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# AIR QUALITY ASSESSMENT AND SURVEILLANCE PROGRAMMES

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NILU

NORWEGIAN INSTITUTE FOR AIR RESEARCH

ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

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# AIR QUALITY ASSESSMENT STUDIES AND SURVEILLANCE PROGRAMMES

## 1 INTRODUCTION

The Norwegian Institute for Air Research (NILU) has on contract with the State Pollution Control Authority, undertaken several comprehensive studies of the air pollution situation in Norwegian cities.

The main objectives of these studies were to provide

- information on the level of air pollution to which the public is exposed:
- a basis for development of strategies to reduce air pollution
- a planning instrument (basis) for estimating environmental impact of further development in the region.

Such studies include the following elements

- area and land use description
- emission inventories
- air quality measurements
- meterological measurements
- development and use of dispersion models
- evalution of the effects of pollution

The efforts put into each of these elements depend on the characteristics of the study area.

## 2 AREA AND LAND USE DESCRIPTION

The characteristics of the geographical area to be studied, affect the selection of the appropriate assessment programme to a great extent. Therefore the area must be carefully examined and be documented.

The main items are:

- the designation of the area (name, district, or part of ....).
- the boundaries and size.
- the geographical and topographical characteristics, including:
  - the geographical location of the area, e.g. location near or at a coast with specific meteorological conditions, and the average height above sea level.
  - the relief (valleys, hills, flat terrain, forests, lakes, agglomeration of the high rise buildings etc.).
- the population, industry, traffic and their spatial distribution.
- the energy production and consumption patterns.
- other kinds of land use within the area, e.g. farm land, recreation areas.
- the surrounding areas and their characteristics which may be of importance as far as they may influence the pollution inside the assessment area.

## 3 EMISSION DATA

Air pollution emission inventories for selected pollutants have to be established for the area. The emission inventory yields a spesific year of reference, supplemented by additional statistical data, providing the basis for emission forecasts.

Emission inventories are generally composed of three categories of emitters: point, line and area sources. In the most detailed inventories, a large fraction of the total emission is represented by the point/line source data base. Thus the comprehensive inventory contains many data items for a large number of individual emitters.

In all emissions inventories, a distinction must be made between the principal air pollutants of concern. Generally, $SO_2$, oxides of nitrogen ($NO_x$), carbo n monoxide (CO), hydrocarbons, and particulates are included.

Other important air pollutants are formed in the athmosphere by chemical and photochemical reactions. The precursors for these pollutants should be included in the emission inventories ($NO_x$, HC, Cl, and others).

Consideration of specific hazardous pollutants (e.g. asbestos, fluorides, vinyl chloride) is important in land use planning and should also be considered with equally high resolution. The emission inventory should be devided into source categories:

- household and small consumers
  based upon: energy consumption rates, type of heating, population distribution, number of dwellings per unit area, use of fuel oils, emission factors etc.
- automative transportation
  based upon: number of motor vehicles, traffic pattern, special emission factors for specific components for the relevant type of vehicles, (passenger, cars, trucks, buses..) traffic density variations (annual, diurnal) for each unit area etc.....

- industry
  based upon: emission measurements, fuel consumption, type of processes, production rate, time variation etc...
- electricity generation (power plants)
  based upon: fuel consumption, fuel type, emission factors, sulfur and ash content in fuel, emission control systems efficiency etc....
- incineration
  based upon: type of furnace, emission control system, emission measurements etc....
- miscellaneous

The establishment of emission factors are essential for the reference emisson inventory, and for enabling emission forecasts.

Emission factors relate emissions of a specific source category (without emission controls) to an actual release rate. The concept and use of emission factors is absolutely necessary in compiling a comprehensive baseline inventory and is also essential in forecasting air quality, where measured emission data are not available. Emission factors can also be developed for processes to be constructed at some future time for use in forecasting emissions.

The emission inventory data also has to include information about stack heights, gas flow rates, exit gas temperatures (heat output) etc.....

The spatial and time resolution (details required) in establishing an emission inventory is based upon the objectives of the study and the use that will be made of the data. Usually all sourcecategories should be broken down to a grid size of at least 1 km x 1 km. The location of large point sources should be specified more precise for dispersion modelling purpose and monitoring programme design.

