting incentive for pollution reductions while leaving the polluter free to choose among alternative means of attaining the emissions reduction. Subsidies can be provided for

¹³ To be more specific, this is true if marginal abatement costs differ between polluters. The advantage does not apply if the charge is being compared with a situation in which abatement cost differences are taken into account in setting standards.

emission reductions investments,¹⁴ or for research and development. Finally, the government can provide financial support to NGOs that work on environmental issues. Generally, subsidies meet with little or no resistance among target groups. Therefore, they may be quite effective and show quick results. On the negative side, subsidies do not comply with the "polluter pays principle," and they place a burden on the public budget. In URBAIR cities, local authorities may not have the power to change fuel taxes, but they could use subsidies and differential taxes for cleaner public transport, including buses, rickshaws, etc. In all cases, however, the subsidies offered should be temporary and phased out within a clearly stated period.

Direct subsidies for emissions reduction. Before a subsidy is provided to firms, a reference point for emission reduction should be established. Present emissions should not serve as a reference point, because firms that have already invested in emissions reduction would be penalized. In practice, subsidies for emissions reduction are rare.

Subsidizing investment in clean technology. Subsidies on investments in clean technologies and emissions reduction equipment are more common than direct emission reduction subsidies. Such subsidies can be given in a lump sum, by depreciation allowances, or by reducing the rate of certain taxes or import duties. In Thailand, import duties on machines, materials or equipment, which have been proven to save energy and/or protect the environment, are being reduced by 50 percent and limited to 10 percent or less of the import value (Phantumvanit and Sathiratai, 1986). India has concessional import duties, as well as depreciation and investment allowances for specific pollution control equipment (Govind, 1989).

A major drawback of investment subsidies is that they tend to favor end-of-pipe techniques. This is because end-of-pipe techniques are easier to identify than process-integrated pollution prevention and recycling techniques. Furthermore, the list of equipment eligible for the subsidy often reflects state-of-the-art technology. In order to become an incentive for innovation, the list has to be revised regularly.

Subsidies for research and development. Direct subsidies for research and development in clean technology are also quite common. They can be justified on the same grounds as general technology subsidies; research and development has certain "collective good" properties. Often the required investment, as well as the risk, may be too great for an individual firm to invest in research and development.

Financial support for NGOs. Financial support for NGOs can be a useful instrument if the authorities feel that such organizations are trusted by the population and can impact public opinion. NGOs may also perform the function of research organizations and provide reliable environmental and other data. For environmental authorities, it may also be strategically important to have a strong external pressure group when negotiating with the more "conservative" parts of the public sector.

¹⁴ Subsidies on investments are often given as a tax credit (e.g. accelerated depreciation, lower import duties, excise tax differentiation) or as a "soft loan" (low-interest and/or subordinated). The first type improves a firm's liquidity; the second its solvency.

Tradable rights

Tradable rights may be seen as a pollutant quota assigned to various sources that may be bought and sold on the open market. In order to establish trading rights, the authorities determine a ceiling for the level of total emissions in a defined area, or the total volume or number of polluting products to be sold or used. Parts of this total are apportioned to individual producers or users, either based on some distribution code (for instance, present emissions or production volume), or by means of a bidding process. Those individuals or producers who are able to innovate or in other ways reduce their total emissions below the amount that has been apportioned to them may trade the remainder on the market. In this way, they are able to compensate some of the cost of innovating and reducing pollution, and a polluter who is unable to do so can increase his rights to pollute. As an example, suppose the government tightens the SO₂ emissions standard and establishes tradable rights for emissions. A firm that has the right to emit 2,500 tons of SO₂ annually may invest in a scrubber and thereby reduce its emissions to 1,500 tons, leaving it a total of 1,000 tons that it may trade on the stock exchange. Another firm, that cannot invest in better technology or innovate may purchase these rights. The total amount of pollution in the area is reduced with the greatest amount of flexibility. Tradable rights can thus combine some of the advantages of direct regulation (reasonable certainty about the total emission level) with the efficiency of charges (knowledge of costs).

Provided they are adequately enforced, tradable rights may be important in a growing economy because they ensure that a certain level of pollution will not be exceeded. A single "command and control" approach could attain this only by ending the issue of new licenses. This would have a paralyzing effect on the economy because it would deny entry to newcomers. Tradable rights create flexibility by enabling the holders of such rights to sell them if they can reduce their pollution, while others may buy them if they want to expand or start a new activity. If the authorities want to lower the ceiling, they can buy rights and thus reduce the total number of rights in circulation.

Tradable rights have been used extensively only in the United States. Experience shows that the system can function well, provided the rights are well defined, and the relevant information on emissions (numbers, volumes, etc.) is precise and well understood. Further, the number of actors and potential transactions should be large enough to create a competitive market. Monopoly-like situations will lead to speculation and inefficient allocation.

Tradable rights may be an attractive option for developing countries, depending upon the specific situation, and the priorities of the authorities (Lyon, 1989). Certainly, this instrument is at least worth considering in cities where industrial growth makes it virtually impossible to control the total level of emissions by enforcing uniform standards for each individual polluter.

Liability

Making the polluter liable for environmental damage is, in a sense, the "purest" form of environmental policy; the external effects are directly internalized.¹⁵ If it functions well,

¹⁵ One might argue that liability is not an instrument in itself, but a matter of principle or policy framework. However, the act of claiming compensation for environmental damage, to which liability regulations apply, is readily comparable to other (economic) instruments.

environmental liability is a preventive instrument.¹⁶ Its main purpose is to make polluters undertake actions that reduce emissions and their risks, in order to avert possible damage claims. These measures will also be required by their insurance companies for third-party insurance. Firms that have a poor environmental record or inadequate environmental management will be charged higher insurance premiums. There are however practical difficulties in trying to apply this approach.

It is often difficult to unequivocally establish the amount of damage. The processes leading to environmental damage are generally extremely complex, making it difficult to prove the causal relationship between a specific emission (at a specific point in time and space) and the damage caused. This complexity is compounded by the fact that many environmental effects become manifest only in the long run, at a time when the legal offense may have become prescribed, or the polluter even does not exist anymore. In order to hold a polluter liable, the plaintiff must show that his personal interests (or the interests he represents) have been affected.

Depending upon the existing legislation and the judicial system, it may have to be proven that the polluter is guilty and can be obliged to pay for the damage. There is, however, a tendency toward a greater role of so-called risk liability. This means that the producer of a substance or product, or the performer of a certain (industrial) activity, may be held liable for the damage caused by it, irrespective of possible guilt. The mere fact that he has created a risk by bringing the substance or product on the market, or by engaging in a hazardous activity, can make him liable to pay for the damage.¹⁷

The problem of proving a causal relationship can be somewhat relaxed by introducing some form of collective liability. This implies that there is no need to prove that an *individual* polluter has caused a certain damage. The onus of proof could be shifted from the individual to the collective polluters.

Liability for environmental damage could, in principle, be a powerful instrument, especially in cases where adequate environmental legislation is lacking. It could be used, not only by individuals suffering private damage, but also NGOs or public authorities acting on behalf of groups or society as a whole. Such "public interest litigation" has become more common in India in recent years (Bowonder and Arvind, 1989; Bhat, 1992). The Bhopal case is the most well-known.¹⁸ Litigants in such cases not only seek damage compensation, but also ask the court to impose regulations that would prevent and reduce risk in the future.

¹⁶ Clearly, the legal actions taken today against polluting firms seek for compensation of past environmental damage. But the prospect of such legal action may induce firms to take preventive measures.

¹⁷ This tendency towards risk liability can, among others, be observed in the 17 February 1996 verdict by the Supreme Court of India. A case was filed against a Delhi firm where a leakage of sulfuric acid had taken place, affecting a large number of people. The Court decided that "(...) where an enterprise is engaged in a hazardous or inherently hazardous activity (...), resulting, for example, in escape of toxic gas, the enterprise is strictly and absolutely liable to compensate all those who are affected by the accident (...)" (Bowonder and Arvind, 1989, p. 189; Bhat, 1992, p. 44). This verdict is also noteworthy because the court decided that the amount of compensation to be paid should be correlated to the magnitude and capacity of the enterprise, because such compensation must have a deterrent effect.

¹⁸ In the Bhopal case, a multitude of private law suits against Union Carbide were annulled by the Indian government which declared itself the exclusive representative of the victims. The Bhopal case came to an end in 1991, when the Supreme Court of India decided that the liability of Union Carbide was restricted to the US\$470 million (which it had already paid). This settlement was reached without any judicial pronouncement on the guilt or negligence of Union Carbide, apparently to prevent the otherwise unavoidable delay. See Bhat (1992).

Other economic instruments

Deposit-refund systems (or return premiums)¹⁹ can be applied to products or substances that pose no significant risk to the environment when properly used, but that should be kept out of the waste stream because they pose considerable risks if they are dumped or incinerated. Deposit-refund systems may be relevant in preventing the incineration of materials that emit noxious fumes when burned. Chlorinated substances, like PVC, which cause hydrochloric acid emissions when burned, fall in this category.

A deposit-refund system is a useful tool if the premium is high enough to compensate for the effort involved in taking the items concerned out of the waste stream and to deliver them at a designated disposal or recycling site. In some cases, this can greatly increase the price of the product and it nearly always requires a costly infrastructure. The system can be financed by industry itself, by government subsidies, or by a difference between the deposit and the refund rate. Some interest on the deposit may also be a source of financing, if the life span of the product is quite long. Until now, experience with deposit-refund systems is mostly confined to packaging.

User advantages are economic instruments that provide a reward, not necessarily financial, for voluntary environment-friendly behavior. Examples from traffic management include separate lanes for car-poolers and exemption from driving bans during smog episodes for cars with low emissions. Alternatively, incentives for polluting behavior may be abolished. Examples of such incentives are the deduction of commuting costs and protectionist tariffs that favor domestic products and technologies, even if these are more polluting than foreign alternatives.

Public procurements help pave the way for cleaner products and technologies. They are applicable to all areas of government policy. Environment-conscious public purchasing may range from organic, solvent-free correction fluid in public offices to laundries that have a closed circuit for chlorinated chemicals. Environmental awareness in public organizations and authorities is a precondition for this instrument to function. Guidelines must state what products and techniques are preferred, and what price differences are acceptable to make an environment-friendly choice.

Macro-economic policy may have an indirect impact on air pollution. The effects of public spending and import levies have been mentioned. Other relevant macro-economic policy instruments are interest, tax, wage and foreign exchange rates. These often have unclear results; a high interest rate affects the profitability of investments, possibly preventing an increase in pollution (by blocking production growth). On the other hand, it may also obstruct a decrease in pollution (by impeding the introduction of cleaner technologies).

Although the impact of high taxes is unclear, from an environmental viewpoint, taxes on energy, raw materials, and products are generally preferred to taxes on income and wealth. High wages may lead to mechanization and automation, which could be both beneficial (more accuracy, less spilling) and detrimental (less reparability) to the environment. Finally, the influence of the foreign exchange rate is comparable to that of levies on imports.

¹⁹ With deposit-refund systems, a premium is only paid for items for which the deposit has been paid before. A return premium system includes a payment for all goods meeting certain specifications, irrespective of their origin. Obviously, the latter system is more expensive, and more susceptible to fraud (by cashing the premium for one item several times).

COMMUNICATION AND AWARENESS-BUILDING INSTRUMENTS

Binding regulations and financial incentives are not the only ways to improve air quality. Individuals and groups may adopt environmentally friendly practices because they feel a sense of responsibility for ensuring a cleaner and healthier environment. In order to do so, however, they must be well informed about their options. There are many types of information that should be generally available to people, and several methods to make them available.

Awareness building, creating a sense of responsibility, and the provision of information are the main elements of a communication plan. The message will differ depending on the specific situation (characteristics of the problem, composition of the target group, level of consciousness). If the main objective is awareness building, the information can be quite general. On the other hand, if the aim is to change behavior, specific options should be provided. Specific information should be directed to the target groups. Examples are advisory centers and information services for specific branches of industry; educational and training courses; publicity and propaganda for "clean" products and courses of action, and directions for an environment-friendly way of using products and appliances. In some cases communicating information may be the only policy tool available.

The choice of information carrier is also important. General information that is important for the entire population can be distributed by means of mass media and educational institutes (such as schools, colleges, churches, other NGOs). The information can sometimes be linked to the product through labeling. An "eco-label" is a simple way of presenting information, but only applicable if the environmental advantages of the labeled product are undisputed.

Although there is a strong preference for preventive measures in environmental policy, zero emission and risk levels are impossible. Emergency plans and warning systems are important communication instruments.²⁰ Substantial damage reductions are possible if people are well-informed about potential risks, and know how to act in case of an emergency. In the Bhopal India, disaster, for instance, it was suggested that many lives would have been saved had people stayed in their homes, with doors and windows closed and covering their faces with wet towels. People were unaware of this simple step and many died because they inhaled the toxic fumes while they were fleeing.²¹

Voluntary agreements

In recent years, several European countries have started using voluntary agreements with industry as a new instrument of environmental policy. The authorities and polluters agree on certain environmental policy targets, preferably in quantitative terms, and with a deadline. The targets may relate to emissions, to the content of pollutants in particular products, or to the percentage of a product that must be recycled, etc.

Voluntary agreements have certain advantages over other types of regulation; the parties are more likely to cooperate when they have a say in determining the objectives. Furthermore, an agreement is sometimes easier and quicker to realize than legislation. An effective agreement should be as specific as possible. Each party to the contract should know its responsibilities.

²⁰ UNEP (1988).

²¹ Bhat (1992), p. 43.

The main objection against voluntary agreements is that they preclude the participation of democratic political institutions such as a legislature. It is also often unclear whether an agreement is seen as a formal contract (including the possibility of sanctions in case of non-compliance), or only as a declaration of intent. Finally, a voluntary agreement may sometimes act as a kind of cartel, creating a monopoly-like structure and excluding outsiders and newcomers.

Environmental impact assessment

Environmental impact assessment (EIA) is not an environmental policy instrument but a procedure that assists in environmental decision making. Generally it includes an assessment of all the environmental implications of an investment or policy project. Several alternatives may be considered, including "zero alternative" (no action at all). The EIA objective is to recommend the alternative that contains the best feasible means to minimize harmful effects of the investment on the environment.

In many countries, EIAs are obligatory for all projects that have a potentially large impact on the environment. Some countries have a list of activities for which an EIA is obligatory. In others like India, EIAs depend on the location of the project and the foreseen impacts.²² The size of the project also affects the scope (concise or comprehensive) of the EIA. EIAs should be made in an early stage of the decision-making process when commitments or investments have not been made.

INFRASTRUCTURE AND PUBLIC SERVICES

Apart from prescribing or promoting environment-friendly activities, the government may create facilities that have a direct or indirect influence on air quality. A well-functioning waste collection system, for instance, will reduce the nuisance of stench and smoke in residential areas. Gas and electricity grids remove the need to burn biomass or coal for cooking.²³ A sewage system, apart from being beneficial to public health, has a positive impact on air quality. The construction of industrial estates facilitates the relocation of pollution intensive industries from densely populated areas. Investments in railways and a good public transport system may reduce the number of private vehicles. In this respect, underground railways deserve consideration even though they are not always the most cost-effective solution. Investments in "clean" buses provide a cheaper and more flexible alternative. In addition, new infrastructure attracts investment and economic activities that partly offset the decrease in congestion and pollution.

Proper maintenance schemes lead to diminished emissions from buses and other vehicles. Maintenance of road surfaces is also important for better energy efficiency and reduced emissions.²⁴ In hot and dry climates, sprinkling streets is an effective way of reducing the dust

²² Bowonder and Arvind, 1989, p. 187.

²³ Provided the prices for gas and electricity are competitive. There may be some conflict here with the general aim to enhance energy efficiency by higher energy prices.

²⁴ It should be added, however, that more and better roads may also lead to a larger number of vehicles. This should be kept in mind when assessing the overall efficiency of such investments.

content of the air. Green belts and parks serve a double function; they provide a place where people can go for relatively fresh air, and they can take away certain pollutants from the air. Since investments such as these burden the public budget, governments adhering to the "polluter pays principle" should pass the costs to the polluters to the extent possible.

INSTITUTIONS, LAWS, AND REGULATIONS

Institutional arrangements, laws, and regulations are an important part of an AQMS. Some roadblocks to successful air quality management in Asia are weak institutions that lack technical skills and political authority; feeble enforcement agencies that often lack both the necessary information and the means to implement policy, and unclear legal and administrative procedures. Countries have their own political and administrative hierarchies, and technical expertise that affect institutions, laws and regulations related to air pollution control. This section provides general guidelines for setting up institutional arrangements for air pollution control in urban areas.

Air pollution control institutions

Institutions responsible for the reduction and control of air pollution have the following functions.

Pollution prevention. This includes revising regulations to incorporate source reduction, and educating industries and households on source-reduction techniques.

Risk assessment and risk reduction. Institutions estimate the form, dimensions, and characteristics of the risks. Each country/local authority must first identify and target those problems that pose the greatest risk to human health and the environment. Communicating the assessment of risk to the public is also important. The public's perception of an environmental threat may or may not parallel those supported by scientific data. It is the responsibility of environmental organizations to educate the public on comparative risks of different environmental problems so that people understand why certain environmental issues are addressed first.

Scientific research and technology. Scientific research and technology play a fundamental role in providing a basis for sound environmental policy. Industries and universities should participate in research and development programs. In promoting research and development, environmental organizations (or AQM units) might consider inviting, engaging and facilitating research conducted by specialists with recognized expertise, through extramural contracts, grants, and cooperative agreements with various organizations. Other options include multi-disciplinary research in university settings; research centers program; a visiting scientists program that could support members of the environmental research community in 1-3 year fellowships at the organization's research facility. Research and development programs should focus on the following elements:

- gathering and analyzing data needed to evaluate environmental risks and trends, measuring environmental results, and educating institutions and individuals about the environmental impacts of their choices;
- promoting and supporting innovative technological solutions to environmental problems;
- encouraging and conducting research that improves the understanding of health and ecological risks;
- providing objectives, and reliable and easy to understand information that helps build trust in the institutions' judgment and actions; and
- share research findings and innovative technologies with other nations.

Regulatory education. Public involvement is fundamental to successful air quality management. An educational program may have the following components:

- multi-media products, jointly developed by the educational programs of government offices, public, private, academic, and foreign organizations;
- academic programs that provide grant assistance to local educational agencies, institutions of higher education and other not-for-profit organizations; and
- an education information clearinghouse to identify and track existing or evolving environmental education information products.

Regulatory development. Institutions develop regulations in order to implement acts, ordinances, or decrees proscribed by legislative bodies. Regulatory development is a process for implementing legislative mandates (e.g., Clean Air Act). In essence, mandates are enforceable requirements with which the regulated community must comply. They are legally binding, and can include operating procedures, reporting and record-keeping guidelines, and standards. Standards dictate what levels of pollutants are permitted in the environment. Standards are extremely important in the enforcement process because they are used to measure compliance with the regulations. Proposed regulations that impact the public should undergo public review and comment. The regulated body, whether public or private, should have the opportunity to comment on the proposal.

Enforcement. Once regulations are established, the enforcing institutions have the responsibility of encouraging and ensuring compliance. An enforcement program should ensure that information on the regulations is available to those who must comply. In addition, there should be a basis for determining compliance. This includes policies that deter unlawful behavior and necessary sanctions against those who do not comply. Actions may be administrative or judicial, handled as civil or criminal enforcement, and as single or multi-media cases. Generally, criminal enforcement is reserved for intentional and willful violations of environmental requirements. Civil judicial enforcement is used in cases that involve a history of noncompliance, and that demonstrate the need for stricter sanctions that the courts can provide. The responsibility for inspection, permitting, monitoring, etc., should be allocated to government authorities that are legally responsible for different components of air quality management. Resources should be assigned according to the level and complexity of the organization's responsibilities.

Air pollution laws and regulations

The regulatory actions that should be taken to develop a legal framework for air pollution control include enactment of a formal legal instrument, such as an act, ordinance, or decree; and development of regulations, by-laws, rules, and orders required to fully implement the authorizing legislation. Although the format and structure of regulations for air pollution control may vary from country to country, regulations generally have the following contents:

- scope of the legal instrument with a definition of the applicable terms and concepts, specification of the responsible authorities and the parties, areas and substances to whom or to which the instrument will apply;
- applicable documents, such as other standards, specifications, and regulations;
- detailed description of the requirements, including limits on pollutants, applicable tests, mandatory control methods, reporting requirements, and timetable (if the requirements are to be implemented over a period of time);
- specific statement of the monitoring, reporting, and inspection systems; and
- statement describing applicable penalties for violations.

Levels of government

Different levels of government—national, regional, and local—have different roles and responsibilities. Air quality standards or guidelines are usually set at the national level, although local government may have the legal right to impose stricter regulations. National governments usually assume the responsibility for scientific research and environmental education, while local governments develop and enforce regulations to control local pollution levels.

In the context of an AQMS, local authorities have the most significant responsibilities. These include the following:

- developing and running the monitoring program,
- assessing the air quality,
- determining the impacts of air pollution,
- setting goals for the quality of air, and
- develop future scenarios and action plans to achieve those goals.

National or state authorities may assume the responsibility for mandating controls, such as regulating fuel quality, setting emissions standards, and providing financial resources, or incentives for the private sector to reduce emissions.

8. AIR QUALITY IMPROVEMENT ACTION PLAN

This chapter outlines a five-step method for developing an air quality improvement action plan. An action plan presents the prioritized list of abatement and other measures to improve air quality, and to maintain it within a pre-described level in the short and medium term. It outlines the steps required to implement a full AQMS in any given city, consistent with that city's circumstances, capabilities, and needs.

The plan is developed using the AQMS model from Chapter 2, and assessment processes described in detail in Chapters 3 through 7. The final aim of an action plan is to identify and implement a least-cost package of measures to improve air quality, such that the marginal costs equal the marginal benefits. However, because of the uncertainties surrounding quantification and monetization of air pollution damage, it is impossible to find an "optimal" level of air quality based solely on economic considerations. Ultimately, the desired levels of air quality, and the measures to be implemented, are a political choice. Responsible authorities base their decisions on subjective assessments of economic and social costs, benefits, feasibility, and other considerations. The air quality improvement action plan provides information that can reduce arbitrariness in decision-making.

Creating an area-specific action plan is not a linear process. Feedback is an important element of this approach. The damage-assessment in the following Step 1 is repeated a number of times for different abatement scenarios, and possibly for different development scenarios, until the "best" policy package is identified based on the costs and benefits. Following are the steps for developing an air quality management action plan:

Step 1.

- Gather data on emissions and sources of pollutants (current and future developments);
- assess ambient concentrations of pollutants;
- define air quality standards or guidelines;
- conduct a geographical comparison of ambient concentrations and standards;
- determine the extent of critical damages in areas where ambient concentrations exceed standards (in physical terms, and where possible in monetary terms); and
- identify the most important (priority) damage categories and priority pollutants.

Step 2. Gather information on technical measures and costs to reduce specific emissions of priority pollutants (abatement scenarios).

Step 3. Specify policy instruments to implement abatement scenarios.

Step 4. Assess the impact of abatement measures on the priority damage categories identified in Step 1 and the costs and benefits (not necessarily expressed in monetary terms) of the abatement methods.

Step 5. Identify major gaps and uncertainties in knowledge of impacts and measures and major deficiencies in the institutional framework, and outline options to reduce uncertainties and to strengthen institutions.

STEP 1: DEVELOP IMPACT SCENARIOS

A. Inventory of emissions and sources. Collect emission data per pollutant and per source. Potentially important pollutants are: NO_x, SO₂, VOC, suspended particles, PAH, and heavy metals. Potentially important sources are mobile sources (traffic), stationary combustion sources (including domestic activities such as cooking), and stationary process sources.

If emission data are not available, emissions must be estimated (see Chapter 3). The general method is to multiply some measure of source activity by emission factors to derive the emission of a pollutant per unit of source activity. The most appropriate measure of activity is source-dependent; it may be a physical measure (e.g., mileage for cars) or some economic measure. Activity scenarios assess likely or feasible developments of these activities.

Data necessary to estimate emissions:

- source name,
- source location,
- source activity,
- emission factor, and
- stack height or other dispersal factors.

Although emissions factors are influenced by policy measures, they can also be influenced by autonomous technological developments. This should be assessed in the reference scenario. Emissions factors are dependent on technological characteristics of the source.

1. Mobile sources

Activity: traffic intensity (motor vehicles/area/time-unit).

Location: street or grid.

Emissions factors depend on:

- a) characteristics of the vehicle engine,
- b) fuel quality,
- c) application of emission control devices,
- d) state of maintenance of vehicles, and road or street pavement, and
- e) pattern of traffic flow (congestion).

2. Stationary combustion sources

Activity: energy use (Joules/time-unit).

Location: exact co-ordinates or grid.

Emission factors depend on:

- a) combustion conditions,
- b) fuel type and fuel quality,
- c) application of emission control devices, and
- d) stack height.

3. Process sources (non-combustion sources)

Activity: a variety of measures.

Location: exact co-ordinates or grid.

Emissions factors depend on:

- a) process type,
- b) technology,
- c) state of maintenance, and
- d) emissions control measures installed.

B. Assessment of ambient concentrations and meteorological conditions. Collect available data on concentrations of pollutants identified in Step 1A. These data are used for the following purposes:

1. identify the most serious pollution problems in specific parts (grids) of the city;
2. study the specifics of the city's air pollution problem (seasonality, episodicity, trends);
3. check the data quality through plausibility evaluation, comparison with other cities, etc.; and
4. check results of dispersion models, or if not available, use data from comparable city.

Dispersion models. Run dispersion model calculations with emission and meteorology data from Step 1A as input (see Chapter 3). The result is a number of maps with isopleths indicating spatial distribution of ambient concentrations of each pollutant.

C. Review of air quality standards and guidelines. Review air quality international guidelines and available local standards of ambient concentrations of the pollutants identified in Step 1A.

D. Compare ambient concentrations with air quality standards.

1. Identify areas with concentrations above standards, and
2. Inventory people at risk in those areas (population exposure distribution).

E. Assessment of health, physical, and economic damage. Step 1D provides a preliminary indication of the seriousness of possible health damage through air pollution by identifying areas with concentrations above standards, and the population in those areas. If it is necessary to be more specific on air pollution damage, further work must be done. This step can be restricted to assessing damage in physical terms, or can be extended to monetary assessment. This step assesses damage to all relevant categories that include health; materials, buildings and monuments; and vegetation.

Assessment of health and physical damage requires the use of dose-response relationships. Chapter 4 provides an overview of the most relevant dose-response relationships. It also discusses the uncertainties surrounding the use of dose-response relationships, especially if they have been

developed in areas with different climatic and other conditions. Necessary steps for a dose-response analysis include an inventory of people, objects, and vegetation at risk between isopleths; and application of dose-response relationships to assess the damage in every area bounded by isopleths.

Assessment of damage in monetary terms is described in Chapter 4. Note that a considerable amount of valuation uncertainty is added to the uncertainty of the dose-response relationships. However, this step is necessary for conducting a full cost-benefit analysis of possible abatement measures.

F. Setting priorities. Based on the previous steps, the following can be identified:

1. most important damage categories,
2. prioritized air pollutants, and
3. most important sources of the priority air pollutants, based on the relative shares of sources to ambient concentrations (with the help of dispersion models, Step 1B), or less accurately based on the relative shares of sources to emissions (Step 1A).

STEP 2: IDENTIFY TECHNICAL MEASURES

A. For each crucial source of priority pollutants identified, describe technical measures, their costs, and their emission reduction potential (see Chapter 6).

B. For every priority pollutant, rank the measures from Step 2.A on the basis of cost-effectiveness (unit of emission avoided per unit of local currency).

C. Make emission-reduction scenarios for packages of measures (starting with the most cost-effective), and calculate their total costs and emission reduction effects.

STEP 3: IDENTIFY POLICY INSTRUMENTS

A. Authorities usually have several policy instruments at their disposal. The most commonly-used type of instrument is direct regulation through licensing, or process and product standards. Command and control instruments are, however, not necessarily the most efficient, and may not even be applicable in certain circumstances (see Chapter 7).

B. In order to design an effective and efficient "instrument-mix" to implement the measures identified in Step 2, the following steps are necessary:

1. inventory environmental policy instruments, and the legislative and institutional framework currently in use;
2. design an effective, efficient, and feasible package of policy instruments to implement the measures; and

3. identify the legislative, institutional, and financial actions needed to implement the package.

STEP 4: ANALYZE IMPACT (COST-BENEFIT ANALYSIS)

A. On the basis of Step 3, which identifies currently-used and potentially applicable instruments to implement the technical measures identified in Step 2, estimate which abatement scenarios can be implemented.

B. Estimate the damage reduction achieved by implementing these scenarios (following Step 1 with different emission factors and different levels of source activities and numbers).

1. If the damage assessment is restricted to comparing ambient concentrations with health standards, the benefits of the abatement scenarios can be expressed by the number of people no longer exposed to concentrations above standards.
2. If the damage assessment uses dose-response relationships to express the damage in physical terms, the benefits of the abatement scenarios can be expressed in physical terms.
3. If the damage assessment expresses damage in monetary terms, the benefits can be expressed in monetary terms.

C. Compare the costs of the abatement scenarios with the benefits.

D. Create an incremental cost of abatement curve (see Chapter 6, Table 6.2) to consolidate the findings and recommendations that emerge from the cost-effectiveness or cost-benefit analysis.

STEP 5: IMPROVE THE DECISION-MAKING PROCESS

A. Steps to improve decision making include the following:

1. conduct additional research to gather missing data,
2. calculate secondary economic effects of abatement scenarios,
3. strengthen research and implementing institutions, and
4. apply the policy instruments.

LEARNING FROM THE URBAIR EXPERIENCE

In the development of action plans for four URBAIR cities, proposed actions were divided into the following categories:

1. Abatement measures

- improved fuel quality,
- technology improvements for various source categories,
- fuel switching,
- traffic management, and
- transport/travel demand management

2. Improvement of database and air quality monitoring system

- improvement of air quality assessment,
- air pollution monitoring data improvements,
- emission inventory data improvement,
- dispersion model/exposure model improvements,
- improvement of assessment of damage and costs,
- improvement of institutional and regulatory framework, and
- awareness raising

Boxes 8.1 and 8.2 show the results from the development of the Metro Manila action plan.

Box 8.1: Results of analysis of selected abatement measures for Metro Manila

Abatement measure	Benefits			Time frame	
	Avoided emissions (tons PM ₁₀) ^a	Avoided health damage (million US\$)	Costs of measure (million US\$)	Introduction of measure ^b	Effect of measure
Vehicles					
Addressing gross polluters:					
Effective smoke-belching campaign	2,000	16-20 158 deaths 4 mill. RSD	0.08	Immediate	Short-term
Improving diesel quality	1,200	10-12 94 deaths 2.5 million RSD	10	Immediate	2-5 years
Inspection/maintenance	4,000	30-40 316 deaths 8 million RSD	5.5	Immediate	2-5 years
Fuel switching: diesel → gasoline in vehicles	2,000	59-73 600 deaths 15 million RSD	?	Immediate	5-10 years
Clean vehicle standards	7,000	94-116 895 deaths 24 million RSD	5-20	Immediate	5-10 years
Fuel combustion					
Cleaner fuel oil	5,000	10-20 100 deaths 2.5 million RSD	10-20	Immediate	1-2 years
Power plants					
Clean fuel	500	small	10	Immediate	1-2 years

a. The various abatement measures are not necessarily independent of each other. Thus, the "avoided emissions" stated in this table for each measure separately may not simply be added, if one wants an estimate of the total effect of a packages of measures.

b. Time frame for starting the work necessary to introduce measure.

Source: World Bank Technical Paper 380 (1997).

Box 8.2: Priority items from action plan proposed for Metro Manila

Issues	Actions required
TRAFFIC MANAGEMENT	
Immediate Improvement of Enforcement/Traffic Laws	Standardize traffic laws, rules and regulations by passing traffic code & use standard form; provide proper training; put in place more stringent drivers licensing system; set up monitoring and evaluation systems for enforcers and for violators.
Reactivate and expand computerized information system	Create technical group to evaluate existing IS and prepare plans.
Strengthen Traffic Safety Program	Effect traffic safety seminars (re-education). Create advisory committee; have traffic police present at all times; use media for information dissemination.
TRANSPORT DEMAND MANAGEMENT	
Implement para transit system and other environment friendly transport	Accelerate LRT and use of railways and improved Metro Ferry; study feasibility of electric vehicles.
Use parking policy to influence traffic mode mix	Provide guidelines; impose higher parking fees; parking restrictions in central areas, parking facilities near mass transit terminals; carpool guidance system, designate park/ride areas
IMPROVED FUEL QUALITY	
Decrease lead level in leaded gasoline	Enforce mandatory regulation
Market unleaded gasoline.	Establish voluntary-use tax system; issue an executive order to accelerate phase in or unleaded gasoline; IEC on proper use of unleaded gasoline
Identify/evaluate other additives.	Regulation, phasing 0.5% by 1996.
Decrease maximum allowable sulfur content in diesel and fuel oil.	
FUEL SWITCH	
Gasoline for diesel in UVs, CNG	Tax/subsidy modification; conduct study on technical requirements, health and safety and price/market implications
AIR QUALITY MONITORING	
Increase and upgrade monitoring capability	Encourage collaboration with NGOs, private sector to set up, operate and maintain monitoring stations. Tap funding support; rehabilitate the air pollution index board.
Encourage third party participation in environmental monitoring.	Solicit active participation of consulting firms and laboratories by accreditation in the conducting of compliance monitoring to encourage compliance and resolve reservations of some sectors on reliability of data.
Establish computerized database of all Manila data	Improve present database regarding air quality, meteorology and share with all concerned..
Develop an integrated and comprehensive emission inventory procedure, including emission factor review, update and QA procedures.	Require through EIS System for new plants by administrative order for old plants.
Improve emission inventory for Metro Manila; develop procedures and cost estimates.	Coordination and collaboration between environment agencies; tap funding support; require firms to submit data; improve present data gathering; seek USEPA assistance; set procedure and conduct study.
INSTITUTIONAL AND REGULATORY FRAMEWORK	
Implement "polluter's pay principle" through increased penalties for violators	Pass bills (Clean Air Act, Phil. Environmental Code) imposing high penalties.
TECHNOLOGY IMPROVEMENT	
Address highly polluting vehicles; upgrade jeepney engines	Enforce existing regulation, I&M engines to system, comply with new emission regulations.
Strict inspection/ maintenance requirement that all vehicles pass emission tests prior to registration.	Expand operations/coverage of MVIS; encourage private sector investment in I&M program through economic incentives and credit. Study possible accreditation of private entities for emission testing with clear sanctions and provision for training without conflict of interest.

Source: World Bank Technical Paper No. 380 (1997).

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APPENDIX 1: POLLUTANT FACT SHEETS

Source: *Handbook for Urban Air Improvement*, Butterwick et al, 1992.

Pollutant fact sheets	page
Sodium dioxide	106
Nitrous oxides	108
Particulates	111
Benzene	113
PAH	115
Formaldehyde	117
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POLLUTANT FACT SHEET: SO₂

1. DESCRIPTION

Sulphur dioxide (SO₂) is a colorless gas. It reacts on the surface of a variety of airborne solid particles, is readily soluble in water and can be oxidized within airborne water droplets.

2. OCCURRENCE IN THE AIR

Annual mean concentrations in most major European cities are now below 100 µg/m³, with maximum daily mean values in the range 250-500 µg/m³. Hourly peak values can be 1,000-2000 µg/m³. Natural background levels are about 5 µg/m³.

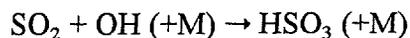
Acid aerosol (most of which is formed from SO₂) occurs in concentrations of the order of 0-20 µg/m³ (measured as sulfuric acid) in North America and Europe.

3. MAJOR SOURCES

The most important sources of emissions of SO₂ are fossil fuel combustion, smelting non-ferrous ores (mainly copper, lead, nickel and zinc), manufacture of sulfuric acid, conversion of wood pulp to paper, incineration of refuse, production of elemental sulfur. Coal burning is the single largest source of atmospheric SO₂, accounting for about 50% of annual global emissions in recent years, with oil burning accounting for a further 25-30% of emissions.

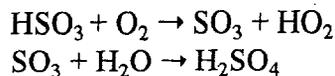
4. ATMOSPHERIC BEHAVIOR

SO₂ is the principal pollutant associated with the problem of acid deposition, after having been oxidized to sulfuric acid. The likely first step in a chain of reactions is oxidation of SO₂ by OH:



(Where M is a molecule of oxygen, nitrogen or other neutral gas which carries off the excess energy, thereby preventing the immediate reversal of the reaction.) Oxidation reactions involving O₂, O₃ and the hydroperoxy radical (HO₂) are so slow as to be insignificant. Oxidation reactions with organic peroxy radicals (RO₂) can become significant in highly polluted atmospheres.

The subsequent reactions of the transient HSO₃ radical are still uncertain, although ultimately it is transformed to sulfuric acid (H₂SO₄). The most likely mechanism is thought to be:



POLLUTANT FACT SHEET: SO₂

This sulfuric acid is generally present as an acid aerosol, often associated with other pollutants in droplets or solid particles of a wide range of sizes. The sulfuric acid is finally removed from the atmosphere by either wet or dry deposition.

5. HUMAN HEALTH EFFECTS

Concentrations of more than 10,000 $\mu\text{g}/\text{m}^3$ SO₂ can give rise to severe effects in the form of bronchoconstriction, chemical bronchitis and chemical tracheitis. Concentrations in the range 2,600-2,700 $\mu\text{g}/\text{m}^3$ give rise to immediate clinical symptoms with bronchospasm in asthmatics.

Epidemiological studies indicate the following effects after short term SO₂ exposures: possible small reversible declines in children's lung function (250-450 $\mu\text{g}/\text{m}^3$); aggravation of bronchitis (about 500 $\mu\text{g}/\text{m}^3$); increased mortality (500-1,000 $\mu\text{g}/\text{m}^3$).

Sulfuric acid and other sulfates also have human health effects. Respiratory effects have been reported for concentrations of 350-500 $\mu\text{g}/\text{m}^3$ sulfuric acid, with a lowest-demonstrated-effect level of 100 $\mu\text{g}/\text{m}^3$ for exercising adolescent asthmatics. The odor threshold for sulfuric acid is in the range of 750-3,000 $\mu\text{g}/\text{m}^3$.

High concentrations of SO₂ (>1,000 $\mu\text{g}/\text{m}^3$) together with suspended particles are believed to have been responsible for high mortality levels during London smog. (The December 1952 smog was associated with 4,000 excess deaths.)

6. OTHER ENVIRONMENTAL EFFECTS

There is evidence that some species of plants are affected by SO₂ concentrations of the order of 50-100 $\mu\text{g}/\text{m}^3$, although concentrations in most agricultural regions in Europe are unlikely to affect cereal yields. Various species of trees have exhibited effects at concentrations of less than 50 $\mu\text{g}/\text{m}^3$; however, interpretations of all of these studies are complicated by the presence of other pollutants (O₂NO_x acid deposition and heavy metal soil contamination).