## 4 AIR QUALITY MEASUREMENTS

A thorough and accurate record of air quality is of fundamental importance in a survey. This should include information on the variations and fluctuations in pollutant concentrations with respect to time and space. Time considerations include diurnal, seasonal, and annual trends and patterns, while spatial factors involve comparisons of pollutant concentrations on the basis of their horizontal and vertical distribution. In large studies, it is desirable to use an air sampling network in and around the area of interest. The design of such a network will depend on available resources; however, its configuration should take into account the sources, receptors, and local climatology.

Air quality models are particularly useful in both the design and augmentation of such networks. If data are used in the regulatory process, it must be shown that the data are representative and relevant to the problem . In such circumstances, air quality simulation models provide a method of testing the relevance of the monitored data.

The amount of data to be gathered and the detail and accuracy required is often not only dependent on the number needed for assessment but is also influenced by the final goals of the study.

The measurement system needed to determine the existing ambient air quality can be combined with the expected surveillance system needed at a later stage. Just as there is a wide range of possible monitoring systems for application to different monitoring requirements, there is also a range of possibilities for assessment and surveillance of existing air quality.

The air pollution components to be studied are dependent of the activity of the specific area, and upon air pollution

impact concern or regulations (air quality standards etc...). Both primary ($SO_2$, $NO_x$, HC, particles etc.) and secondary (Ozone, $NO_2$, $SO_4$ etc..) pollutants should be considered.

The choice of the means of data collection is determined to a large extent by the space and time resolution that is needed. The choice of the time and space resolution of the measurement system is also determined by the resolution of the effects that will be usefully examined.

The design of the monitoring programme should provide a basis for the data analysis and presentation, where information should be available to answer specific questions concerning the existing air quality of the region.

As a minimum the following information should be supplied:

- mean daily concentrations for all the pollutants concerned
- diurnal variation of these concentrations
- the frequency distribution of the concentrations
- maximum values (hourly, daily)
- the major source areas responsible for the concentrations found at the receptor points.

The data can be collected using measurements at fixed monitoring stations, measurements made using mobile sampling or remote sensing or a combination of these techniques. In addition, model calculations have to be performed to study the reliability and representativeness of air quality data, and to give a total picture of the spatial concentration distribution of the area. For this purpose also meteorological data are needed.

## 5 METEOROLOGICAL AND CLIMATOLOGICAL DATA

Concentrations of air pollutants vary in space and time, partly because of the uneven distribution of sources, but also

because of meteorological conditions, which vary from hour to hour and from day to day. Special attention must therefore be given to the meteorological/climatological data requirements.

An important first steps in the development of a monitoring programme is to make an inventory of existing meteorological observing stations in the survey area. Although such an inventory will be helpful, it should not automatically be accepted as the basis for an air quality assessment study. The station sites where usually selected because of their relevance to synoptic weather forecasting, to aviation, or perhaps to agriculture, but not necessarily to air pollution.

In the design of a meteorological climatological data system for an air quality assessment study one of the criteria to be considered is the meso-meteorology of the region. Particularly when synoptic-scale winds are light and skies are clear, the mesoscale circulations can have a major affect on air quality. The existence of meso-meteorological wind fields can often be estimated by:

- careful examination of topographic maps and aerial photographs and
- study of published wind roses.

The presence of a coast-line, valley or escarpment is an indication that mesoscale winds may occur. Site inspections may help to confirm the existence of such flows. Because most mesoscale circulations show a day-night reversal, the wind roses are most informative when they have been prepared separately for daylight and night-time hours.

The following meteorologial observations may be useful:

<u>wind speed and direction</u> measured along meteorological towers (of at least 10 m). The number of measurement stations should be sufficient to determine the wind field within the study area, and should be located relative to sources and topography so that they can be

used to estimate transport and diffusion. Winds at some elevation above the study area should be available (television tower, radisonde, geostrophic wind ....)

Air temperature should be measured to provide horizontal and vertical gradients.

Turbulence measurements are essential to estimate the dispersion of air pollutants. This can be accomplished by measuring 3-component wind speed fluctuation, wind direction fluctuations and vertical stability (vertical temperature gradient and wind speed) or by measuring vertical temperature gradient and wind speed only. Also indirect but less accurate methods for estimating turbulence from other climatological data are available.

Relative humidity should be measured to explain visibility and humid plumes.

Precipitation amounts, intensity and chemical composition should be available to estimate wet deposition.

Vertical temperature and wind profiles data and mixing heights should be collected at least once at daytime and once during the night. Alternatively data along a tall televison tower could provide parts of this information to estimate mixing heights.