POLLUTANT FACT SHEET: NO_x

1. DESCRIPTION

NO₂ is a collective term used to refer to two species of oxides of nitrogen: nitric oxide (NO) and nitrogen dioxide (NO₂). (Other members of this species exist, but are not included in the definition of NO_x). These two oxides are grouped together because most anthropogenic NO₂ derives from emissions of NO. Because this transformation occurs quite rapidly, NO₂ is generally regarded as being more important from the point of view of human health. Consequently, data on health risks, ambient concentration and standards and guidelines are generally expressed in terms of NO₂ rather than NO_x. NO₂ is a reddish-brown gas. It is a strong oxidant and soluble in water.

2. OCCURRENCE IN THE AIR

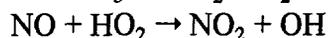
Annual mean concentrations in urban areas are generally in the range of 20-90 µg/m³. Levels vary significantly throughout the day, with peaks generally occurring twice daily as a consequence of "rush-hour" traffic. Maximum daily and 1/2 hour means can be as high as 400 µg/m³ and 850 µg/m³, respectively.

3. MAJOR SOURCES

On a global scale, natural emissions of nitrogen oxides (by bacterial and volcanic action and by lightning) far outweigh anthropogenic emissions. These give rise to low level background atmospheric concentrations. Anthropogenic emissions are mainly due to fossil fuel combustion from both stationary sources (heating, power generation) and transport (internal combustion engines.) In most cases, atmospheric nitrogen is oxidized to NO during combustion and then oxidized to NO₂ when emitted into the atmosphere. This process is temperature dependent, with less "thermal" NO being produced in lower temperature combustion processes. (Nitrogenous compounds in coal, and to a lesser extent in oil, also make a contribution to the total quantity of NO emitted.) The atmospheric oxidation of NO to NO₂ is caused by reaction with O₃ and other oxidants, such as HO₂. This occurs rapidly even when there are relatively low concentrations of NO and oxidants in the atmosphere. Other atmospheric contributions come from non-combustion processes. (For example, nitric acid manufacture, welding processes and the use of explosives.) Indoor sources of NO₂ include tobacco smoking and the use of gas fired appliances and oil stoves.

4. ATMOSPHERIC BEHAVIOR

When NO is emitted into the atmosphere, most of it is rapidly oxidized to NO₂ by O₃ or other oxidants such as HO₂:



POLLUTANT FACT SHEET: NO_x

In polluted atmospheres, other oxidation reactions take place involving hydrocarbons, aldehydes, CO and other compounds. NO also combines with OH radicals to produce nitrous acid (HNO₂).

Once formed, the atmospheric residence time of NO₂ is of the order of one day. It is then converted to nitric acid (HNO₃) by reaction with OH radicals. Most HNO₃ is then removed from the atmosphere by wet deposition, and to a lesser extent, by dry deposition.

5. HUMAN HEALTH EFFECTS

A variety of respiratory system effects have been reported to be associated with exposure to short- and long-term NO₂ concentrations less than 3.8 mg/m³ in humans and animals, including: (1) Altered lung function and symptomatic effects observed in controlled human exposure studies and in community epidemiological studies, (2) increased prevalence of acute respiratory illness and symptoms observed in outdoor community epidemiological studies and indoor community epidemiological studies comparing residents of gas and electric stove homes, and (3) lung tissue damage, development of emphysema-like lesions in the lung, and increased susceptibility to infection observed in animal toxicology studies. Certain human health effects may occur as a result of exposures to NO₂ concentrations at or approaching recorded ambient NO₂ levels.

Human pulmonary function effects of clear health concern resulting from single, short-term exposures of less than 3 hours duration have been unambiguously demonstrated only at concentrations (greater than 1.9 mg/m³) well in excess of ambient exposure levels typically encountered by the public. More subtle health effects that were of uncertain health significance, such as mild symptomatic effects, had been reported for some asthmatics after a single 2-hour exposure to about 1 mg/m³.

Young children and asthmatics are the groups at greatest risk from ambient NO₂ exposures. Chronic bronchitis and individuals with emphysema or other chronic respiratory disease may also be sensitive to NO₂ exposures. In addition, there is reason to believe that persons with cirrhosis of the liver or other liver, hormonal, and blood disorders, or persons undergoing certain types of drug therapies may also be more sensitive to NO₂.

POLLUTANT FACT SHEET: NO_x

6. OTHER ENVIRONMENTAL EFFECTS

Other environmental effects of NO₂ and NO_x compounds include increased acidic deposition and vegetation effects. Visible injury to vegetation due to NO₂ alone occurs at levels which are above ambient concentrations generally occurring within the United States and Europe, except around a few point sources. For long-term exposures, such as a growing season, the lowest concentration reported to depress growth is approximately 0.5 mg/m⁻³. Interactive effects with SO₂ may however be important.

POLLUTANT FACT SHEET: Particulates

1. DESCRIPTION

Particulate matter is a complex mixture of organic and inorganic substances, present in the atmosphere as both liquids and solids. Coarse particles can be regarded as those with an aerodynamic diameter greater than 2.5 μm , and fine particles less than 2.5 μm . Coarse particles usually contain earth crustal materials and fugitive dust from roads and industries. Fine particles contain the secondarily formed aerosols, combustion particles and recondensed organic metallic vapors. The acid component of particulate matter generally occurs as fine particles.

A wide range of terminology is applied to particulate matter, reflecting measuring methods (e.g. total suspended particulates, black smoke), site of deposition in humans (e.g. inhalable, thoracic particles) or physical characteristics (e.g. PM_{10} , which refers to an aerodynamic diameter of less than 10 microns).

A further distinction that can be made is to classify particulates as either "primary" or "secondary", according to their origin. Primary particulates are those emitted directly to the atmosphere while secondary particulates are those formed by reactions involving other pollutants. In the urban context, most secondary particulate matter occurs as nitrates formed in reactions involving NO_x .

2. OCCURRENCE IN THE AIR

Reported concentrations vary according to the sampling technique. In urban areas, typical annual mean values are 10-40 $\mu\text{g}/\text{m}^3$ (black smoke method) or 50-150 $\mu\text{g}/\text{m}^3$ (gravimetric method). Corresponding peak values are 100-250 $\mu\text{g}/\text{m}^3$ (black smoke method) and 200-400 $\mu\text{g}/\text{m}^3$ (gravimetric method). Background levels in rural areas range from 0-10 $\mu\text{g}/\text{m}^3$ (black smoke method).

3. MAJOR SOURCES

Particulate matter is emitted from a wide-range of sources including power plants and industrial processes, vehicular traffic, domestic coal burning and industrial incinerators. Natural sources are less widespread and less important. These include volcanoes and dust storms. Particulate matter can also be formed by the transformation of gaseous emissions such as oxides of sulfur and nitrogen, and VOCs.

4. ATMOSPHERIC BEHAVIOR

Particulate matter is removed from the atmosphere by both wet and dry deposition.

POLLUTANT FACT SHEET: Particulates

5. HUMAN HEALTH EFFECTS

Short term health effects of exposure to combined SO₂ black smoke and particulates include increased mortality, morbidity and deficits in pulmonary function. Some of the "lowest-observed effect" levels for short term exposure to particulate matter are: excess mortality -500 µg/m⁻³ (smoke); increased acute respiratory morbidity (adults) -250 µg/m⁻³ (smoke); decrements in lung function (children) -180 µg/m⁻³ (total suspended particulates)/110 µg/m⁻³ (thoracic particles). Smoke levels of up to 1,500 µg/m⁻³ occurred in the 1952 London smog (see also SO₂).

In addition, exposure to air pollutants and especially particulates may give rise to feelings of discomfort, which may cause annoyance. This subjective response has been widely reported in studies of Swedish cities.

6. OTHER ENVIRONMENTAL EFFECTS

Other environmental effects include the soiling of exposed surfaces, impairment of visibility, potential modification of climate and contribution to acid deposition.

POLLUTANT FACT SHEET: Benzene

1. DESCRIPTION

Benzene is a colorless, clear liquid with a boiling point of 80.1 degrees C. It is fairly stable chemically, but highly volatile (that is, it readily evaporates).

2. OCCURRENCE IN THE AIR

Ambient concentrations of benzene are typically between 3 and 160 $\mu\text{g}/\text{m}^3$. Levels close to major emission sources (for example, petrol stations) can be as high as several hundred $\mu\text{g}/\text{m}^3$.

3. MAJOR SOURCES

About 80% of anthropogenic emissions of benzene comes from petrol-fueled cars. This results from both the benzene content of petrol and the pyrolysis (thermal breakdown) of petrol. A further 5% of emissions comes from the handling, distribution and storage of petrol, and about 1% comes from oil refining. Significant emissions also come from benzene producing and handling industries, involving such processes as the catalytic reforming of naphtha and toluene hydrodealkylation.

The burning of wood and other organic material also results in an appreciable release of benzene. Some emissions also come from the use of benzene as a laboratory reagent and in sample collection, preparation and extraction. Cigarette smoking may be a significant source of benzene for smokers, especially in the indoor environment. Another source in the indoor environment is the use of benzene in glues, adhesive and solvents.

4. ATMOSPHERIC BEHAVIOR

Benzene is removed from the atmosphere by both wet deposition and chemical transformation in the atmosphere (principally in reaction with the hydroxyl radical OH). The half life for chemical transformation is about five days. Deposition on the soil usually leads to degradation by bacterial action or re-evaporation (owing to benzene's high vapor pressure).

POLLUTANT FACT SHEET: Benzene

5. HUMAN HEALTH EFFECTS

Benzene is known to have both carcinogenic and toxic effects. At levels of occupational exposure (several hundred mg/m^{-3}) there is a clear excess incidence of leukemia. No case of leukemia has been confirmed following regular and repeated occupational exposure to benzene in air at concentrations below $320 \text{ mg}/\text{m}^{-3}$.

Early manifestations of toxicity are anemia, leucocytopenia or thrombocytopenia (literally, "poverty" of leucocytes or thrombocytes). Persistent exposure to toxic levels of benzene may cause injury to the bone marrow, resulting in pancytopenia. Exposure to high levels ($>3,200 \text{ mg}/\text{m}^{-3}$) of benzene causes neurotoxic symptoms. No adverse effect on blood formation in humans has been confirmed following regular and repeated occupational exposure to benzene in air at concentrations below $80\text{-}96 \text{ mg}/\text{m}^{-3}$.

6. OTHER ENVIRONMENTAL EFFECTS

Benzene is generally toxic to biota, but there are not significant effects at ambient levels.

POLLUTANT FACT SHEET: PAH

1. DESCRIPTION

Polycyclic (or polynuclear) aromatic hydrocarbons (PAH) are a large group of organic compounds with two or more benzene rings. About 500 such compounds (including derivatives) have been detected in air. The best-known and most-measured of these is benzo[a]pyrene (BaP). The relative occurrence of individual compounds (the PAH profile) varies according to the source of the PAH.

2. OCCURRENCE IN THE AIR

BaP concentrations in most cities are in the range of 1-5 ng/m^{-3} . (Values of the order of 100 ng/m^{-3} were recorded in the 1960s when the use of open coal fires for domestic heating was more common). BaP concentrations of 40 ng/m^{-3} have been found in areas close to coke oven plants, and occupational exposures can be in the range of 10-40 $\mu\text{g/m}^{-3}$ (e.g. in aluminum smelting and coke production plants).

3. MAJOR SOURCES

PAH are formed mainly as a result of pyrolytic (thermal degradation) processes, especially the incomplete combustion of organic matter. Major sources include coke production, coal-fired heating, motor vehicles and, to a lesser extent, oil-fired heating and coal-fired power generation. (The contribution from coal-fired heating has decreased substantially as a result of smoke controls, especially in urban areas.)

4. ATMOSPHERIC BEHAVIOR

PAH are present in the atmosphere in gaseous form as well as adsorbed onto particulate matter. Smaller-molecule PAH tend to be predominantly in the gas phase, while larger-molecule PAH are more commonly bound to particulate matter. PAH are removed from the atmosphere by transformation (photochemical and thermal reactions involving OH radicals, O_2 , O_3 and oxides of nitrogen and sulfur) and by wet and dry deposition.

POLLUTANT FACT SHEET: PAH

5. HUMAN HEALTH EFFECTS

There is evidence that people working as chimney sweeps and tar workers suffered from skin cancers caused by substantial dermal exposure to PAH. There is also evidence that inhaled PAH have induced lung cancers in coke-oven workers, coal-gas workers and employees in aluminum production plants.

BaP is thought to be one of the most carcinogenic PAH. High levels of lung cancer have been observed in coke oven workers exposed to BaP concentration of about $300 \mu\text{g}/\text{m}^3$. (Ambient levels in major urban areas are typically in the range $1\text{-}10 \text{ ng}/\text{m}^3$.) It is believed that there is no safe level of exposure.

There are no known toxic effects other than carcinogenicity.

6. OTHER ENVIRONMENTAL EFFECTS

Laboratory tests involving exposure by skin painting, injection and inhalation have shown that PAH are toxic to animals, particularly small mammals.

POLLUTANT FACT SHEET: Formaldehyde

1. DESCRIPTION

Formaldehyde (HCHO) is the simplest and most common aldehyde found in the environment. At normal room temperature it is a colorless gas with a pungent odor.

2. OCCURRENCE IN THE AIR

Annual average concentrations in urban areas are generally in the range 5-10 $\mu\text{g}/\text{m}^3$ (compared to a natural background level of a few $\mu\text{g}/\text{m}^3$ or less). Levels in the vicinity of industrial sources are higher and short term peaks can be in the range 50-100 $\mu\text{g}/\text{m}^3$. (These peaks are most likely at peak traffic times or during photochemical smog episodes.) Indoor concentrations tend to be much higher than ambient concentrations, and can exceed 200 $\mu\text{g}/\text{m}^3$.

3. MAJOR SOURCES

Formaldehyde occurs naturally in low concentrations. (It is intermediary in the methane cycle.) The major anthropogenic sources of atmospheric formaldehyde include: the production and use of formaldehyde and reactions of oxidized hydrocarbons from stationary and mobile sources (especially diesel vehicles). This can give rise to "primary" formaldehyde, emitted directly to the atmosphere, and "secondary" formaldehyde, which is formed in the atmosphere from reactions involving hydrocarbons. Major indoor sources include products containing formaldehyde (e.g. resins), insulating materials, chipboard, plywood, fabrics, cigarette smoke, heating and cooking.

4. ATMOSPHERIC BEHAVIOR

Formaldehyde breaks down relatively rapidly in the atmosphere during the day time, by photolysis and in reaction with the hydroxyl radical. One of the products of these breakdown processes is CO, but this is not produced in significant quantities. Formaldehyde is also removed from the atmosphere by wet and dry deposition.

5. HUMAN HEALTH EFFECTS

Epidemiological studies of occupationally exposed groups and controlled exposure studies indicate a range of health effects resulting from short term exposure. The threshold for eye irritation has been reported at 10 $\mu\text{g}/\text{m}^3$ and that for throat at 100 $\mu\text{g}/\text{m}^3$. More serious effects (e.g. oedema, inflammation and pneumonia) are only reported for concentrations of about 40 mg/m^3 and above. There is evidence of carcinogenicity in animals but the evidence of carcinogenicity in humans is inadequate. There appears to be great variability in individual susceptibility to formaldehyde, with some individuals showing extreme sensitivity of an allergenic nature.

6. OTHER ENVIRONMENTAL EFFECTS

There are no other environmental effects of great significance.

POLLUTANT FACT SHEET: VOCs

1. DESCRIPTION

VOCs (Volatile Organic Compounds) comprise a very wide range of individual substances, including hydrocarbons (alkanes, alkenes and aromatics), halocarbons (e.g. trichloroethylene) and oxygenates (alcohols, aldehydes and ketones). All are organic compounds of carbon and are of sufficient volatility to exist as vapor in the atmosphere.

2. OCCURRENCE IN THE AIR

Most measurements of total VOCs are in terms of their carbon content, without analysis as individual compounds. The major contributor to VOCs is normally methane which has a global background concentration of 1.6 ppm (approximately $1,100 \mu\text{g}/\text{m}^3$). Whilst most other individual compounds (e.g. benzene) are present in urban air at concentrations of a few $\mu\text{g}/\text{m}^3$, or less, total VOCs amount to several hundred $\mu\text{g}/\text{m}^3$ in concentration in excess of the methane level.

3. MAJOR SOURCES

These vary greatly for individual compounds. Hydrocarbons arise substantially from gasoline evaporation and incomplete combustion, and from leakage of natural gas from distribution systems. Oxygenates arise in vehicle exhaust and are also formed in atmospheric chemical reactions. Evaporation of solvents, used for example in paints, or industrial decreasing processes, causes release of hydrocarbons, oxygenates and halocarbons to the atmosphere.

There is at present uncertainty about the significance of coal combustion as a source of VOCs. Given the uncertainty and the lack of cost effective measures for VOC emission reduction from this source, this aspect is not considered further in the Guidebook

4. ATMOSPHERIC BEHAVIOR

Immense variations occur between compounds, with some being highly reactive and of short atmospheric lifetime, and others very long-lived. The short-lived compounds, especially the chemically reactive hydrocarbons, contribute substantially to atmospheric photochemical reactions and thus to formation of ozone and PAN. Less reactive substances are dispersed away from urban areas and decompose slowly in the non-urban atmosphere. Certain of the halocarbons (e.g. methyl chloroform) are so unreactive in the lower atmosphere that they enter into the stratosphere where they can contribute to ozone destruction.

5. HUMAN HEALTH EFFECTS

No generalizations can be made, as health effects are compound-specific. Some VOCs are of significant toxicity, and benzene, PAH and formaldehyde are given detailed consideration elsewhere in this Guidebook. A number of VOCs are proven or suspected carcinogens.

POLLUTANT FACT SHEET: VOCs**6. OTHER ENVIRONMENTAL EFFECTS**

Many VOCs are of significance in relation to their environmental effects, particularly their contribution to secondary pollutant formation and to stratospheric ozone depletion. VOCs also contribute indirectly to formation of atmospheric acidity. Ethylene, a major VOC component, is a plant hormone and can seriously inhibit the growth of plants.

POLLUTANT FACT SHEET: Lead

1. DESCRIPTION

Lead is a bluish or silver-gray soft metal. In the context of air pollution, two of its most important compounds are tetraethyl and tetramethyl lead, which are used extensively as "anti-knock" additives in petrol.

2. OCCURRENCE IN THE AIR

In rural areas lead levels fall in the range of 0.1-0.3 $\mu\text{g}/\text{m}^3$. Most European urban values are now less than 1 $\mu\text{g}/\text{m}^3$.

Most of the lead in air occurs as fine, inorganic particles (e.g. PbBrCl). These particles are mainly submicron sized ($<10^{-6}$ m), although larger particles are also present. Some 10% or less occurs as organic (e.g. alkyl) lead which has escaped combustion.

3. MAJOR SOURCES

Historically, the principal source of atmospheric lead has been the combustion of alkyl lead additives in motor fuels. However, the contribution from this source is decreasing in most countries as a result of controls on the lead content of fuels and the availability of lead free petrol. Other contributions come from: the production of metals (lead, copper, nickel, zinc, cadmium, iron and steel), thermal power plants and other coal combustion plants. Smaller contributions come from mining, cement production, refuse incineration and wood combustion. Lead based paints also contribute to lead in dust and hence in air by resuspension.

4. ATMOSPHERIC BEHAVIOR

Particulate lead is removed from the atmosphere by wet or dry deposition. The residence time of lead-containing particles in the atmosphere varies according to a number of factors such as particle size, wind currents, rainfall and emission height. Alkyl lead in the atmosphere is decomposed, primarily by reaction with hydroxyl radicals (OH).

5. HUMAN HEALTH EFFECTS

Human exposure to lead is through inhalation of airborne lead and ingestions of lead in foodstuffs and beverages. Whilst most airborne lead is man-made, an appreciable proportion of that in food and water is of natural origin. Nevertheless both deposition of airborne lead, and lead from other man-made sources (e.g. pipes and solders) contribute to dietary intake. Blood lead concentrations are a good indicator of recent exposure to lead from all sources, and adverse health effects tend to increase in severity with increasing blood lead level.

POLLUTANT FACT SHEET: Lead

EPA standards are based on the concept of a relationship between ambient air lead and blood lead concentrations, and presume that a blood lead level of $0.15 \mu\text{g}/\text{m}1^{-1}$ (mean value for children) can be achieved at an ambient air lead level of $1.5 \mu\text{g}/\text{m}^{-3}$.

The most sensitive body systems to the effects of lead are the haematopoietic system, the nervous system and the renal system. In addition, lead has been shown to affect the normal functions of the reproductive, endocrine, hepatic, cardiovascular, immunologic and gastrointestinal systems. The most sensitive group to lead poisoning is children. Some studies indicate that children with high levels of lead accumulated in their baby teeth experience more behavioral problems, lower IQs and decreased ability to concentrate, although these findings are currently controversial.

Examples of some "lowest-observed-effect" levels for children (identified by the EPA) are: disturbance of haem synthesis via enzyme inhibition at $0.1 \mu\text{g}/\text{m}1^{-1}$; anaemia at $0.4 \mu\text{g}/\text{m}1^{-1}$; encephalopathic symptoms at $0.8 \mu\text{g}/\text{m}1^{-1}$.

6. OTHER ENVIRONMENTAL EFFECTS

Lead is generally toxic to both plants and animals, and although no serious effects are generally seen at current environmental levels, it is widely considered prudent to limit further dispersal of lead as far as possible.

POLLUTANT FACT SHEET: Cadmium

1. DESCRIPTION

Cadmium is a soft, silver-white metal, with a relatively high vapor pressure.

2. OCCURRENCE IN AIR

Yearly mean concentrations in rural areas range from $<1-5 \text{ ng/m}^3$; in urban areas from $5-15 \text{ ng/m}^3$; in industrial areas from $15-50 \text{ ng/m}^3$. Short term values near metals processing industries can be as high as $5-11 \text{ } \mu\text{g/m}^3$.

3. MAJOR SOURCES

The major sources of emissions of cadmium to the air are oil and coal combustion, metal production (iron and steel, zinc, cadmium, copper, nickel), solid waste disposal, battery manufacture and cement production. Emissions from natural sources (e.g. volcanoes) are also significant. Tobacco smoking can make a significant contribution in the indoor environment. Tyre abrasion is also a source of cadmium.

4. ATMOSPHERIC BEHAVIOR

Cadmium is mainly present in the atmosphere in particulate form. It is removed by either wet or dry deposition, and can thus enter the food chain. The atmospheric residence time depends, amongst other things, upon particle size, the height of emission, and climatic conditions.

5. HUMAN HEALTH EFFECTS

Human exposure to cadmium occurs both by inhalation of airborne cadmium and ingestion of cadmium which has entered the food chain. Cadmium enters the food chain from natural sources and via the deposition of airborne cadmium.

Airborne cadmium is absorbed in the lungs and travels to the liver and to the kidneys. The health effects of cadmium occur because it competes with and displaces zinc in a number of zinc-containing metalloenzymes. The cadmium binds irreversibly with active sites, thereby destroying normal metabolism.

In terms of long term low level exposure, the kidney is regarded as the critical organ, with renal dysfunction expected as cadmium accumulates to levels of about 200 mg/kg^{-1} wet weight. Acute and chronic respiratory effects (chemical pneumonia) may be expected to result from exposure to 1 mg/m^3 and $20 \text{ } \mu\text{g/m}^3$ (for 20 years), respectively.

POLLUTANT FACT SHEET: Cadmium

The best known example of the health effects of cadmium occurred in Japan. A number of people (mainly post-menopausal women) suffered from what came to be known as "Itai-itai" ("ouch-ouch") a condition characterized by severe pains in the back, joints and abdomen, development of a waddling gait, kidney lesions, proteinuria, glycostria, and loss of calcium from the bones leading, in some cases, to multiple fractures. While the disease was related specifically to high cadmium levels, the contribution of other metals (especially zinc) and of poor nutrition is uncertain.

Other health effects of cadmium that have been identified in the literature include pulmonary and gastrointestinal effects (nausea, vomiting, diarrhea, cardio-pulmonary depression) and damage to the liver.

6. OTHER ENVIRONMENTAL EFFECTS

Cadmium is generally toxic to both aquatic and terrestrial biota. For example, toxic effects have been found in aquatic organisms at levels which can be observed in polluted environments. Cadmium toxicity is enhanced by the presence of other metals (e.g. zinc and copper) and is also affected by the hardness of water. For this reason, it has been difficult to establish definitive dose-response characteristics.

POLLUTANT FACT SHEET: CO

1. DESCRIPTION

Carbon monoxide (CO is a colorless, odorless, tasteless gas that is slightly lighter than air.)

2. OCCURRENCE IN AIR

Natural background levels of CO fall in the range 0.01-0.23 mg/m³. Levels in urban areas are highly variable, depending upon weather conditions and traffic density. 8-hour mean values are generally less than 20 mg/m³ but can be as high as 60 mg/m³.

3. MAJOR SOURCES

CO is an intermediate product through which all carbon species must pass when combusted in oxygen. In the presence of an adequate supply of O₂, most CO produced during combustion is immediately oxidized to CO₂. However, this is not the case in spark ignition engines, especially under idling and deceleration conditions. Thus, the major source of atmospheric CO is the spark ignition combustion engine. Smaller contributions come from all other processes involving the combustion of organic matter (for example in power stations, industry, waste incineration). In the indoor environment, tobacco smoking can be a significant source of CO.

4. ATMOSPHERIC BEHAVIOR

Once emitted to the atmosphere, CO is oxidized to CO₂.

5. HUMAN HEALTH EFFECTS

When CO is inhaled it can enter the blood stream and disrupt the supply of essential O₂ to the body's tissues. The health effects of CO result principally from its ability to displace O₂ on hemoglobin, forming carboxyhemoglobin (COHb). (The normal function of hemoglobin is to transport O₂ from the lungs to all body tissues.) The consequent reduced O₂ availability (hypoxia) can give rise to a wide range of health effects (depending on how much the flow of oxygen to the body is impeded).

These health effects are usually related to blood levels of COHb (expressed as a percentage), which can in turn be related to exposure (as a function of exposure time as well as concentration). The "no-observed-effects" level is about 2% COHb which can be related to an 8 hour exposure (moderate activity) to 15-20 mg/m³.

POLLUTANT FACT SHEET: CO

Certain neurobehavioral effects can be expected at about 5% COHb (moderate activity for 8 hours in 40 mg/m^3) that can be related to observable ambient concentrations. These include: impaired learning ability, reduced vigilance (ability to detect small changes in the subject's environment), decreased manual dexterity, impaired performance of complex tasks, and disturbed sleep activity. There is suggestive but not conclusive evidence that drivers in fatal auto accidents often have elevated COHb levels. (There is no evidence as to the significance of this.)

In addition, increased risk of certain effects on the cardiovascular system can be expected to begin at levels close to peak ambient conditions. These effects include: local myocardial ischemia (in which a part of the heart muscle is deprived of O_2), aggravation of angina pectoris, myocardial infarction (heart attack including those leading to sudden death), reduced exercise and physical work capacity, enhanced development of arteriosclerosis and coronary artery disease.

Elevated COHb levels can also reduce the availability of O_2 to the central nervous system (CNS), including the brain. High levels may cause strokes, involving (depending on the duration of the O_2 deficit): unconsciousness and convulsing, brain swelling and protusions, death to part of the brain or even the death of the individual. Repeated episodes of impaired O_2 supply would be expected to damage the blood-brain barrier and possibly cause structural damage resulting in the reduced ability of the CNS to transmit information.

Individuals most at risk to the effects of CO include those with existing cardiovascular or chronic respiratory problems, the elderly, young children and fetuses.

6. OTHER ENVIRONMENTAL EFFECTS

There are few, if any, other significant environmental effects. Plants both produce and metabolize CO and are only harmed by prolonged exposure to very high levels. (The lowest level for which significant effects on vegetation have been reported is 115 mg/m^3 for 3 to 35 days.)

POLLUTANT FACT SHEET: O₃ and PAN

1. DESCRIPTION

Ozone (O₃) is the tri-atomic form of molecular oxygen. (Most atmospheric oxygen is in the di-atomic molecular form, O₂.) It is one of the strongest oxidizing agents, which makes it highly reactive. Peroxyacetyl nitrate (PAN) is an oxidizing agent formed by the reaction of organic compounds (e.g. aldehydes) with OH radicals, followed by the addition of O₂ and NO₂.

2. OCCURRENCE IN THE AIR

Background levels of O₃ in Europe are usually less than 30 µg/m⁻³ but can be as high as 120 µg/m⁻³. Maximum hourly values may exceed 300 µg/m⁻³ in rural areas and 350 µg/m⁻³ in urban areas.

PAN concentrations seem to have a diurnal pattern similar to that of O₃ with the peak value of PAN occurring several hours before that of O₃. Daily mean values for PAN tend to be some 2-20% of values for O₃. Maximum values reported for PAN approach the figure of 100 µg/m⁻³.

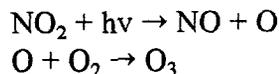
3. MAJOR SOURCES

Most of the O₃ in the troposphere (lower atmosphere) is formed indirectly by the action of sunlight on nitrogen dioxide. There are no direct emissions of O₃ to the atmosphere. About 10-15% of tropospheric O₃ is transported from the stratosphere where it is formed by the action of UV radiation on O₂. In addition to O₃, photochemical reactions produce a number of oxidants including peroxyacetyl nitrates (PAN), nitric acid and hydrogen peroxide, as well as secondary aldehydes, formic acid, fine particulates and an array of short-lived radicals.

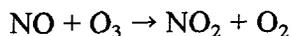
As a result of the various reactions that take place in the atmosphere, O₃ tends to build up downwind of urban centers (where most of the NO_x is emitted from vehicles).

4. ATMOSPHERIC BEHAVIOR

The O₃ producing reactions are:

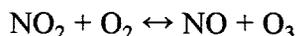


The reaction products, NO and O₃ can react to O₂ and NO₂:

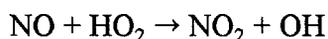


POLLUTANT FACT SHEET: O₃ and PAN

Thus, the net result can be summarized as reversible reaction:



The rate at which O₃ is produced is determined by a number of factors including the concentrations of each of the compounds and the intensity of sunlight. For this reason, O₃ episodes occur on hot days. The presence of other oxidants (e.g. HO₂) in the atmosphere contributes to the build up of O₃ by oxidizing NO (produced during O₃ formation) to NO₂:



The NO₂ is then available for further O₃ formation. Short-lived VOCs, especially the chemically reactive hydrocarbons, contribute substantially to atmospheric photochemical reactions and thus to the formation of both O₃ and PAN. The lifetime of O₃ in polluted areas is about one day (and more in unpolluted areas). O₃ is removed from the atmosphere at approximately equal rates by dry deposition and chemical decomposition. One such reaction involves the OH radical:



The removal of NO₂ from the atmosphere disturbs the equilibrium position of the reversible reaction, NO₂ + O₂ ↔ NO + O₃, such that the concentration of O₃ is decreased. Once in water or soil, O₃ decomposes very rapidly.

5. HUMAN HEALTH EFFECTS

O₃ and other oxidants cause a range of acute effects including eye, nose and throat irritation, chest discomfort, cough and headache. These have been associated with hourly oxidant levels of about 200 µg/m⁻³. Pulmonary function decrements in children and young adults have been reported at hourly average O₃ concentrations in the range 160-300 µg/m⁻³. Increased incidence of asthmatic attacks and respiratory symptoms have been observed in asthmatics exposed to similar levels of O₃. The non-ozone components of the photochemical mixture cause eye irritation at O₃ levels of about 200 µg/m⁻³.

6. OTHER ENVIRONMENTAL EFFECTS

Other environmental effects include damage to materials (including as a result of prolonged exposure to low concentrations), and vegetation effects. (Claims that O₃ concentrations of 200 µg/m⁻³ cause a significant reduction in plant growth have not been accepted by the USEPA.)

APPENDIX 2

MONITORING METHODS

FACT SHEETS

Source: *Handbook for Urban Air Improvement*, Butterwick, et al, 1991.

Monitoring fact sheets	page
Particulates	130
Nitrogen dioxides	131
Sodium dioxide	133
O ₃	135
Carbon monoxide	136
VOCs	137
Benzene	138
PAH	139
Lead and Cadmium	140

MONITORING FACT SHEET: Particulates
Hi-Volume Sampler Method (Total Suspended Particulates)
<p>Method: Particulate matter is collected by drawing air through a filter. The concentration is then determined from the mass collected.</p> <p>Analysis: Laboratory based.</p> <p>Sampling Period: The sampling period is 24 hours.</p> <p>Sophistication: High</p> <p>Interference: Interference can occur from gases which are also collected by reaction on the filter paper.</p> <p>Cost: The cost of each sampler is about 1,500 ECU.</p> <p>Detection Limit: About $5 \mu\text{g}/\text{m}^3$.</p>
Smoke Shade Reflections Method
<p>Method: Particulate matter is collected by drawing air through a filter. The concentration is then inferred from the light reflectance of the darkened filter.</p> <p>Analysis: Laboratory based.</p> <p>Sampling Period: The sampling period is 24 hours.</p> <p>Interference: The method is not strictly a measure of total suspended particulates. It actually measures "standard smoke", the value for which is derived from a calibration curve. This measure indicates the elemental carbon content of the air, rather than the total suspended particulate content.</p> <p>Cost: The cost of each sampler is about 1,500 ECU. (This does not include the cost of the reflectometer.)</p> <p>Detection Limit: About $5 \mu\text{g}/\text{m}^3$.</p>
Beta-Gauge Method
<p>Method: Particulate matter is collected on high efficiency glass fiber filter tape, through which the sample air is drawn. The filter tape runs between a radioactive source (emitting β-radiation) and a detection device. The mass of particulate is estimated from the observed absorption of β-radiation.</p> <p>Analysis: Semi-continuous automatic.</p> <p>Averaging Time: The monitoring is cyclic and permits a time resolution of the scale of hours or even minutes.</p> <p>Sophistication: Intermediate.</p> <p>Interference: There are no interferences, but the reading is dependent upon the chemical nature of the particulate matter, as well as its mass.</p> <p>Cost: The cost of each analyzer is about 15,000 ECU.</p> <p>Detection Limit: About $5 \mu\text{g}/\text{m}^3$.</p>

MONITORING FACT SHEET: NO₂**Chemiluminescence Method**

Method: The analyzer actually measures the NO concentration of air. This is determined by measuring the light emitted when NO is reacted with O₃. (The O₃ is generated within the instrument). To investigate the NO₂ content of air, the NO₂ must first be thermally decomposed to NO. The concentration of NO₂ is then inferred by comparing the reading for NO from the primary sample with the reading for air containing NO and decomposed NO₂.

Analysis: Continuous automatic.

Rise Time: The 90% rise time is about 2 seconds.

Sophistication: High.

Interference: There is some interference in the NO₂ channel from the decomposition of other atmospheric nitrogen based compounds, including nitric acid, alkyl nitrates and alkyl nitrites.

Cost: The cost of each analyzer is about 17,000 ECU.

Detection Limits: About 1 µg/m⁻³.

Christie Arsenite Method

Method: Nitrogen dioxide is collected by bubbling air through a sodium hydroxide-sodium arsenite solution to form a stable solution of sodium nitrite. The nitrite ion produced during sampling is reacted with color forming reagents and the concentration of NO₂ is then inferred colorimetrically.

Analysis: Laboratory based.

Sampling Period: The sampling period is 24 hours.

Sophistication: Low.

Interference: The presence of NO can increase the NO₂ response by 5-15%. Interference from SO₂ can be eliminated by converting it to sulfate ion with hydrogen peroxide before analysis takes place.

Cost: Low.

Detection Limits: About 2 µg/m⁻³.

Diffusion Tube Method

Method: NO₂ is absorbed and converted to nitrite by triethanolamine, after diffusion along a plastic tube. The NO₂ concentration is then determined colorimetrically after the nitrite has been reacted with a color forming reagent.

Analysis: Laboratory based.

Sampling Period: Sampling usually takes place over a seven to fourteen day period, from which daily averages can be calculated. Shorter sampling periods can be used at the expense of the sensitivity of the method.

Sophistication: Low.

Interference: There can be small amount of interference from SO₂, but not at the concentrations normally present in ambient air. This is a simple technique potentially subject to a number of interferences. However, recent trials have nevertheless shown the technique to give remarkably reliable measurements.

Cost: Low.

Detection Limits: About 2 µg/m⁻³.

MONITORING FACT SHEET: NO₂**Differential Optical Absorption Spectroscopy Method**

Method: The Differential Optical Absorption Spectroscopy (DOAS) technique makes use of the fact that gases (e.g. NO₂) absorb light at precise wavelengths which are unique to themselves. In operation, a beam of light with a known spectrum is transmitted through the atmosphere from a source to a receptor. The concentration of a number of gases can be determined by analysis of the spectrum of light incident at the receptor. This involves comparison of the intensity of light at that wavelength absorbed uniquely by a specific gas (e.g. NO₂) with the intensity of light absorbed at a wavelength which is not absorbed by any gas.

Analysis: Semi-continuous automatic.

Sampling Period: Data is integrated over a period of five minutes.

Sophistication: High.

Interference: None.

Cost: 70,000-115,000 ECU (capable of measuring several gases).

Detection Limits: 1 µg/m⁻³.

MONITORING FACT SHEET: SO₂**Hydrogen Peroxide Acidimetric and Colorimetric Methods**

Method: SO₂ is absorbed in an oxidizing solution (e.g. dilute hydrogen peroxide, H₂O₂) which converts it to sulfuric acid (H₂SO₄). The original concentration of SO₂ is then inferred by determining the free acid (H⁺ ion) concentration by filtration or electrically, by conductivity or pH measurements. Alternatively, the sulfate concentration can be determined by reaction with a color forming reagent, followed by spectrophotometric measurement of the color or by ion chromatography.

Location of Analysis: Laboratory based.

Sampling Period: 24-hour sampling period allows calculation of averaging time of one day or greater.

Sophistication: Low sophistication, especially acidimetric methods.

Interference: The acidimetric method is prone to interference from any other gas which yields an acid when absorbed in solution, and more seriously, from any alkaline substance (i.e. ammonia, NH₃) which neutralizes the acid. Acid and alkaline particulate matter can also interfere with the determination of SO₂ but is normally excluded by a filter. The acidimetric method has been widely criticized on account of these interferences. In contrast to the acidimetric method, colorimetric methods are highly specific, and therefore relatively free from interference.

Cost: The acidimetric methods are very low cost. Colorimetric methods are more expensive, but not prohibitively so, especially in developed countries. Ion chromatographic analysis of sulfate is more reliable but requires costly equipment.

Detection Limits: Both kinds of methods have a detection limit of about 5 µg/m⁻³. However, if acidimetric determination of SO₂ is by means of titration, the detection limit might rise to around 25 µg/m⁻³, depending on the quality of titration work.