## 6 AIR QUALITY DISPERSION MODELS

Air quality models are essential tools in establishing the mathematical connection between emmission and air quality, through the use of meteoroligical dispersion data and know-

ledge of physical and chemical reactions in the atmosphere. The fundamental problem is to calculate air concentrations of one or more species as a function of time and space.

The ability to perform diffusion calculations depends on the availability of appropriate input data, representative dispersion parameters and sufficient meteorological information relevant to the diffusion process. The following check list gives a survey of the data necessary to perform calculations, which also is in accordance with the above specified data in the assessment programme.

Emission and source data:

- source location, i.e. geographical coordinates
- source dimensions, i.e. height and exit diameter
- exhaust gas exit temperature
- mass flow rate of air pollutant from the source
- volumetric flow rate of the total exhaust gas
- time dependence of pollutant emission rate, i.e. duration, frequency as well as diurnal and seasonal dependence, if applicable

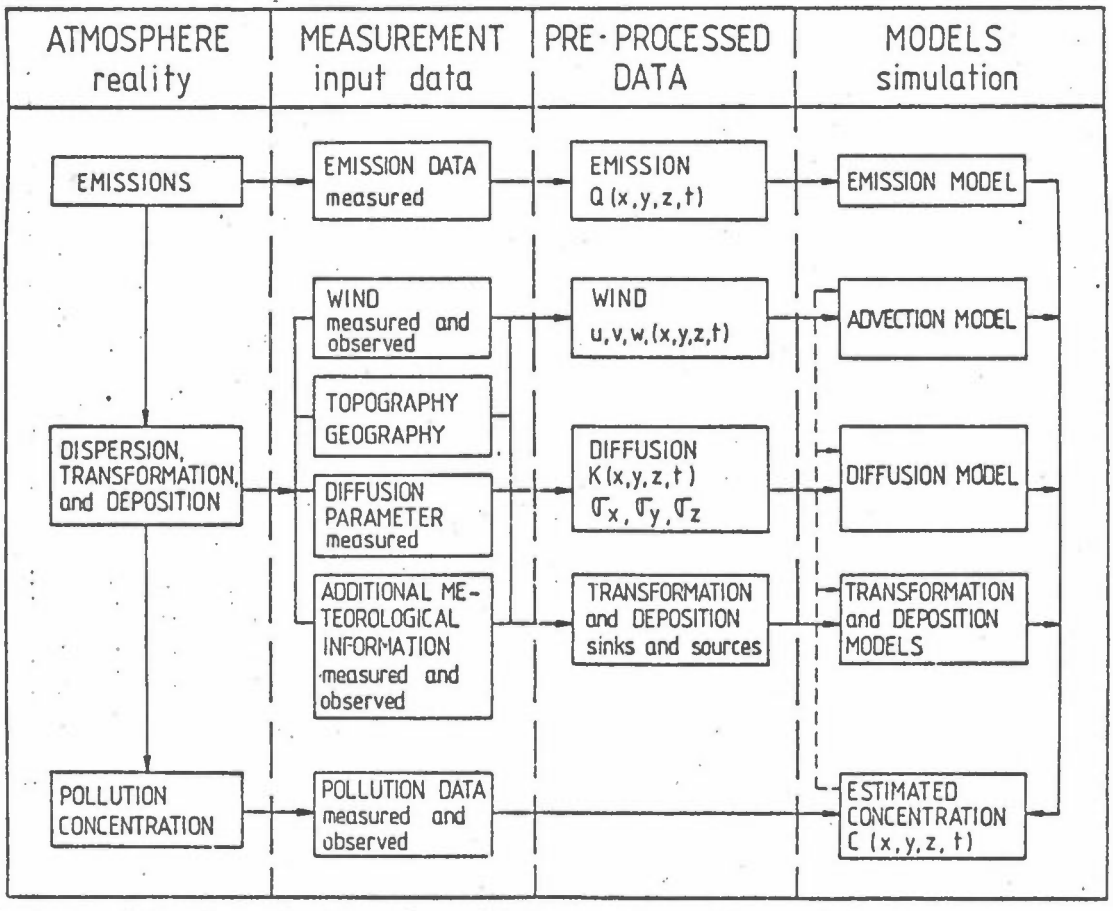
Transport and dispersion (meteorological) data:

- average wind direction
- average wind speed
- description of turbulent structure of the atmosphere
- mixing height (height of inversion layer)
- ambient air temperature (for plume rise calculations)
- joint frequency distribution of at least the first three meteorological parameters
- vertical and horizontal dispersion parameters representative of characteristic turbulence situations.