Colorimetric Pararosaniline Method

Method: Air is bubbled through a solution of dipotassium tetrachloromercurate. SO₂ is continuously absorbed to form the non-volatile dichlorosulphitomercurate ion, which then reacts with formaldehyde and bleached pararosaniline to form red purple pararosaniline methyl sulphonic acid. The concentration of SO₂ is determined from the color intensity of the dye, which is measured at a wavelength of 560 nm.

Analysis: Laboratory based.

Sampling Period: The sampling period can be as little as 30 minutes, but 24 hours is most commonly used.

Sophistication: Intermediate.

Interference: The reaction is specific to SO₂ and sulfite salts which means that there is no significant interference in general atmospheric monitoring.

Cost: Low.

Detection Limits: About 5 µg/m⁻³.

MONITORING FACT SHEET: SO₂
Gas Phase Fluorescence Method
<p>Method: Pulsed ultra-violet light (with a wavelength of 214 nm) is used to irradiate the sample gas (i.e. air) flowing continuously through an optical cell. SO₂ molecules absorb the radiation and re-emit part of the energy at a different wavelength. This "fluorescence" is then detected by a photomultiplier. SO₂ has a fluorescence band centered near 340 nm. The strength of the electrical signal generated in the photomultiplier indicates the concentration of SO₂ in the air sample.</p> <p>Analysis: Continuous automatic.</p> <p>Rise Time: The 90% rise time is two minutes.</p> <p>Sophistication: High.</p> <p>Interference: There is no interference. The fluorescent response to incident radiation of 214 nm is specific to SO₂. (The wavelength of the incident radiation is precisely selected using optical filters.)</p> <p>Cost: The cost of each analyzer is about 14,200 ECU.</p> <p>Detection Limits: About 1 µg/m⁻³.</p>
Differential Optical Absorption Spectroscopy Method
<p>Method: The SO₂ content of air can be determined by burning air samples in a hydrogen rich flame. Light emissions are measured with a photomultiplier in a photometric detector. The concentration of SO₂ can be derived from the intensity of light emissions of a wavelength (394 nm) characteristic of sulfur. This method is being increasingly displaced by the gas phase fluorescence method.</p> <p>Analysis: Continuous automatic.</p> <p>Rise Time: The 90% rise time is about 25 seconds.</p> <p>Sophistication: High.</p> <p>Interference: Interference can occur from other gas phase sulfur compounds that are present in the atmosphere. Selective filters to remove these compounds are available, but their efficiency needs to be tested.</p> <p>Cost: The cost of each analyzer is about 14,200 ECU.</p> <p>Detection Limits: 1 µg/m⁻³.</p>
Flame Photometric Method
<p>Method: The SO₂ content of air can be determined by burning air samples in a hydrogen rich flame. Light emissions are measured with a photomultiplier in a photometric detector. The concentration of SO₂ can be derived from the intensity of light emissions of a wavelength (394 nm) characteristic of sulfur. This method is being increasingly displaced by the gas phase fluorescence method.</p> <p>Analysis: Continuous automatic.</p> <p>Rise Time: The 90% rise time is about 25 seconds.</p> <p>Sophistication: High.</p> <p>Interference: Interference can occur from other gas phase sulfur compounds that are present in the atmosphere. Selective filters to remove these compounds are available, but their efficiency needs to be tested.</p> <p>Cost: The cost of each analyzer is about 14,200 ECU.</p> <p>Detection Limits: 1 µg/m⁻³.</p>

MONITORING FACT SHEET: O₃**Ultra-violet Photometry Method**

Method: This technique is based on the fact that O₃ absorbs ultra-violet radiation at 253.7 nm. Sample air is drawn through an absorption cell across the path of a beam of ultra-violet light. The concentration of O₃ is determined from the degree of absorption at 253.7 nm.

Analysis: Continuous automatic.

Rise Time: The instruments typically give a reading every 30 seconds.

Sophistication: High.

Interference: There can be some interference from atmospheric hydrocarbons, but this is usually slight in urban air.

Cost: The cost of each analyzer is about 11,000 ECU.

Detection Limit: About 6 µg/m⁻³.

Chemiluminescence Method

Method: Sample air is mixed with ethylene, C₂H₄ (supplied from a cylinder) in a flow cell at atmospheric pressure. The two gases react rapidly with accompanying emissions in the 350 to 600 nm wavelength region. These emissions are monitored with a sensitive photomultiplier and the concentration of O₃ is inferred from the intensity of the signal.

Analysis: Continuous automatic.

Rise Time: The 90% rise time is approximately 3 seconds.

Sophistication: High.

Interference: There are no known interferences.

Cost: The cost of each analyzer is about 11,000 ECU.

Detection Limit: About 2 µg/m⁻³.

Differential Optical Absorption Spectroscopy Method

Method: The Differential Optical Absorption Spectroscopy (DOAS) technique makes use of the fact that gases (e.g. O₃) absorb light at precise wavelengths which are unique to themselves. In operation, a beam of light with a known spectrum is transmitted through the atmosphere from a source to a receptor. The concentration of a number of gases can be determined by analysis of the spectrum of light incident at the receptor. This involves comparison of the intensity of light at that wavelength absorbed uniquely by a specific gas (e.g. O₃) with the intensity of light at a wavelength which is not absorbed by any gas.

Analysis: Continuous automatic.

Sampling Period: Data is integrated over a period of five minutes.

Sophistication: High.

Interference: None.

Cost: 70,000-115,000 ECU (capable of measuring several pollutants).

Detection Limit: 3 µg/m⁻³.

MONITORING FACT SHEET: CO**Infra-Red Absorption Method**

Method: This technique is based on the fact that CO absorbs light at a characteristic wavelength (4.67 μm) in the infra-red spectrum. When an air sample is irradiated with such light, the CO concentration can be determined from the extent to which the sample absorbs the radiation. There are two main variants in analyzer design, referred to as the non-dispersive infra-red and gas filter correlation techniques.

Analysis: Continuous automatic.

Rise Time: The 90% rise time is about 5 seconds.

Sophistication: High.

Interference: There is negligible interference ($< 1 \text{ mg/m}^3$ in urban air). Potential interferences from CO_2 and water vapor are overcome in instrument design.

Cost: The cost of each analyzer is about 11,000 ECU.

Detection Limit: Less than 0.5 mg/m^3 .

Electrochemical Cell Method

Method: The concentration of CO is determined electrochemically during the oxidation of CO to CO_2 .

Analysis: Continuous automatic.

Rise Time: The 90% rise time is about 25 seconds.

Sophistication: High.

Interference: Other oxidizable gases can interfere. However, inlet filters are available and in any case concentrations of interferent gases are generally well below those of CO.

Cost: The cost of each analyzer is about 3,000 ECU.

Detection Limit: Less than 0.5 mg/m^3 .

MONITORING FACT SHEET: Volatile Organic Compounds (VOCs)
Total Hydrocarbon/Non-Methane Hydrocarbon Analyzer Method
<p>Method: Hydrogen is mixed with the sample air and combusted. An electric current produced from charged ions in the flame indicates the total hydrocarbon content of the air. The methane content can be determined by catalytically decomposing all other hydrocarbons before measurement. The non-methane hydrocarbon content can be inferred by subtracting the methane value from the total hydrocarbon value.</p> <p>Analysis: Continuous automatic.</p> <p>Rise Time: The 90% rise time is about 30 seconds.</p> <p>Sophistication: High.</p> <p>Interference: There is some interference from chlorinated hydrocarbons and oxygenates.</p> <p>Cost: The cost of each analyzer is about 15,000 ECU.</p> <p>Detection Limit: Less than 5 $\mu\text{g}/\text{m}^3$.</p>
Specific Hydrocarbons/Halocarbons/Oxygenates Method
<p>Method: Specific compounds are separated by gas chromatography and detected individually by an appropriate method (i.e. flame ionization; electron capture).</p> <p>Analysis: Semi-continuous automatic.</p> <p>Sampling Period: The analyses are cyclic and generally have a period of about one hour.</p> <p>Sophistication: High.</p> <p>Interference: There should be no interference if the appropriate combination of chromatographic separation and detection method are used.</p> <p>Cost: The cost of each analyzer is about 21,000 ECU.</p> <p>Detection Limit: Less than 1 $\mu\text{g}/\text{m}^3$ for an individual compound.</p>

MONITORING FACT SHEET: Benzene**Gas Chromatography Method**

Method: Benzene is collected from ambient air on a porous polymer adsorbent. It is then thermally desorbed into a gas chromatography, separated and measured using a flame - or photo-ionization detector.

Analysis: The analysis is generally laboratory based.

Sampling Period: The collection by adsorption usually takes place over a period of about one hour.

Sophistication: High.

Interference: There should be no interference if the analysis is competently performed.

Cost: Each sampler costs about 700 ECU, with an additional cost of about 21,000 ECU for the analytical system.

Detection Limit: Less than $0.1 \mu\text{g}/\text{m}^{-3}$.

Differential Optical Absorption Spectroscopy Method

Method: The Differential Optical Absorption Spectroscopy (DOAS) method makes use of the fact that gases (e.g. benzene) absorb light at precise wavelengths which are unique to themselves. In operation, a beam of light with a known spectrum is transmitted through the atmosphere from a source to a receptor. The concentration of a number of gases can be determined by analysis of the spectrum of light incident at the receptor. This involves comparison of the intensity of light at that wavelength absorbed uniquely by a specific gas (e.g. benzene) with the intensity of light at a wavelength which is not absorbed by any gas.

Analysis: Continuous automatic.

Sampling Period: Data is integrate over a period of five minutes.

Sophistication: High.

Interference: None.

Cost: 70,000-115,000 ECU (capable of measuring several pollutants).

Detection Limit: $5 \mu\text{g}/\text{m}^{-3}$.

MONITORING FACT SHEET: Polynuclear Aromatic Hydrocarbons (PAH)**High Performance Liquid Chromatography (HPLC) Method**

Method: PAH are collected on filters (particulate PAH) followed by polymeric adsorption (gaseous PAH). Both are then extracted and partitioned chromatographically using high performance liquid chromatography. The individual PAH are detected using fluorescence or ultra-violet absorption detection techniques.

Analysis: Laboratory based.

Sampling Period: The sampling period is 24 hours.

Sophistication: High.

Interference: There are negligible interferences.

Cost: The cost of each sampler is about 3,500 ECU. There is an additional cost of 21,000 ECU for the laboratory-based analytical system.

Detection Limit: The detection limit depends upon the particular compound, but generally is less than $0.1 \mu\text{g}/\text{m}^3$. (Fluorescence detection techniques are typically more sensitive than absorption detection techniques.)

MONITORING FACT SHEET: Lead and Cadmium**Atomic Absorption Spectroscopy Method**

Method: Lead and cadmium particles are collected on filters, and then extracted into strong acid solution and analyzed by atomic absorption spectroscopy. (The metal ions in solution can be atomized electrothermally or by chemical reduction in a flame, prior to spectroscopic analysis.)

Analysis: Laboratory based.

Sampling Period: The sampling period is 24 hours.

Sophistication: High.

Interference: There are no interferences if the analytical procedures are optimized.

Cost: The cost of each sampler is about 700 ECU. There is an additional cost of 28,000-70,000 ECU for the absorption spectrometer.

Detection Limit: The detection limits are about $0.01 \mu\text{g}/\text{m}^{-3}$ for lead and $0.001 \mu\text{g}/\text{m}^{-3}$ for cadmium. (If the metal ions are atomized in a flame, rather than electrothermally, the sensitivity of the process is reduced.)

X-Ray Fluorescence Method

Method: Samples are collected by drawing air through filter paper. After preparation, the samples are placed in an X-Ray Spectrometer. When irradiated with X-ray metal pollutants absorb energy and then re-emit the energy at wavelengths characteristic of the individual metals. The metal concentrations are determined from the intensity of secondary X-rays emitted at these characteristic wavelengths, as observed with a spectrometer.

Analysis: Laboratory based.

Sampling Period: The sampling period is usually 24 hours.

Sophistication: Very high.

Interference: None is appropriate secondary X-rays are used.

Cost: The cost of each sampler is about 700 ECU. The analytical facilities cost 70,000-140,000 ECU.

APPENDIX 3
EXAMPLE OF QUESTIONNAIRES
FOR COLLECTION OF POINT
SOURCE EMISSION DATA

Questionnaire Form A: Emission inventory data to be filled in by all receiving this questionnaire.

Firm, name: _____
 Postal address: _____
 Contact Person _____ Telephone no: _____

GENERAL PLANT DATA

Type of business/trade _____

Geographical location* and height above sea level

x coordinate				y coordinate			
km		m		km		m	

geod. height			
m (a SL)			

Regular breakdowns: _____

CONSUMPTION OF SOLID AND/OR LIQUID FUELS OF THE FIRM IN 1985

	Type according to supplier	Consumption amount per time unit	Unit (kg, tons, liters)	Usage (space, heating, power/steam-production, etc)
Coal				
Coke				
Gasoline				
Diesel fuel				
Fuel oil I				
Fuel oil II				
Liquid petroleum gas				
Others				

Does the fuel consumption vary from one year to another?

* The geographical location of the plant is to be specified by the emission point coordinates (x/y) of the plant. The coordinates can be fixed where the UTM-reference system is used.

Questionnaire Form B: Emission inventory data to be filled in by all firms with fuel consumption greater than 500 m³ (500,000 liters) fuel oil, or 500 tons of coal/coke

Fuel usage (space heating, power/steam production, etc.)

Emission point height above ground: _____ m.

Diameter of flue stack, internal at the top: _____ m.

Does this flue stack also serve other emission sources? YES or NO
 If YES, data on the other emission sources must be given on a copy of this form (referring to it).

Volume of flue gas: _____ m³ N/h* or flue stack gas velocity: _____ m/s
 Flue gas temperature: _____ ° C.

Consumption of fuel: Type: _____ Amount: _____ % S:** _____
 Type: _____ Amount: _____ % S:** _____
 Type: _____ Amount: _____ % S:** _____
 Consumption of coal: Origin:*** _____ Amount: _____ % S: _____
 Consumption of coke: Origin:*** _____ Amount: _____ % S: _____

Does consumption vary diurnally, weekly, monthly or yearly? Please describe.

If emission control installations are used, please specify type and efficiency.

If there is more than one emission point flue stack, please specify each individually by x/y coordinates.

Emission type:	x coordinate				y coordinate			
Emission coordinates:	km	m	km	m				

* Volume of flue gas per hour at O° C. and 101.3 kPa (760 mm Hg).
 ** Sulfur content, percent by weight.
 *** Country supplying the coal/coke.

Questionnaire Form C: Emission inventory data to be filled in by firms using individual processes/activities that cause any kind of atmospheric pollution:

Type of process/activity: _____

Emission point, high above ground: _____ m.

Diameter of flue stack, internal at the top: _____ cm.

Diameter of flue stack also serve other emission sources? YES/NO

If yes, data on the other emission sources must be given on a copy of this form (referring to it).

Volume of flue gas: _____ m³ N/h* or flue stack gas velocity: _____ m/s

Flue gas temperature: _____ ° C.

Are emission data based upon actual measurements? _____

If yes, please provide data: _____

Do the emissions vary diurnally, weekly, monthly, or yearly? Please describe.

If emission control installations are used, please specify type and efficiency:

EMISSION PRODUCTS

Emission constituent (name and/or chemical formula)	Emission rate (kg/h)	Emission hours per year	Remarks

Note: If your firm uses any of the substances listed here, please specify name and quantity on the backside of this form: organic acids, tri and tetrachlor-ethylene, carbon tetrachloride and other halogenated hydro-carbons, other solvents, paints and laquers; specify additives, pharmaceutical products, pesticides or similar products.

* Volume of flue gas per hour at 0° C. and 101.3 kPa (760 mm Hg).

APPENDIX 4

HEALTH DAMAGE ASSESSMENT

Chapters 3 and 4 outline the procedures used to collect data and assess health and non-health impacts of air pollution. This appendix gives additional information on these topics.

IDENTIFICATION OF POTENTIALLY DANGEROUS COMPOUNDS

The first step in the assessment of health damage from air pollution is the identification of potentially dangerous compounds emitted into the air. City-specific lists can be compiled from an inventory of the emissions (with respect to both volume and hazard) in each city. All major pollution sources should be included in this inventory, i.e. from industry, households and traffic. Potentially dangerous compounds are those compounds for which a risk factor, a limit or guideline exists, or which are suspected to be harmful. Comparison of the emitted compounds with standards (risk factors, limits etc.) shows which compounds are potentially dangerous.

There are different kinds of standards or guidelines for pollutants. *Threshold values* or *guidelines* denote the concentrations below which no negative effects are expected. Other standards express a *maximum concentration* which may not be exceeded. The third type of standard, a *unit risk factor*, applies only to carcinogenic compounds.

This report focuses on only a limited number of pollutants for which standards have been developed. These include NO_x, SO₂, CO, TSP, PM₁₀, ozone, PAN, VOC, PAH and lead. One reason for selecting these compounds is that they are probably the most important ones in terms of health damage. See Table 4A.1 for the U.S. air quality standards and Table 4A.2 for WHO air quality guidelines.

Table 4A.1: US standards for air quality

Parameter	µg/m ³	Averaging time
SO ₂	80	1 yr.
	365	24 hr.
CO	10,000	8 hr.
	40,000	1 hr.
NO _x	100	1 yr.
O ₃	235	1 hr.
TSP	75	1 yr.
	260	24 hr.
Pb	1.5	per quarter

Source: (USAID and USEPA, 1990b).

Table 4A.2: Summary of WHO air quality guidelines (AQG)

Substance	AQG	Averaging time	Components
Organic			
1) Acrylonitrile	None		Carcinogen ^a , (1 µg/m ³ presents a 2 x 10 ⁻⁵ lifetime risk)
2) Benzene	None		Carcinogen ^a , (1 µg/m ³ presents a 4 x 10 ⁻⁶ lifetime risk)
3) Carbon disulfide	100 µg/m ³	24 hours	
4) 1,2-dichloroethane	0.7 mg/m ³	24 hours	
5) Dichloromethane	3 ng/m ³	24 hours	
6) Formaldehyde	100 µg/m ³	30 minutes	
7) PAH	None		Carcinogen ^a , (1 µg/m ³ presents a 1 x 10 ⁻⁶ lifetime risk)
Inorganic			
8) Arsenic	None		Carcinogen ^a ; (1 µg/m ³ presents a 3 x 10 ⁻³ lifetime risk)
9) Asbestos	None		Carcinogen ^a ; (1 fiber/m ³ presents a 10 ⁻⁶ -10 ⁻⁵ lifetime risk of developing lung cancer, and a 10 ⁻⁵ -10 ⁻⁴ lifetime risk of developing mesothelioma)
10) Cadmium	1-5 ng/m ³ 10-20 ng/m ³	1 year (rural) 1 year (urban)	
11) Carbon monoxide	100 mg/m ³ 60 mg/m ³ 30 mg/m ³ 10 mg/m ³	15 minutes 30 minutes 1 hour 8 hours	
12) Chromium	None		Carcinogen ^a ; (1 µg/m ³ presents a 4 x 10 ⁻² lifetime risk)
13) Hydrogen sulfide	150 µg/m ³	24 hours	
14) Lead ^b	0.5-1.0 µg/m ³	1 year	
15) Manganese	1 µg/m ³	1 year	
16) Mercury	1 µg/m ³	1 year	
17) Nickel	None		Carcinogen ^a ; (1 µg/m ³ presents a 4 x 10 ⁻⁴ lifetime risk)
18) Nitrogen dioxide	400 µg/m ³ 150 µg/m ³	1 hour 24 hours	
19) Ozone & other photochemical oxidants	150-200 µg/m ³ 100-120 µg/m ³	1 hour 8 hours	
20) Radon	None [≥100 Bq/m ³]	[1 year]	Carcinogen ^a ; (1 Bq/m ³ presents a 0.7-2.1 x 10 ⁻⁴ lifetime risk [recommended level for remedial action in buildings])
21) Sulfur dioxide	500 µg/m ³ 350 µg/m ³ 125 µg/m ³ 50 µg/m ³	10 minutes 1 hour 24 hours 1 year	
22) Particulate matter ^c	150-230 µg/m ³ 60-90 µg/m ³	24 hours 1 year	
23) Vanadium	1 µg/m ³	24 hours	

a A linear one-hit extrapolation model has been used to calculate the lifetime cancer risks.

b According to the revised WHO AQG for Europe, the AQG for lead has been lowered from the 0.5-1.0 µg/m³ range to 0.5 µg/m³.

c The revised WHOAQG for Europe indicates that there is no safe level of particulate matter. Effect-response should form the guideline.

Source: World Health Organization (1987).

**NATURE OF THE WHO AIR QUALITY GUIDELINES
CITED FROM *AIR QUALITY GUIDELINES FOR EUROPE* (WHO, 1987)**

The primary aim of the air quality guidelines¹ is to provide a basis for protecting public health from adverse effects of air pollution and for eliminating, or reducing to a minimum, those contaminants of air that are known or likely to be hazardous to human health and well-being. The guidelines are intended to provide background information and guidance to governments in making risk management decisions, particularly in setting standards, but their use is not restricted to this. They also provide information for all who deal with air pollution. The guidelines may be used in planning processes and various kinds of management decisions at community or regional level. When guideline values are indicated, this does not necessarily mean that they must take the form of general countrywide standards, monitored by a comprehensive network of control stations. In the case of some agents, guideline values may be of use mainly for carrying out local control measures around point sources.

It should be emphasized that when air quality guideline values are given, these values are not standards in themselves. Before standards are adopted, the guideline values must be considered in the context of prevailing exposure levels and environmental, social, economic and cultural conditions. In certain circumstances there may be valid reason to pursue policies which will result in pollutant concentrations above the guidelines values.

Ambient air pollutants can cause several significant effects which require attention: irritation, odor annoyance, acute and long-term toxic effects (including carcinogenic effects). Air quality guidelines either indicate levels combined with exposure times at which no adverse effect is expected concerning non-carcinogenic endpoints, or they provide an estimate of lifetime cancer risk arising from those substances which are proven human carcinogens or carcinogens with at least limited evidence of human carcinogenicity.

The guidelines represent the current best scientific judgment, but there is a need for periodic revision, since much remains to be determined regarding the toxicity of air pollutants for humans. It is believed that inhalation of an air pollutant in concentrations and for exposure times below a guideline value will not have adverse effects on health and, in the case of odorous compounds, will not create a nuisance of indirect health significance. Compliance with recommendations regarding guideline values does not guarantee the absolute exclusion of effects at levels below such values. For example, highly sensitive groups especially impaired by concurrent disease or other physiological limitations may be affected at or near concentrations referred to in the guidelines values. Health effects at or below guideline values can also result from combined exposure to various chemicals or from exposure to the same chemical by multiple routes.

It is important to note that guidelines have been established for single chemicals. Chemicals, in mixture, can have additive, synergistic or antagonistic effects; however, knowledge of these interactions is still rudimentary. With a few exceptions, such as the combined effect of sulfur dioxide and particulates, there is insufficient information at present to establish guidelines for mixtures. An adequate margin of safety should exist between the guideline values and concentrations at which toxic effects will occur.

¹ Guidelines in the present context are not restricted to suggested numerical values, but also include any kind of recommendation or guidance in the relevant field.

Risk estimates for carcinogens do not indicate a safe level; they are presented so that the carcinogenic potencies of different carcinogens can be compared and an assessment of overall risk made (Table 4A.3).

Although health effects were the major consideration in establishing the guidelines, ecologically based guidelines for preventing adverse effects on terrestrial vegetation were also considered and guideline values were recommended for a few substances. These ecological guidelines for vegetation have been established because, in the long term, only a healthy total environment can guarantee human health and well-being. Ecological effects on species other than plants have not been discussed, since they are outside the scope of this book.

The guidelines do not differentiate between indoor and outdoor exposure (with the exception of exposure to mercury) because, although the sites influence the type and concentration of chemicals, they do not directly affect the basic exposure-effect relationship. Occupational exposure has been considered in the evaluation process, but it was not a main focus of attention as these guidelines relate to the general population. However, it should be noted that occupational exposure may add to the effect of environmental exposure.

The guidelines do not apply to very high short-term concentrations which may result from accidents or natural disasters.

The health effects of tobacco smoking have not been assessed here, the carcinogenic effects of smoking having recently been evaluated by IARC. Neither have the effects of air pollutants on climate been considered, since too many uncertainties remain to allow an evaluation of the possible adverse and environmental effects. However, possible changes of climate have to be investigated very seriously by the appropriate bodies because their overall consequences, for example the "greenhouse effect", may go beyond direct adverse effects on human or ecosystems."

Table 4A.3: Unit risk factors for carcinogenic compounds

Compound	Unit risk factors*
Acrylonitrile	$2 * 10^{-5}$
Arsenic	$4 * 10^{-3}$
Asbestos	$10^{-6} - 10^{-5}$
1,3-Butadiene	$2.80 * 10^{-4}$
Benzene	$4 * 10^{-6}$
Cadmium	$1.80 * 10^{-3}$
Chromium (VI)	$4 * 10^{-2}$
1,2 dichloromethane	$2.6 * 10^{-5} - 1 * 10^{-6}$
Diesel fuel	
(high duty)	$1.00 * 10^{-4}$
(low duty)	$2.00 * 10^{-5}$
Ethylene	$2.70 * 10^{-6}$
Ethylene dibromide	$5.10 * 10^{-4}$
Formaldehyde	$1.30 * 10^{-5}$
Nickel	$4 * 10^{-4}$
PAH	$9 * 10^{-2}$
Vinyl chloride	$1 * 10^{-6}$

*For lifetime (= 70 year) exposure to $1 \mu\text{g}/\text{m}^3$.

Source: WHO (1987); USAID/USEPA (1990b).

WHAT TO DO IF STANDARDS ARE NOT AVAILABLE

If information on standards is not available, assumptions have to be made about potentially dangerous compounds (Box 4A.1). Alternatively, toxicological data may be used instead of a standard. This is justifiable since most standards are based on toxicological experiments. However, the issue of extrapolation of experimental results to limits or guidelines is a complicated one. The use of such data must, in the framework of this report, be seen as a last

resort. If they have to be used, the NOAEL (No Observed Adverse Effect Level) or the LOAEL (Lowest Observed Adverse Effect Level) are preferred.

DATA COLLECTION

The second step in the procedure involves collecting data on the concentrations of pollutants, including temporarily or locally high concentrations. Concentrations are required for different time-intervals and locations within the city. For each pollutant different types of data are preferred, depending on the risk involved. See Table 4A.4 for a complete list of major emission categories with significant health impacts.

Box 4A.1: What to do when data on standards are missing

When standards or guidelines are missing for a city:

- use WHO guidelines, or
- adapt standards and guidelines from other cities, or
- use toxicological data on NOAEL and/or LOAEL from the international scientific literature to develop a standard (see e.g. WHO, 1983):

NOAEL: express the dose given to the tested animals in mg/kg live weight, or in mg/J. The resulting figure can be seen as an 'acceptable' or reference dose below which no effects will occur

LOAEL: set a reference dose between 1/10 and 1/1000 of the LOAEL

Table 4A.4: Summary of major emission source categories for WHO criteria air pollutants with significant health impacts

Substance	Major Emission Sources
Organic substances	
Acrylonitrile	<ul style="list-style-type: none"> • chemical industry, especially polymers production.
Benzene	<ul style="list-style-type: none"> • gasoline-powered motor vehicles without catalytic converters (80-85%), chemical & petroleum industry, domestic heating, coke ovens.
Carbon disulfide	<ul style="list-style-type: none"> • production of viscose rayon fibers, coal gasification.
1,2-dichloroethane	<ul style="list-style-type: none"> • synthesis of vinyl chloride, production of ethylene diamines, use as solvent & fumigant.
Dichloromethane	<ul style="list-style-type: none"> • use as solvent & paint remover, polyurethane foam blowing, use as refrigerant & propellant in aerosol cans.
Formaldehyde	<ul style="list-style-type: none"> • catalytic cracking in petroleum refining industry, charcoal production, internal combustion engines, resin & formaldehyde production.
Polynuclear aromatic hydrocarbons (PAH)	<ul style="list-style-type: none"> • residential wood combustion & small combustion sources, aluminum smelting.
Styrene	<ul style="list-style-type: none"> • production of polymers, co-polymers, reinforced plastics & polystyrene.
Tetrachloroethylene	<ul style="list-style-type: none"> • dry cleaning & metal cleaning, textile industry, use as solvent and grain fumigant, and production of fluorocarbons.
Toluene	<ul style="list-style-type: none"> • production, marketing & use of gasoline, tobacco smoke, and use as paint thinner.

Table 4A.4: Summary of major emission source categories for WHO criteria air pollutants with significant health impacts

Substance	Major Emission Sources
Trichloroethylene	<ul style="list-style-type: none"> degreasing with solvents, polyvinyl chloride (PVC) production, use in inks & adhesives, surface coating & dry cleaning, and pharmaceutical industry.
Vinyl chloride	<ul style="list-style-type: none"> production of polyvinyl chloride (PVC).
Methane	<ul style="list-style-type: none"> decomposition of organic matter.
VOCs	<ul style="list-style-type: none"> road traffic, and use of solvents.
Inorganic substances	
Arsenic	<ul style="list-style-type: none"> non-ferrous metal industry, stationary combustion sources, and use as catalyst & reagent in inorganic chemical industry, pesticides use.
Asbestos	<ul style="list-style-type: none"> manufacture of asbestos-containing products, construction activities, and removal of friable asbestos.
Cadmium	<ul style="list-style-type: none"> metal production, especially zinc processing, electroplating, production of plastics, pigments & batteries, waste incineration, fertilizer processing and application, and natural sources, especially volcanoes.
Carbon monoxide	<ul style="list-style-type: none"> automobiles (90% in industrialized countries), and biomass burning.
Chromium	<ul style="list-style-type: none"> production of chromium compounds, and chromium production from chromite.
Hydrogen sulfide	<ul style="list-style-type: none"> decomposition of organic material, viscose rayon production, waste water treatment, wood pulp production with sulphate process, oil refining, and tanning industry.
Lead	<ul style="list-style-type: none"> road traffic, mainly gasoline-powered vehicles, non-ferrous metal industry, iron and steel industry, and production of lead-acid batteries.
Manganese	<ul style="list-style-type: none"> use as additive in metallurgical processes, production of dry-cell batteries, and chemical industry.
Mercury	<ul style="list-style-type: none"> coal combustion in stationary sources, electrical apparatus, electrolytic production of caustic soda & chlorine, pharmaceutical industry, and production and use of anti-fouling paints.
Nickel	<ul style="list-style-type: none"> burning of residual and fuel oils, nickel mining and refining, and municipal waste incineration.

Table 4A.4: Summary of major emission source categories for WHO criteria air pollutants with significant health impacts

Substance	Major Emission Sources
Nitrogen dioxide	<ul style="list-style-type: none"> road traffic (50%), power plants and industrial combustion, and industrial processes, especially nitric acid production.
ozone & other photochemical oxidants	<ul style="list-style-type: none"> N.B. not directly emitted, but formed in the atmosphere from nitrogen, dioxide, volatile organic compounds and methane.
Radon	<ul style="list-style-type: none"> building materials, natural emissions from ground, and well-drilled tap water.
Sulfur dioxide	<ul style="list-style-type: none"> energy production, especially in power plants, industrial combustion, and industrial processes, especially sulfuric acid production.
Particulate matter	<ul style="list-style-type: none"> fuel combustion (95% in industrialized countries), natural and man-made dust erosion, construction industry, and mining operations.
Vanadium	<ul style="list-style-type: none"> natural sources, especially weathering and volcanoes, metallurgical processes, and burning of coal, crude and residual oils.

It is likely that some of the required concentration data are unavailable or only partially available. If this is the case, data estimates have to be obtained. Effective short term solutions are preferred, even though those that take a longer time may give more accurate results. The quality of data used should be specified along with the final estimate of health damage. Box 4A.2 outlines options to obtain concentration data. Alternatives have been roughly ranked in descending order of preference. Which is the best option depends on the city-specific situation, e.g. available information, time, and budget.

To overcome lack of data, low-cost mobile monitoring yields the most accurate results. However, when monitoring is not possible, concentrations have to be assessed. The inventory of emissions sources (industry, and households) and emitted quantities can be used to estimate concentration data. Dispersion models are used to assess the concentration at a certain point in time and space. These models account for geographic factors such as wind speed and direction.

Concentration data based on emissions inventories need to be checked for plausibility. One way of doing this is by comparing such data with other concentration data gathered elsewhere. Control data should come from conditions similar to those prevailing in the city in question. If differences between the gathered and control data set can be explained, the former may be used for further calculations, with minor adjustments. When the differences cannot be explained, it is advisable to re-assess the concentration data using a different option.

Box 4A.2: What to do when data on concentrations or emissions are missing

When *concentration* data are missing:

- measure concentrations using a mobile monitoring unit;
- estimate concentrations from emissions data by using dispersion models;
- aggregate emissions data from low levels to higher levels, e.g. estimate total SO₂ emission by summing up all separate emissions;
- use indicators to assess concentrations from data from other cities;
- use data from a higher level, e.g. use ambient air concentrations if local air concentrations are absent.

When *emissions* data are missing:

- estimate emissions from emission factors or emission coefficients to make a rough estimate of emissions, based on economic activities, traffic and number of households; then use dispersion models to assess concentrations.

Emission factor: a constant which relates the emission of a certain compound to the input or output of another compound by the same source, e.g. the emission of SO₂ by a factory can be estimated from its coal consumption.

Emission coefficient: a constant that relates the emission to a monetary flow such as the production value.

IDENTIFICATION OF PRIORITY COMPOUNDS

The assessment of health damage from pollutants is complicated and time consuming. Therefore, it is preferable to know beforehand which compounds have the highest priority. Concentrations of those compounds which have the highest priority should be used to assess the bulk of damage to human health and/or the benefits of reductions in emissions. PM₁₀ and lead are priority compounds in cities where traffic is a major source.

The number of people affected by a certain pollutant can be estimated from a comparison of the pollutant concentration with a standard (e.g. for the average air concentration of PM₁₀) and the population density in the area. It is important to use standards that correspond to concentrations in terms of both time and location, and to make a comparison at the most appropriate time-scale and site. A quick and easy way of identifying stress areas where standards are exceeded is to use an overlay Geographical Information Systems (GIS)-method. However, when part of the necessary information is lacking, no stress areas can be identified. This is the case, for example, if the concentration of PM₁₀ is known for each sub-area of the city while only aggregate, city-wide population figures are known. An estimate of the number of people affected can then be obtained by assuming that, if the city is divided in five areas, every area is inhabited by one-fifth of the population.

Results of the comparison can be expressed as the percentage by which the standard is exceeded, affecting a certain number of people. This number can best be calculated in relation to the vulnerability of different groups within a population, e.g. poor, elderly, young children, pregnant women, or those already suffering from respiratory diseases.

Air pollution affects human health in varying degrees, ranging from minor irritations to fatal diseases or sudden death. Generally speaking, many more people are affected by one or more minor diseases. Prioritizing the compounds according to the need for further study can be based on the importance of the effect and the number of people affected. The ranking of health effects according to importance is, of course, a subjective matter. Compounds that increase mortality, such as carcinogenic compounds, should be given the highest priority. Morbidity can be classified, for instance, according to the duration of the illness, degree of impairment of activity, type of symptoms and number of symptom days. Table 4A.5 lists some of the important categories of health damage from air pollution.

This step allow us to rank compounds according to their effect, multiplied by the number of people at risk. With this information it can be decided which compounds have highest priority for assessment of health damage.

Table 4A.5: Potential health damage from air pollution

Potential health damage	Air pollutant
Cardiac spasm	CO
Lower birth weight	CO
Respiratory diseases	SO ₂ , TSP, PM ₁₀ , NO _x , O ₃ , PAN
Reduced activity	CO, TSP, PM ₁₀
Carcinogenic diseases	VOC
Coronary diseases	Pb
Spontaneous abortion	Pb
Altered behaviour pattern	Pb
Reduced intelligence	Pb
Reduced fertility	Pb
Anaemia	Pb

Source: Bradley et al., 1991.

USE OF DOSE-RESPONSE RELATIONSHIPS AND UNIT-RISK FACTORS

Dose-response relationships relate health effects to concentrations of pollutants. A distinction can be made between specific dose-response relationships, where the effect is expressed as a specific disease such as bronchitis, asthma, heart attacks etc., and non-specific dose-response relations, where the effect is not expressed as a specific disease, but as restricted activity days (RAD), work loss days (WLD), mortality cases etc. Non-specific effects can be related to specific effects, as can be seen in Table 4A.6.

Table 4A.6: Symptom days per chronic disease due to air pollution

Disease	Increased effects	Symptom days per attack
Asthma	Annual attack (per person per year)	Severe breath shortness, 1 day
Chronic bronchitis	Prevalence (fraction of population)	Severe cough, 240 days
Bronchitis	Annual attacks	Severe cough, 7 days
Heart and lung diseases	Annual attacks	Chest pain, 1 day
Eye irritation	Annual attacks	Eye irritation, 1 day

Source: Loehman et al.(1979).

Threshold values. An important issue in the use of dose-response relationships is whether a threshold level exists, i.e. whether a concentration exists below which no adverse health effects are found. It may be assumed that, for non-carcinogenic compounds, air quality standards and guidelines are based on such threshold values. Therefore one could argue that dose-response relationships should only be applied to that part of the concentration of a pollutant which exceeds the standard or guideline. On the other hand, many studies have produced linear or log-linear functions, and do not identify a threshold level. This holds for all carcinogens. In such cases the use of threshold values is disputable and should be included in the interpretation of results.

Reliability. Reliable dose-response relationships may be derived from epidemiological time-series (longitudinal) research rather than from cross-sectional investigations. Time-series analysis examines changes in health over time, in relation to air pollution levels. A cross-sectional analysis compares differences in health across several cities at a selected point or period of time. However, relationships from time-series research are limited. Most information on dose-response relationships comes from cross-sectional investigations. Their reliability is often questioned because of the difficulties in accounting for confounding factors such as smoking habits. In his overview of relationships between air pollution and specific diseases, Ostro (1992) used criteria on study design and methodology, confounding variables, seasonality, weather, and analysis of data. Most dose-response relationships in this report are derived from Ostro's study. Further information may be obtained from WHO (1983).

Transferability. The usefulness of a dose-response relationship is not only dependent on its relevance and reliability, but also on its transferability to other circumstances and conditions, for instance, adaptation from European to Asian conditions. This implies that information is also needed on other factors that may play a role, for example other pollutants, temperature, etc. Although it may not be possible to actually include the influence of these co-factors in the dose-response relationships, conclusions can usually be drawn as to the direction of their influence, i.e. positive or negative.

Linearity. For the sake of simplicity, the curve of a dose-response relationship is often assumed to be linear from the threshold value. This is not always the case, however, since both sides of the curve may divert from linearity. For instance, it has been shown that the slope of the relationship between mortality and pollutant concentration decreases with increasing concentrations. The use of a linear relationship overestimates health damage at both low and high exposure levels.