The type and complexity of the air quality model to be used will depend upon:

- source characteristics
- type of pollutants to be estimated (primary. inert, secondary, gas, particles.....)
- size of the area (space and time scaling)
- topographical features (complexity of terrain)
- available computers
- economy

Figure 1 indicate the modules or elements to be considered in developing, adjusting or applying air pollution dispersion model in a specific area.




Figur 1: The elements in air pollution dispersion model simulation.

Several types of air pollution dispersion models are available, and several of these have also been developed and applied in various assessment studies and surveillance programmes at NILU. In principal, these source oriented models can be devided into deterministic models and statistical models.

Deterministic models calculate concentrations from emission-inventories and meteorological data with mathematical equations describing the relevant physical processes.
Statistical models estimate concentrations from empirical statistical relationships between air quality and meteorology. Emission data are not neccessarily needed in this case, and these models are thus not well suited for long term planning. For short term forecast used in operational air quality control programmes, these models have, however, been widely used.

Most deterministic models are based upon various solutions of the diffusion equation.

The steady state models have been most widely applied. Some of these are:

- gaussian point source models for estimating impact from single point sources, verified from numerous measurement programmes

- multiple source gaussian models for point and area sources in urban areas

- simple area source models based upon a input/-output (flux) consideration where concentrations are inversely proportional to the wind speed.

Time dependent models are usually more demanding than steady state models. All variables can be functions of time and the concentration output is also calculated depending on time. Some of these models available are:

- box models for urban areas has been developed to estimate the flux of pollutants advected across boundaries of boxes taking into account sources, dispersion, deposition, transformation etc.

- grid models usually solve the diffusion equation numerically in an Eulerian gridded space. A large number of grid models exist for solving different specific problems, also including photochemical reactions in the atmosphere.

- Lagrangian (puff trajectory) models advert puffs of pollutants along the wind trajectory and estimate diffusion, transformation and deposition during the course.

Several other air quality models could be mentioned, however, it is belived that when a set of source oriented models are to be established for an air quality assessment programme, they will be within the families mentioned above.

For the optimal use of air quality data in estimating single source contributions and verifying model performances it is recommended also to use receptor oriented statistical models. The principle in applying the two types of models is indicated in Figure 2

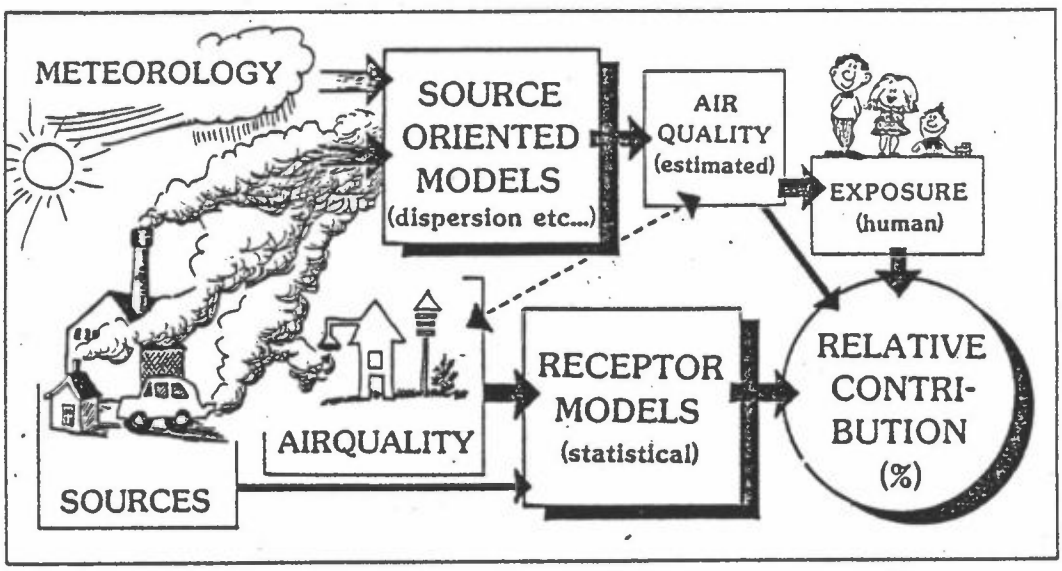



Figure 2: The combined used of source oriented air pollution dispersion models and statistical receptor models, form the basis for evaluating source contributions and air quality data control.