Carcinogenic compounds. In calculating the effects per disease, special attention should be given to the occurrence of cancer. In the case of carcinogenic compounds we can, therefore, only speak in terms of risk or probabilities.

Because of ethical objections to epidemiological experiments, no research results are available on the effects of carcinogenic compounds on human beings. In order to assess health damage from carcinogenic compounds, unit risk factors can be used. A unit risk factor indicates the number of cases of cancer that may arise from lifetime exposure to $1 \mu\text{g}/\text{m}^3$ of a compound.

The number of potential cases of cancer can be estimated for carcinogens by multiplying the actual human dose with the unit risk factor. These calculations can be made with both average

and maximum concentrations and calculated for both the maximum and averaged exposed part of the population. Unit risk factors, as set by international bodies, are given in Table 4A.7.

It is customary to assume additivity of cancer estimates. This means that in the case of simultaneous exposure to more than one carcinogenic compound, a calculation is made separately for each compound, after which the results are summed.

INVENTORY OF DOSE-RESPONSE RELATIONSHIPS

There are many kinds of dose-response relationships with varying degrees of utility. Given a choice, the most suitable dose-response relationships should be used for assessing health damage. In many cases, however, there will be no choice at all due to lack of location-specific information. In order to get an estimate of health damage, expressed as mortality or RAD, less suitable dose-response relationships may have to be used, with or without correction factors. In such cases, results should be interpreted with caution.

Table 4A.8 presents a preliminary inventory of appropriate dose-response relationships. It includes dose-response relationships from review articles on macro-epidemiological regression analysis, using both international and local literature sources. The results are grouped according to compound, effect, and social group. In addition to the actual dose-response relationships, information is needed on the circumstances and conditions of the underlying research. With this information the usefulness and reliability of the dose-response relationships for assessing health damage can be evaluated.

The following tables include mathematical formulae and some background information. The tables focus on mortality (Table 4A.8), WLD and RAD (Table 4A.9), specific diseases (Table 4A.10), and co-factors (Tables 4A.11 and 4A.12).

Table 4A.7: Unit risk factors for carcinogenic compounds

Compound	Unit risk factors ^a
Acrylonitrile	$2 * 10^{-5}$
Arsenic	$4 * 10^{-3}$
Asbestos	$10^{-6} - 10^{-5}$
1,3-Butadiene	$2.80 * 10^{-4}$
Benzene	$4 * 10^{-6}$
Cadmium	$1.80 * 10^{-3}$
Chromium (VI)	$4 * 10^{-2}$
1,2 dichloromethane	$2.6 * 10^{-5} - 1 * 10^{-6}$
Diesel fuel	
(high duty)	$1.00 * 10^{-4}$
(low duty)	$2.00 * 10^{-5}$
Ethylene	$2.70 * 10^{-6}$
Ethylene dibromide	$5.10 * 10^{-4}$
Formaldehyde	$1.30 * 10^{-5}$
Nickel	$4 * 10^{-4}$
PAH	$9 * 10^{-2}$
Vinyl chloride	$1 * 10^{-6}$

^a For lifetime (= 70 year) exposure to $1 \mu\text{g}/\text{m}^3$.

Source: WHO (1987); USAID/USEPA (1990b).

Table 4A.8: Relationships between air pollutants and mortality

Pollutant and source	Population	Area/country per 10 $\mu\text{g}/\text{m}^3$ pollutant ^a	% change in mortality	Reference
PM₁₀				
Steel mill	all	Utah County, USA	1.48	Pope et al., 1992.
unknown	all	St. Louis, USA	1.62	Pope et al., 1992.
unknown	all	Kingston, USA	1.74	Pope et al., 1992.
urban air	< 65	Philadelphia	0.49 (0.12 - 0.87)	Schwartz and Dockery, 1992.
urban air	> 65	Philadelphia	1.67 (1.37 - 1.97) ^b	Schwartz and Dockery, 1992.
urban air	all	USA, UK, Indonesia	0.98 (0.49-1.47)	Ostro, 1994.
SO₂				
urban air	all	Athens, Greece	0.20 (0.10 - 0.30) ^c	Hatzakis et al., 1989.
urban air	all	Marseille, France	2.1 (1.4 - 2.8)	Hatzakis et al., 1989.
urban air	< 65	Lyon, France	1.4 (0.8 - 2.0) respiratory mortality	Hatzakis et al., 1989.
urban air	> 65	Lyon, France	4.2 (2.8 - 5.6) cardiologic mortality	Hatzakis et al., 1989.
TSP				
urban air	all	UK, USA, Indonesia	0.682 (0.479-0.891)	Ostro, 1992.
Pb^{e, d}				
$\Delta\text{PRMORT} = (1 + \exp(5.3158 - 0.03516(\text{DBP}_{\text{old}})))^{-1} - (1 + \exp(5.3158 - 0.03516(\text{DBP}_{\text{new}})))^{-1}$				

a. Range between brackets.

b. PM₁₀ calculated from TSP.

c. Starting at 150 $\mu\text{g}/\text{m}^3$.

d. PRMORT = 12 year probability of death from all causes.

e. DBP = diastolic blood pressure.

Source: Ostro (1994).

Table 4A.9: Relationships between air pollutants and WLD or RAD

Pollutant and source	Relation (Change in number of days (per person, per year) per $\mu\text{g}/\text{m}^3$ pollutant)
TSP	
WLD age 18-65	0.0377
RAD age > 18	0.032 (0.022-0.050)
PM₁₀	
RAD age > 18	0.0575 (0.0404 - 0.0903)

Notes

1. The TSP dose-response relationship was used to derive a dose-response function for PM₁₀ by using a ratio PM₁₀/TSP of 0.55.

2. It is strange that the coefficient of WLD is higher than the one of RAD since restricted activity days include work loss days. As the dose-response relation for RAD is the more recent one, it is most probably the more reliable one.

Source: Ostro, B. (1983, 1992, 1994).

Table 4A.10: Relationships between air pollutants and specific diseases

Pollutant	Disease	Relation
Lead	Diastolic blood pressure (DBP)	$\Delta \text{DBP} = 2.74 (\ln [\text{Pb in blood}]_{\text{old}} - \ln [\text{Pb in blood}]_{\text{new}})$
Lead	Coronary Heart Disease (PRCHD = 10 year probability of case)	$\Delta \text{PRCHD} = (1 + \exp(4.996 - 0.030365(\text{DBP}_{\text{old}})))^{-1} - (1 + \exp(4.996 - 0.030365(\text{DBP}_{\text{new}})))^{-1}$
Lead	Decline in IQ-points (children)	$\Delta \text{IQ-points} = 0.975 * \Delta \text{air lead } (\mu\text{g}/\text{m}^3)$
NO ₂	Respiratory symptoms per year (RS = number per year per unit NO ₂ mg/kg)	$\Delta \text{RS} = 10.22 (6.02-14.42)$
PM ₁₀ TSP (ambient)		per $\mu\text{g}/\text{m}^3$ PM ₁₀
Respiratory hospital diseases (RHD) per 100,000 people		$\Delta \text{RHD} = 1.20 (0.657-1.56)$
Emergency room visits (ERV) per 100,000 people		$\Delta \text{ERV} = 23.54 (12.83-34.25)$
Bronchitis (B) (children)		$\Delta \text{Bronchitis} = 0.00169 (0.0008-0.00238)$
Asthma attacks per asthmatic (A)		$\Delta \text{A} = 0.0326 (0.0163-0.273)$
Respiratory symptoms days per person per year (RSD)		$\Delta \text{RSD} = 0.183 (0.090-0.274)$
Chronic Bronchitis		$\Delta \text{CB} = 6.12 \times 10^{-5} (3.06 \times 10^{-5} - 9.18 \times 10^{-5})$

Source: Ostro (1994).

Table 4A.11: Influence of cofactors in relationships between air pollutants and mortality

Cofactor Factor	Age	Season	Temperature	Reference
SO ₂	+	?	-	Schwartz and Dockery (1992); Derriennic et al. (1992)
TSP			?	Hatzakis et al., 1986

+ = positive influence (i.e. increases mortality), - = negative influence, ? = positive and negative influences have been found, 0 = apparently no influence).

Source: Ostro (1994).

Table 4A.12: Influence of cofactors in relationships between TSP and WLD or RAD

Cofactor Factor	Temperature	Family income	Age	Chronic illness	Married	Blue collar worker	Smoking	Female	Pop.dens	Non-workers
WLD										
Event	+		-	0	+	+				
# days			+	+	-	-	0	+	+	0
RAD										
Event	+	0	0	0			0	0		0
# days		-	+	+			+	+	+	

+ = positive influence, - = negative influence, ? = positive and negative influences have been found, 0 = apparently no influence).

Source: Ostro (1983).

CALCULATION OF MORTALITY AND RESTRICTED ACTIVITY DAYS

A general procedure to calculate the change in mortality from a change in the concentration of a certain compound is given in Box 4A.3. Similar procedures can be developed for calculating other forms of health damage. To calculate IQ loss, the dose-response relationship should be applied to only the working part of the population. Calculations can be made using a relationship for the entire population, or for every subgroup separately, or only for the most vulnerable subpopulation.

Box 4A.3: General procedure for the calculation of mortality due to a compound

1. Decide whether or not a threshold value is applicable; if so, use a guideline for air quality as the threshold value.
2. Choose the relevant dose-response relationship(s) from Tables 10-12, simultaneously assessing their transferability.
3. Calculate the relative change in daily mortality by multiplying the change in pollutant concentration with the relevant percentage from the dose-response relationship.
4. Calculate the total change in daily mortality by multiplying the percentage change in daily mortality with the total number of daily mortality.
5. Express the results in percentages and in absolute figures as the change in daily mortality resulting from a reduction or an increase in the concentration of the compound. Use cofactors and other information for the interpretation of the results.

DISCUSSION AND RECOMMENDATIONS

The use of dose-response relationships for assessing health damage is controversial. In order to estimate health damage from air pollution, either an index that represents the major components of the air mixture is needed, or an expression that includes the major air pollutants as explanatory variables. In Table 4A.8, TSP and PM_{10} are used as proxies for air pollution. Various studies included in the table refer to a wide range of mixtures resulting from various pollution sources.

PM_{10} is considered a good index of particulates in the air pollution mixture. However, its use is restricted by the availability of direct measurements. In a study by Schwartz and Dockery, PM_{10} was calculated from TSP with the standard conversion factor used in the United States— $PM_{10} = 0.55 \text{ TSP}$. The use of this fraction, however, does not account for differences in the TSP mixture. When direct measurements of PM_{10} are not available and/or the effects on human health can be attributed to different air pollutants, an index may be established using a combination of pollutants. For instance, a choice may be made to use the product of SO_2 and TSP for predicting excess mortality from air pollution.

Ostro's 1983 study showed significant regression coefficients with TSP and WLD and RAD. In contrast, regressions with SO_4 on TSP or WLD were not significant. It is known, however, that SO_4 is potentially dangerous. This unexpected result was attributed to the fact that 40-60 percent of the TSP consisted of SO_4 , and there are no adequate measurement techniques for sulphate. Hatzakis et al (1986) found that in Athens, SO_2 and not TSP were related to mortality, and a similar conclusion was drawn by Derriennic et al (1989) for the cities of Lyon and Marseille in France. In contrast, Schwartz and Dockery (1992) found no relationship between SO_2 and mortality when TSP was included as an explanatory variable in the relationship. These results imply that the relationship between TSP and mortality is more basic than between SO_2 and mortality, and that there is no interaction between the two. Research by the same authors (1992b) in Steubenville, Ohio, gave similar results. Other investigations also demonstrate relationships between morbidity and TSP in cities in temperate countries such as Germany and

Austria, and between morbidity and SO₂ in the Mediterranean city of Barcelona. This suggests an influence of local temperature on health damage from TSP and SO₂.

DATA REQUIREMENTS SPECIFICATION

The steps used to assess health damage require many types of information. Each consecutive step assumes the availability of the information required for the previous step. For the identification of potentially dangerous compounds, the following qualitative information is needed on emissions and on standards, guidelines and unit risk factors.

- Emission data: compounds emitted in the city (e.g. PM₁₀, SO₂, O₃, NO_x, CO, VOC, and heavy metals).
- Standards: for what compounds have standards/guidelines been developed? Which compounds are suspect although no standards have been developed?

For the collection of concentration data, figures are needed on the concentrations of various compounds in relation to time and space.

1. Time-intervals
 - annually averaged ambient air ($\mu\text{g}/\text{m}^3$)—heavy metals
 - peak emissions—O₃, NO_x, SO₂
 - accumulated doses—carcinogenic compounds
2. Locations: indoors and outdoors
 - offices/houses—TSP, SO₂, CO, PAH
 - industrial buildings
 - chemical industry—VOC
 - cotton factories—TSP
 - smelters, battery factories—heavy metals
 - waste incineration plants—PAH, SO₂, NO_x, carcinogens
 - electricity generation plants—SO₂, NO_x
 - along motorways—VOC
 - industrial areas
 - residential areas
 - ambient air

For the identification of priority compounds, the following demographic data are needed for the population as a whole and for various subgroups.

Demographic data:

- size of the population,
- size of various age groups,
- number of people employed,
- annual growth trends,

- smoking habits,
- health statistics,
- census data—size of social groups with increased risk in terms of either exposure or sensitivity, or both: children; pregnant women; elderly; those already suffering from respiratory or other diseases; undernourished people; or combinations of the above.

For calculating mortality, WLD, and RAD information is needed on epidemiological dose-response relationships between air pollution and health damage.

Date for calculating mortality:

- non-specific dose-response relationships,
- disease-specific dose-response relationships,
- statistical model specification; linear range of the dose-response relationship,
- cofactors, (1) environmental—temperature, other components in the air mixture, seasonal and other cyclic patterns; (2) human factors (see census data),
- influence of co-factors on dose-response relationships,
- transferability of dose-response relationships
 - of biological to social terms of expression and vice versa,
 - one socio-economic population to another, e.g. from children to adults,
 - of one time interval of exposure to another, e.g. peak interval to 24 hours exposure,
- adaptation of local population to high background levels.

APPENDIX 5

NON-HEALTH DAMAGE ASSESSMENT

DAMAGE ASSESSMENT

Materials

Materials are subject to deterioration caused by the combined reaction of a number of meteorological and atmospheric chemical factors. Deterioration occurs also through natural processes, in the absence of human influences on the environment. However, both empirical experiences and systematic studies have shown that polluted urban and industrial atmospheres increase deterioration processes.

Quantitative descriptions (dose-response) of the influence of different meteorological and chemical factors have been reported for some construction materials. These are mainly based on results from the moderate climatic zone of the world. For many materials, dose-response equations or service lifetime correlations are missing.

Metals. Several studies have reported corrosion equations for metals which clearly show the corrosive effect of SO₂, chloride and humidity. The effect of humidity is normally described as time of wetness or TOW. TOW is the number of hours in the year when humidity is above 80 percent RH and the temperature is above 0°C. Other studies have shown corrosive effect of low pH and synergistic corrosive effects of SO₂+NO₂ and SO₂+O₃.

ISO-standard 9223 "Corrosion of metals and alloys - Corrosivity of atmosphere - Classification", has developed a classification system where the corrosivity of steel, zinc, copper and aluminium described in g/m²a, are grouped into five categories. These corrosivity categories are linked to a matrix of different environmental factors: TOW, SO₂-concentrations and deposition rate of chloride.

Experience from the more warm and humid parts of southern Japan indicates that this classification is also valuable for tropical areas. However, the corrosion rate in tropical marine environments along the coast can be as much as four times higher than the highest value given in the standard.

Paint. Paint systems have varying durability and susceptibility to SO₂. As a decorative and protective film applied on different materials, it is more important to evaluate the degradation of the paint system (paint and paint substrates) instead of the paint by itself. In this context it is more fruitful to define the lifetime of the paint system before maintenance than to define a deterioration rate. Lifetimes of paint systems have been estimated for different materials, such as zinc, steel, rendering and wood, at different SO₂-levels mainly in moderate climates.

Buildings and structures

For rough estimates of the impact of the environment on buildings, average values can be used for the deterioration factors in an area. However, for closer studies of special buildings, a mapping of the micro-climate may be needed. Different parts of the building will have different stress levels. The humidity will change from the sunny side of the building to the shady part, drifting rain will more frequently reach facades facing the dominating wind directly. Even the pollutant level can change from side to side of the building. Techniques are available for measuring the local impact from meteorological and pollution effects.

RILEM (International Union of Testing and Research Laboratories for Materials and Structures) has come up with a technical recommendation for service life prediction of building materials (L. Masters, 1989). The methodology gives guidelines for statistically predicting the service life of building materials for repainting, repairing or replacement, from field inspection and field tests, and

how this can be linked to accelerated tests in laboratories. This method has been used experimentally in a project jointly conducted by Sweden, Norway and the Czech Republic. The results can be seen in Table 5A.1. Although many of these results are based on materials from climates that are completely

different from the climate in South and East Asia, the values listed could be used as a first approximation until better values are available.

Calcareous materials (marble, stone, rendering). All calcareous materials react with SO₂ by changing durable calcium carbonate into gypsum. More soluble gypsum is washed off in the

Table 5A.1: Lifetime in years for maintenance of exterior materials

Materials	SO ₂ yearly			
	<20 µg/m ³	<20-60 µg/m ³	60-90 µg/m ³	90 µg/m ³
Galvanized sheets (paint)	30	10	6	5
Galvanized (replacement)	45	15	9	7
Galvanized profile (paint)	90	30	20	15
Galvanized wire (replacement)	45	15	10	7
Rendering repair	60	50	40	35
Bitumen felt (replacement)	20	16	14	12
Wood/concrete	?	?	?	?
Painted steel	9	6	5	3
Painted galvanized steel	11	9	7	5
Coilcoated steel (new)	25	23	20	15
Coilcoated steel (repaint)	15	13	11	9
Coilcoated Al (new)	30	27	25	20
Coilcoated Al (repaint)	15	13	11	9
Painted rendering	45	35	25	15
Painted wood	10	8	6	5

Source: Masters (1989).

rain. In sheltered areas, gypsum and soot form a black crust on top of the surface which eventually scales off leaving a rough yet sensitive surface with a bad visual impression.

Studies report different dose-response relationships. This reflects not only the complexity of dererioration processes, but also the fact that different stone materials have different susceptibilities to SO₂-attack depending on the crystal structure, density, percentage of calcite, etc.

The reaction depth is often greater and more severe on calcareous sandstone and rendering than on marble and limestone. In an ongoing international study in Europe, this is illustrated by the different equations found for White Mansfield sandstone tables (5x5x1 cm) compared to Portland limestone.

$$\begin{aligned} \% \text{ Wt. Corr. (White Mansfield)} &= 0.37 + 0.015 \text{ SO}_2 \\ \% \text{ Wt. Corr. (Portland)} &= 0.41 + 0.012 \text{ SO}_2 \end{aligned}$$

Since calcareous materials generally come from local sources, only indications of a possible effect can be drawn from the reported literature.

Brickwork. Brickwork is made of bricks and mortar. While there seems to be a consensus that brick as a calcium-aluminium silicate ceramic is only somewhat affected by SO₂ attack, mortar is susceptible to SO₂ in the same way as rendering. However, at present, there is no qualitative information about the effect of SO₂ on brickwork.

Concrete. For years the greatest concern for the deterioration of concrete has been carbonation and chloride attack on steel rebars inside the concrete. Since concrete is an alkaline material, there has been some concern about the reaction of SO₂ both with calcium carbonate and directly with the calcium hydroxide phase in cement. These reactions can lead to the build-up of internal stresses and cause crumbling of the concrete. The effects of SO₂ on concrete are still uncertain.

Wood. Very little information is available on the deterioration of wood caused by air pollution. SO₂ has so far not been reported as a deterioration factor. For some contexts there has been a discussion of a possible increased danger of rotting in the presence of NO_x, however, for this process the SO₂ impact will reduce this possibility since SO₂ is believed to have poisonous effect on fungus.

Monuments and tourism

Cultural monuments include prestigious buildings and ruins from the past. Monuments are often situated in city centers where the pollutant levels are high. The deterioration factors are the same as for materials, however, monuments are normally richly decorated and may visually degrade more quickly.

Ruins may often be more susceptible to the climate conditions. The ruins are most frequently parts of buildings or structures not constructed to be exposed directly to the environment. Quite often the roof is missing and the wall structures and fundaments can be worn down by rain at a higher speed than expected.

Bad odor, decay of monuments, and reduced visibility in the city and its surroundings may lead to a decline in tourism and thus economic losses. City-specific dose-effect relationships that link air quality to the number of tourists and the length of their stay are not available. When tourism is an important source of foreign exchange, the economic loss may well be substantial.

VALUATION OF NON-HEALTH DAMAGES

Building Repair and Maintenance

Economic valuation of the damage should ideally be based on a measure of willingness to pay (WTP) to avoid this damage. However, no direct assessments of WTP are available. Valuation approaches usually assume that the expenditures for increased maintenance, repair and replacement of building materials can be used as a reasonable proxy estimate of economic damage.²

Engineering assessments specify which actions are required when the thickness or weight of a material has reduced to some critical point. It should be noted, however, that extra actions are only required if increased repair and replacement is called for within the economic lifetime of a material. If air pollution reduces the service life of some material from 100 to 75 years, while the economic lifetime of the component (which contains the material) is on average 50 years, no economic damage will occur. Additional repair and replacement actions can be valued at market prices. Table 5A.2 provides some estimates of unit cost factors for specific maintenance and repair actions.

A joint study in Sweden, the Czech Republic and Norway used Swedish market prices from 1991 in their calculation of repair and replacement costs. The price seems to be about 20 percent higher than United Kingdom prices. Benefits from a reduction in SO₂-impacts were calculated from the increased lifetime of the material.

One final point of attention is the timing of the costs. If air pollution increases, when will the costs occur, or *vice versa*, if air pollution decreases, when will the benefits occur? It can be shown that the frequency of repair and replacement costs offers an adequate basis for estimating the damage costs in the year of the change in air pollution, if and only if, the age distribution of the building stock is homogeneous. As this is not likely to be the case in fast growing Asian cities, the timing of costs should be addressed explicitly.

Table 5A.2: Unit costs for repair and replacement in 1990

Repair action	Unit costs (UK £/m ²)
Repainting	8.04
Repointing (brick)	16.25
Replacing zinc/galvanized steel	32.14
Replacing steel	17.92
Refacing stone	177.04
Replacing concrete	34.33

Source: CEC, 1992.

² Freeman (1982) has pointed to the fact that this approach assumes that households will always alter their repair and cleaning activity so as to maintain an average level of cleanliness and materials quality, no matter what the level of air pollution. This implies that the price elasticity for cleanliness or materials maintenance is zero. He shows that if the price elasticity is not zero, maintenance and cleaning expenditures may actually increase with a better air quality. If a non-zero price elasticity is assumed, economic equilibrium models should be used.

Soiling

Apart from causing damage to building materials, air pollution also damages buildings in a more superficial way (soiling). Such aesthetic damages may result in increased cleaning activities and expenditures. Research has been carried out on the statistical relationship between air pollution (particulate matter) and cleaning activities by households. Table 5A.3 summarizes some results of empirical research in the United States.

Table 5A.3: The effect of air pollution on cleaning activities

Author/year	Air quality scenario	Benefits/costs per household US\$/year
Jackson et al (1976)	from 235 $\mu\text{g}/\text{m}^3$ to 115 $\mu\text{g}/\text{m}^3$	42
Ryan et al. (1981)	from average 1970 levels ^a to 45 $\mu\text{g}/\text{m}^3$	6.63/ $\mu\text{g}/\text{m}^3$
Watson & Jaksch (1982)	from av. 1970 levels to U.S. primary standards ^b	26-91
	from av. 1970 levels to U.S. secondary standards ^c	48-180
Hamilton (1979)	25% reduction from av. 1970 levels	40

^a Composite annual average 70.4 $\mu\text{g}/\text{m}^3$, annual 90th percentile 106 $\mu\text{g}/\text{m}^3$; composite average of peak daily reading 234 $\mu\text{g}/\text{m}^3$, 90th percentile of peak daily reading 390 $\mu\text{g}/\text{m}^3$.

^b U.S. primary standard: annual composite average of 75 $\mu\text{g}/\text{m}^3$, peak daily reading of 260 $\mu\text{g}/\text{m}^3$.

^c U.S. secondary standard: annual composite average of 60 $\mu\text{g}/\text{m}^3$.

Source: Freeman, 1982.

On the basis of these and other studies, Freeman (1982) concludes that a 20 percent reduction of ambient TSP concentration from 1970 levels (equivalent to a reduction of 14.1 $\mu\text{g}/\text{m}^3$) would provide soiling benefits in the range of US\$18 to 108 (1978) per US household, with a most reasonable point estimate of US\$54. This means a benefit of US\$1.3 to 7.7 per $\mu\text{g}/\text{m}^3$ reduction in TSP (most reasonable point estimate of US\$3.8 per $\mu\text{g}/\text{m}^3$), or a benefit of US\$0.9 to 5.4 per percent reduction (most reasonable point estimate of US\$2.7 per $\mu\text{g}/\text{m}^3$).

Monuments

Air pollution also affect the physical condition of buildings that have great cultural or religious importance. The repair of such monuments not only involves financial costs, it may also result in a loss of authenticity. Therefore, it is generally assumed that the economic damage caused by air pollution to monuments (as measured by WTP) is larger than the cost of maintenance and repair. However, since no studies account for such hard to value losses as authenticity, damage estimates are usually based on maintenance and repair costs.

Vegetation (agriculture, forests, trees and parks)

For valuation purposes, vegetation can be divided into the following categories:

1. vegetation grown for commercial purposes (agricultural crops, pastures, forestry); and
2. vegetation without commercial purposes (ornamental trees, parks).

Damage to commercial vegetation is relatively easy to value. Damage is either the loss in yield multiplied by the relevant off-farm selling prices, the costs of mitigating measures (e.g. liming), or a combination of both. The bottleneck of a valuation exercise is most likely to be the availability of reliable dose-response functions. Dose-response functions are available for a number farm crops grown in Europe and the United States. Reliable dose-response functions for trees do not yet exist. In valuing damage a decision has to be made as to which crops to include in the damage assessment; only the crops grown within the city limits, or also those in the neighboring countryside.

Damage to non-commercial vegetation is more difficult to value. A first approximation of the damage is the costs of mitigating measures such as liming, or the replacement costs of affected ornamental trees. There is little prospect of finding reliable dose-response functions for non-commercial vegetation.

APPENDIX 6 ENVIRONMENTAL SURVEILLANCE AND INFORMATION SYSTEM (ENSIS)

INTRODUCTION

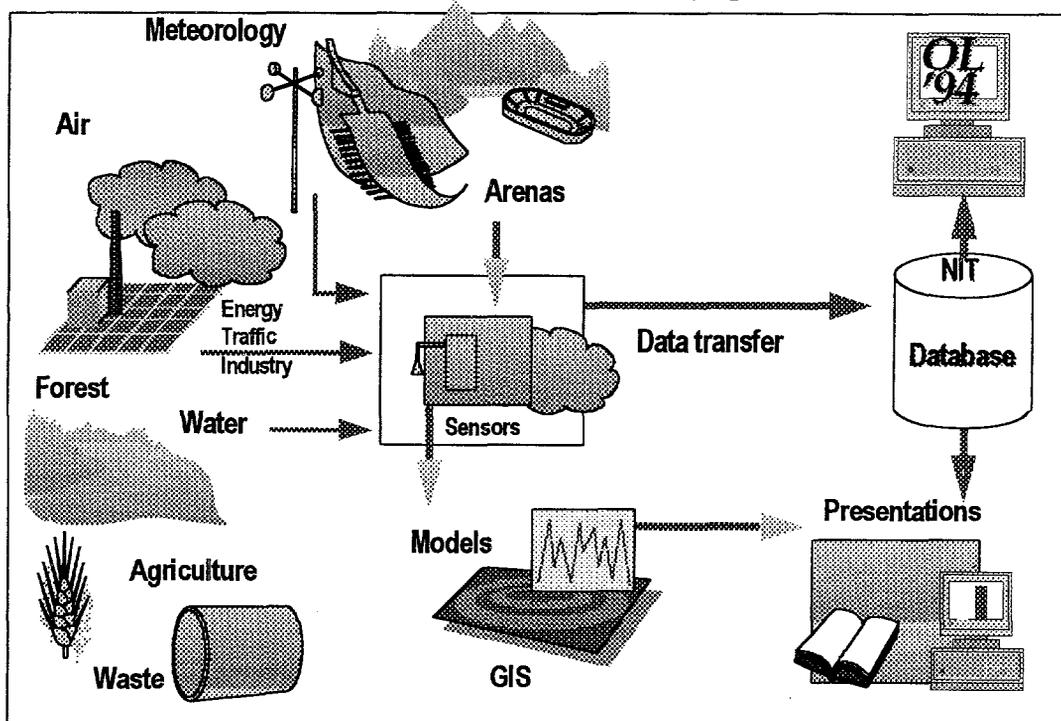
A modern Environmental Surveillance and Information System (ENSIS) has been developed within the Eureka framework of the European Union. A first version of this user-oriented system for collection and storing of measurements, emission inventory module, dispersion models and map oriented presentation systems was applied and demonstrated during the Winter Olympic Games in Lillehammer, Norway in 1994.

The ENSIS system was developed through close cooperation among institutions dealing with air and water pollution, data handling, information technology and geographical information systems (GIS). The combination of online data collection, statistical evaluations and numerical modeling enable the user to obtain information, carry out forecasting and future planning of air quality. The system can be used to estimate environmental impacts from planned measures to reduce air pollution. For air pollution impact assessment, authorities and governments may select total human exposure as an indicator. The ENSIS system is designed and prepared to include the estimation of such parameters.

THE ENSIS SYSTEM

The system was designed to fulfill the need for real time presentation of environmental measurements and dispersion modeling during the Winter Olympic Games (Figure 6A.1). It is user friendly with respect to both collection and presentation of measurements and model results.

Figure 6A.1: The ENSIS '94 concept for the 1994 Winter Olympic Games in Lillehammer

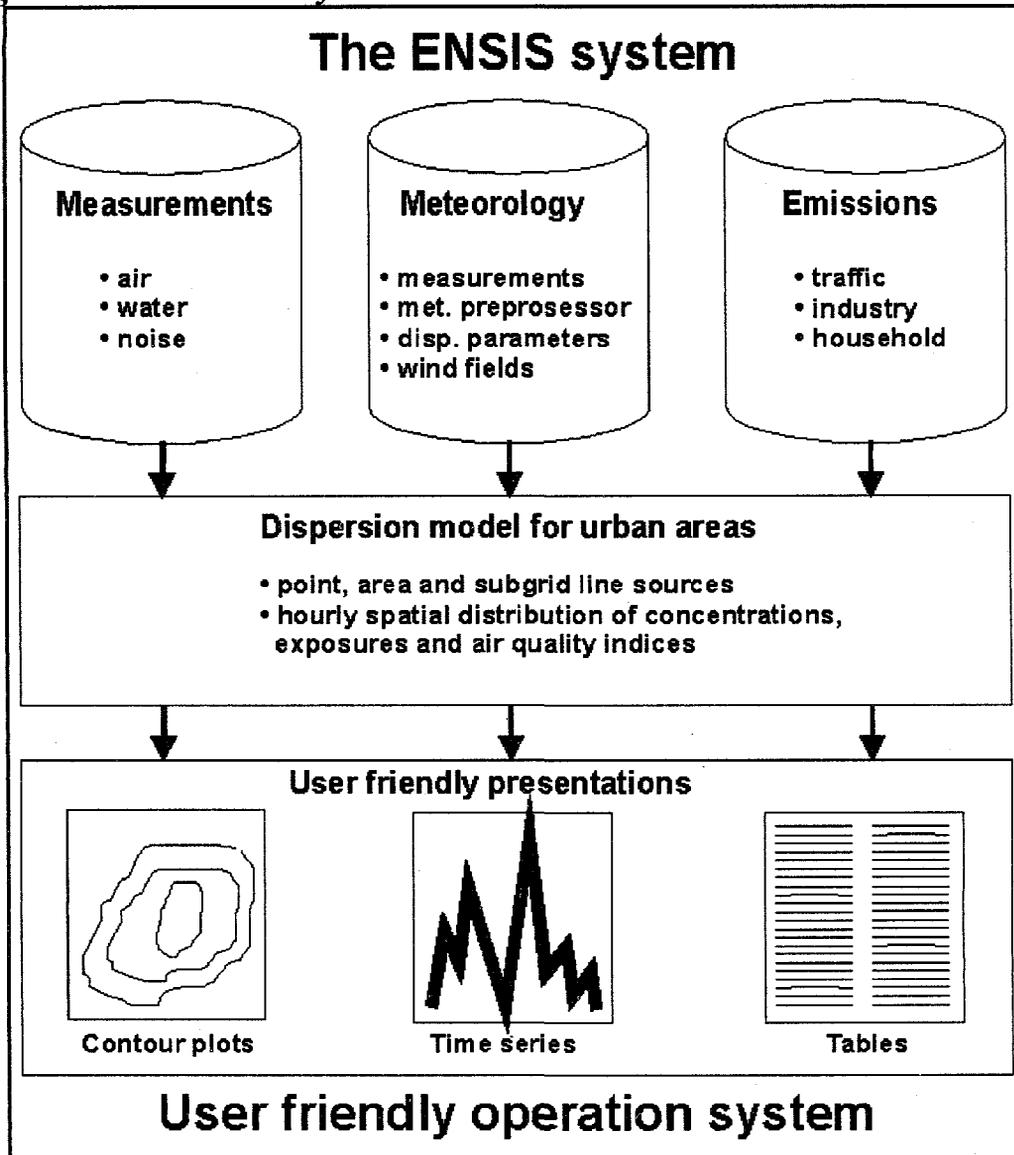


The development of the ENSIS system involved the following steps:

- on-line monitoring system;
- modern databases for emission inventory;
- statistical and numerical models for transport and dispersion;
- user friendly graphical presentation system ;
- presentations based upon a geographical information system (GIS);
- application for the Winter Olympic Information System INFO '94.

The ENSIS system in Lillehammer included different environmental aspects, such as meteorology and climate, air pollution dispersion models, drinking water quality and river surveillance and controls, waste water treatment systems, an information data platform and link to the INFO '94 Olympics information system containing a graphical presentation package (Figure 6A.2).

Figure 6A.2: The ENSIS System



On-line monitoring system

A monitoring system of modern on line sensors for air and water quality measurements was established in the Olympic region. Also, a specially designed data logger for meteorology and air quality has been included as part of the system, The logger is robust and may serve as a local backup storage in case of line break down (lightening, storms, etc.). The measurements are automatically transferred from the monitoring hut to central database for quality control.

Data quality control is performed at different levels in the data collection process; in field during automatic and manual calibrations and controls, at the central data collection base, where calibration and raw data controls are performed and in the approvals of the final storage

database, where simple statistics and data graphics are used to check the validity and representativity of the data.

Database for emission inventory

As a continuation of the ENSIS prototype used during the Winter Olympic Games, an air quality database has been developed for emissions inventories. The new emissions module is a flexible system containing a user friendly map oriented interface for each of the main sources of air pollution, such as industry, traffic, consumption of fossil fuels, and emissions related to airport and harbor activities.

The industry emissions module allows the user to select sources related to specific activities or areas. The time variation in emissions can be entered specifically for each source or as a standard variation for groups of sources. Based on emission factors, emissions can be calculated from consumption data.

The consumption of fossil fuel can be distributed according to population distribution in the area or as direct input into subareas defined in the total area. By using default emission factors or factors specified for fossil fuels, emissions of different compounds can be calculated for parts of or the entire area under consideration.

The traffic module is the most complex part of the emissions module, containing flexible functionality concerning descriptions of road types and facades, vehicle type distribution, traffic time variation and emission factors dependent on parameters such as vehicle type, traffic speed and road type.

The emission module can be used to evaluate the effects on emission reductions related to different measures for improving the air quality in an area. The module also performs gridded emission fields as direct input to the atmospheric dispersion model adapted for the area. The emission inventory module is modeled for applications into modern databases such as Access on PC and Sybase and Oracle on Unix work stations.

Statistical and numerical models

Various atmospheric transport and dispersion models have been developed and included in the ENSIS system. These models represent air pollution on all scales; traffic in street canyons and along roads, industrial emissions, gridded pollution from household etc. within the urban areas and regional air pollution.

NILU's source oriented, numerical dispersion model EPISODE, calculates spatial distribution of hourly concentrations of SO₂, NO_x, NO₂ and PM₁₀ (Larssen et al., 1994) ROADAIR and CONTILENK, also developed by NILU, correspond to US EPA HIWAY (Peterson, 1980) for open roads, and NERI OSPM (Hertel and Bercovicz, 1989) for street canyons respectively. These models are used to estimate subgrid concentrations close to roads within the square grid. A puff-trajectory model is used to calculate the influence of point sources.

All model results are displayed by using the ArcInfo/ArcView based GIS system. The models are running on Unix work station. The presentation system can be operated both on PC and Unix platforms.

The GIS-system

For the presentation of measurement data, emissions inventory and results from model estimates, the ENSIS system has selected a geographical information system based upon ArcInfo and Arc View. Many kinds of geographically-linked environmental data are presented on various maps for the area. In general, the ENSIS system has also been developed also to serve other types of geographical information systems. The geographical information system is directly linked to the databases, from which statistical evaluations, graphical presentations and spatial distributions of emissions and models result can be presented.

Applications for the Winter Olympic Information System, INFO '94

In cooperation with local authorities, environmental information centers were established in the cities in the Olympic region. Data from the ENSIS system were presented continuously both on the INFO '94 platform and on more advanced computers with GIS based graphical mapping of environmental data. More than 50 institutes and organizations received information about ENSIS, and more than 60 users received automatically daily environmental data on fax during the Olympics.

The use of INFO '94 was based on transactions and requests for information, lists, texts, tables and graphics. A total of 1130 terminals were operated, and between 4000 and 10000 transactions were performed in search for environmental and weather data every day. Two thirds of the requests were for environmental information adding to a total of 100,000 requests for environmental data during the Olympic Games.

Applications of ENSIS

ENSIS has been developed as a user oriented continuous surveillance and information system for all types of environmental data. It includes monitors, data quality control, transmission systems, various models, graphics, a GIS system and data displays and presentations. As a management system it can be used for planning and automatic controls. It also represents the basis for a forecast and alarm system.

The ENSIS system contains a number of different applications and tools. The ENSIS concept can be used to establish an application for that fulfills the user's environmental information needs.

Potential users:

- Local traffic and urban authorities;
- Industries;
- National and international environmental agencies;
- Organizers of large events like the Olympics, World Fairs, etc.

The ENSIS system is now being established in Oslo, Norway, and is also being adapted to other major Norwegian cities. The system will be an effective tool for an air pollution abatement strategy.

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