## 7 EFFECT ASSESSMENT

Area-wide air pollution surveys are initiated because a problem is thought to exist, which implies the existence of an undesirable effect, such as reduced visibility, haze, irritation of the eyes or respiratory tract, obnoxious odors, damage to vegetation, livestock, property, or health, or other unwanted effects. An air pollution survey, therefore, must seek to identify and evaluate the undesirable effects and relate them to air quality and source. In this manner, the cause-and-effect relationships are clarified and there exists a basis for development of a rational control and abatement of the problem.

Health studies are difficult and usually expensive to carry out. Air quality data can, however, be compared with air quality standards, e.g. those proposed by the World Health Organization, but this procedure only gives an indication of potential hazards. Epidemiological studies have been carried out also at NILU to investigate air pollution effects on the population.

Complaint studies can be undertaken in a simple manner, directed to a central "office" where records are kept. These data could then be analyzed statistically by number, type, location etc.. and related to air quality data.

Odor mapping has also been achieved in various ways, by expert panels or expert individuals.

Vegetation damage has been mapped using photographic techniques, by expert surveillance and collection of samples for analysis. Mapping of lichens, fungus and moss has also been indicative for potential air pollution impact.

Material damage (atmospheric corrosion) has been studied in several atmospheric field testing programmes. Network designs for standardized testing and evaluation of the impact of air pollution on the corrosion rate of various materials and coatings have been developed at NILU as part of air quality assessment studies.

## 8 POPULATION EXPOSURE ESTIMATES

Air quality data (from measurement programmes and air quality dispersion models) and population statistics can be used to estimate the exposure of specific pollution componds to humans or specified organs in humans (e.g. lead to blood). Such estimates have been carried out for the inhalation exposure of $SO_2$ and $NO_x$ to the total population in the Nordic capitals. Annual average concentration of lead in blood in a population of southern Norway, has also been estimated.

The exposure commitment methods used, emphasized that exposure commitment is a combined measure of the concentration and duration of pollutants presence in a specified environmental medium:

$$E = \int_{0}^{\infty} C(t)dt$$

An important input is thus the living pattern of the population, and knowledge of both outdoor and indoor air quality. Air quality also has to be known in streets, cars, in working atmospheres etc.... It is believed at the moment, that these methods will be of importance in future evaluations of air quality health impact assessments. However, at present there is a lack of dose/response data available.

# *APPENDIX A*

Norwegian Institute of Air Research (NILU)

Presentation and past experience

# *NORWEGIAN INSTITUTE FOR AIR RESEARCH*

## PRESENTATION AND PAST EXPERIENCE

The Norwegian Institute for Air Research (NILU) was founded in 1969 by the Royal Norwegian Council for Scientific and Industrial Research (NTNF) to carry out research, to advise Norwegian authorities and to servie private industries in all aspects of air pollution. Part of the budget is forwarded by NTNF, but most of it is being obtained through consulting services and assignments.

The total staff numbers, more that 90, including research scientists, university graduates and technical personnel.

The main fields of activity include:

- Air quality measurements
- Air pollution modelling
- Site studies
- Atmospheric corrosion
- Emission inventories
- Instrumentation and chemical analyses
- Meteorological measurements and analyses
- Photochemical reaction in the atmosphere

With special emphasis on:

- Dispersion of air pollution from industrial sources
- Air pollution from motor vehicles
- Long range transport of air pollution
- Acid precipitation
- Atmospheric corrosion testing and evaluation
- Advanced laboratory for organic compounds

NILU intimately collaborates with:

- The Norwegian Meteorological Institute for meteorological information and trajectories
- Institutt for energiteknikk (IFE) for neutron activation analysis and x-ray fluorescence spectroscopy
- Other NTNF institutes, specialised laboratories and industries for environmental effects and abatement techniques.

To be able to supply the highest degree of quality and advanced techniques, NILU maintains extensive chemical and instrument laboratories for evaluation of samples, calibration and development of new instruments, as well as computer facilities for data quality control, data storage, statistical data analyses and dispersion model calculations.

To supplement the measurements at ground stations with data for the dispersion of pollutants and for rapid surveying of large areas, NILU has a twin engine research aircraft (Piper Navajo) fully instrumented with:

- Two filter sampling system for aerosol and reactive gases
- Particle light scattering detector
- Condensation nuclei counter
- Recording instruments for gaseous air pollutants
- Sensors for turbulence, humidity and free air temperature with facilities available for remote sensing equipment.
- Single channel recorders
- Complete data logging equipment which enable data processing immediately after landing

Through its wide range of activities NILU has developed a series of new instruments and improved existing instruments for efficient and reliable data collection and testing.

Through funds from the Royal Norwegian Council for Scientific and Industrial Research, NILU has been able to carry out extensive research programmes.

NILU has carried out a large number of assignments both in Norway and abroad. Some of the more significant projects are described below.

## MAJOR ASSIGNMENTS

NILU undertakes 70-80 air pollution projects each year. Below are mentioned the most relevant projects from the latest years.

| COUNTRY | | SERVICES RENDERED | CLIENT | |
|---|---|---|---|---|
| Europe | Long Range Transport of Air Pollutants | Planning, development of methods, data evaluation and central co-ordination of the programme | OECD and 11 particip-ating countries | 1971-1977 |
| Europe | The European Moni-toring and Evaluation Programme (EMEP) | Planning, development of methods, data evaluation co-ordination and quality control of chemical measurement programme | UN, Economic Commission for Europe | 1977 |
| Greece | Environmental impact in the metropolitan aera of Athens | Planning of monitoring programme and model calculations | United Nations UNDP/WHO project GRE/GEP001 | 1975 |
| Switzerland | Air Quality modelling and assessment | Model calculations and identification of sources | Hoffman - La Roche | 1975 |
| England | Plume Dispersion Studies | Measurements with the NILU aircraft | Central Electricity Research Laboratory | 1976 |
| Norway | Norwegian Monitoring System | Air Quality Studies in more 50 cities and communities | State Pollu-tion Control Authority | 1971 |
| Norway | Site studies for power plants | Meteorological and dispersion studies concerning site studies of nuclear-, coal-, and oil-find power stations | Ministry of Environment and the Norw. Water Resources and Electricity Board | 1974-1977 |
| Norway | Investigation of photochemical oxidants from petro-chemical industries | Measurements and modelling of photochemical oxidants and their precursors in the atmosphere | Ministry of Environment and private industries | 1974-1977 |
| Norway | Air pollution from road traffic | Measurement and modelling of pollution (HC, NOx, SO2 and particulates) | Ministry of Environment, communities and Road Directorate | 1975 |

| | | | | |
|---|---|---|---|---|
| Norway | Model studies | Development of air pollution models for major Norwegian cities | Royal Norwegian Council for Scientific Research (NTNF) | 1975-1976 |
| Norway | Ambient air study from major industries | Planning, instrumentation, measurements. Development of aera- and single source models | Communities, in cooperation with private industries | 1971-1977 |
| Norway | Emissions from power stations | Evaluation of effects on health and environment from power stations | NTNF and Institute for Atomic Energy | 1974-1975 |
| Norway | Atmospheric corrosion | Measurement and modelling of meteorological and corrosion parameters in southern Norway | NTNF and private industries | 1976-and on |
| North Sea | Gas dispersion from the Bravo blowout | Measurements (aircraft), and modelling of gas cloud from Bravo blowout in North Sea relative to explosive limits | | 1977 |
| Norway | Environmental impact at Mongstad | Meteorological programme, dispersion calculations and air quality measurements at petrochemical complex Mongstad | Norsk Hydro | 1972-1977 |
| Norway | Air Quality Slagentangen | Measurements and calculations of air quality around oil refinering at Slagentangen | Ministry of Environment | 1971 and 1977 |
| Norway | Bamble investigations | Air quality studies prior to operation of petrochemical complex at Rafnes | Industries | 1975-1977 |
| Sweden | Tracer experiments and air quality assessment | Problem identification in the surroundings of an aluminium plant | Gränges Aluminium | 1977-1980 |
| Spain | Meteorological dispersion study | The potensial impact at ground level from the Teruel power plant | Ecopol | 1979-1980 |
| Norway | Tracer experiments | To estimate diffuse leakages from petrochemical factories | Local industries and control board | 1979-1981 |
| Arctic | Air pollution transport studies | Extensive research programme to investigate the transport of pollutants to the Arctic | British Petroleum(BP) | 1980-1985 |
| Spain | Environmental impact | Estimated environmental impact at a planned power plant | INYPSA | 1981 |

| | | | | |
|---|---|---|---|---|
| Norway | Basic assessment and surveillance programmes | Emissions, air quality and modelling for establishment of surveillance methologies in Sarpsborg, Bergen, Mo, Drammen | Pollution control authorities | 1981- and on |
| Sweden | Tracer field studies | To estimate diffuse leakages at petrochemical industries | "MUST" Swedish environmental protection board | 1984 |
| Nordic countries | Field studies | Mesoscale meteorologial dispersion experiment in the Malmø - Copenhagen area | Nordic org. for applied research | 1984 |
| Norway | Assessment of air quality around Aluminium smelters | Measurements and evalutions of organic and other pollutions included effect studies | Aluminium industries | 1980-1984 |
| Norway | Chemical and photochemical modelling | Studies of the formation of haze i Telemark | State Pollution Control authorities/ Norsk Hydro | 1981-1984 |
| Norway | Epidemiological study | Interview investigations and Pb-blood probing in various areas. | Ministry of Environment | 1979-1980 |
| Norway | Waste incinerators | Impact of waste conbustions i several communities | Local authorities | 1981- and so |
| Iceland | Impact at electro-chemical industries | Environmental impact statements for Fe-Si and Al-smelters | Local industries | 1979-1985 |

# *APPENDIX B*

NILU modelling experience

NILU
SEPTEMBER 1981

## NILU MODELLING EXPERIENCE

### Gaussian type point source models

The NILU Gaussian type dispersion models (1) have been applied for several purposes. Input parameters have been examined through meteorological measurement programs (2,3) literature surveys (4), and with the use of $SF_6$-tracer techniques (5,6). Several verification experiments have also been undertaken (7). These models are capable of estimating maximum ground level concentrations (1hr-average) stack height requirements, average concentration distributions for specified periods of time.

The models have frequently been applied to power plant site studies (8).

### Multiple source Gaussian model (KILDER)

A multiple source Gaussian type air quality model for point- and area sources is also available at NILU. This model has been applied for studies in urban areas and for evaluating the environmental impact of emissions from industrial complexes. It was tested on a data base from Frankfurt (9).

### Sea breeze fumigation model

A sea breeze fumigation model based upon Gaussian formulation of dispersion and modelling of the build up of an unstable surface layer as a function of distance from the shore line, has been applied to several power plant sites. A brief description is available in ref. 1. A modification of this model was applied to the build up of unstable surface layers over land in Spain (10).

Dispersion model for inter regional air pollution problems

The time variation in concentration in three levels is considered by describing: a) advection, b) vertical exchange, c) horizontal diffusion, d) chemical reactions, e) emission from natural and antropogenic sources (11). Dry deposition and exchange with the surroundings are incorporated as boundary conditions. The model is composed by subroutines describing the different processes. The procedures has been applied to mesoscale, non stationary phenomena.

Numerical transport/diffusion models

Different numerical solution schemes have been applied for solving the continuity equation in complex nonstationary meteorological situations (12). The models were first developed for the Oslo area (13). Photochemical reaction schemes have also been incorporated into these models and applied to an industrial area of southern Norway (14).

Other model activities

NILU also have experience in heavy gas dispersion modelling (15), the modelling of long range transport of air pollutants (16), chemical reactions in the atmosphere (14) and dry deposition. The US EPA UNAMAP modelling package is also available on the NILU computer, and has been applied to different problems. Models for the emissions from automobile traffic and the dispersion in street canyons have also been developed at NILU.

NILU computer facilities

Since 1970, all computations have been carried out at the computer centre Blindern-Kjeller (RBK). The centre was from September 1981 equipped with a CDC Cyber 170/730 computer with 512k 60-bits word core storage, extended to 1024k in 1982. In addition, there is a number of disk and magnetic tape stations, equipment for computer graphics, plotting etc.

In 1981 NILU was equipped with a NORD ND-100 computer with 512 byte core storage, disk and tape stations. The computer acts mainly as a local computer and partly as a terminal to the RBK computer centre. The combination of a medium-size local computer connected to one of the largest computer centres in Norway provides the institute with a fast and large datahandling and calculation capability.

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# *APPENDIX C*

Photochemical reactions.
Modelling experience at NILU

# *THE EFFECT OF CHLORINE ON THE FORMATION OF PHOTOCHEMICAL OXIDANTS IN SOUTHERN TELEMARK, NORWAY*

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Key words: Ozone, peroxyacetylnitrate, chlorine, petrochemical industry, plume model, measurements.

ABSTRACT

Hourly average concentrations of up to 15 ppbv of PAN was measured during the summer 1982 a few kilometers downwind of the chemical industries in Southern Telemark, Norway, in sea breeze situations. The $O_3$/PAN ratio was as low as 13 by volume for the highest PAN concentrations. The chemical industries are emitters of, among other gases, $Cl_2$, $NO_x$, $SO_2$, and hydrocarbons. A model for the chemistry and dilution of the plume from the main industrial complex is described. The emission of $Cl_2$ seems to be the cause of the photochemical activity. The release of atomic chlorine through the rapid photodissociation of $Cl_2$ is calculated to give maximum hydroxyl concentration close downwind of the main industrial complex where also the peak concentrations of $SO_2$ and $NO_x$ are found, giving rise to rapid nitric acid and sulphate formation. A reduction in the $NO_x$ emissions would increase the photochemical activity, while it is calcu lated that reducing the $Cl_2$ emissions would reduce the formation of photochemical oxidants. It is shown that PAN is a much better indicator of the photochemical activity than $O_3$.

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# DIURNAL VARIATIONS OF OZONE AND OTHER POLLUTANTS IN AN URBAN AREA

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(*First received* 10 *February* 1977 *and in final form* 4 *July* 1978)

**Abstract** – A theoretical model is used to describe the diurnal variations of primary and secondary pollutants, with emphasis on ozone. This is done for an urban basin with anthropogenic sources of nitrogen oxides and hydrocarbons. We propose a scheme for the decomposition of aromatic compounds. According to this scheme, each aromatic molecule gives rise to six transfers of NO to $NO_2$ without consumption of odd oxygen. It is concluded that it is not a good approximation to represent urban hydrocarbon emissions by one single species, neither in short term (a few hours) nor multiday simulations. Species with both high and low reactivity ought to be included. We show that the nocturnal minimum in ozone often observed in urban areas, is mainly induced by gas chemistry. It is not a good approximation to omit the chemical development during the night-time in a theoretical analysis of urban photochemical pollution. Such an omission introduces errors also in the day-time chemistry. Application of constant dissociation rate coefficients over the day gives rise to false morning and evening ozone maxima.

# Computer Modeling Studies of the Impact of Vehicle Exhaust Emission Controls on Photochemical Air Pollution Formation in the United Kingdom

**Richard G. Derwent*** **and Øystein Hov†**

Environmental and Medical Sciences Division, Atomic Energy Research Establishment, Harwell, Oxfordshire, England

■ Numerical simulation techniques are applied to the formation of photochemical air pollutants in the London region from emissions of NO, CO, $SO_2$, $CH_4$, and 35 organic hydrocarbon and oxygenated species. The model gives a realistic simulation of the observed production of ozone, peroxyacetyl nitrate (PAN), peroxyproprionyl nitrate (PPN), and sulfate aerosol during photochemical episodes. The relative effects of reducing hydrocarbon and nitrogen oxide emissions have been investigated, and hydrocarbon control appears to offer much greater potential for reducing secondary pollution formation in the London region. The controls of vehicle exhaust emissions required or proposed in the United Nations Economic Commission for Europe (ECE) Regulations should markedly reduce ozone and PAN formation in the London region.

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# ONE-DIMENSIONAL VERTICAL MODEL FOR OZONE AND OTHER GASES IN THE ATMOSPHERIC BOUNDARY LAYER

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(*First received* 29 *December* 1981 *and received for publication* 22 *July* 1982)

**Abstract**—A vertical eddy diffusion coefficient profile for mass transport in the atmospheric boundary layer is established on the basis of a calculation where the equations of motion and the thermodynamic energy equation are solved. A one-dimensional vertical model for the chemical turnover is then developed. It is assumed that the turbulent mass transport is equal to the product of the vertical mean concentration gradient and the vertical eddy diffusion coefficient for mass transport. About 40 chemical species are calculated in the model, and about 90 chemical reactions are involved. A log-linear grid is introduced, with close spacing near the ground and coarser towards the free troposphere. The diurnal cycle of ozone in an atmospheric boundary layer with strong convective mixing during the day and a shallow layer under the influence of mechanical stress at night, is computed and compares well with observations. It is found that in polluted air, depletion of ozone close to the ground through reaction with NO prevents ozone from reaching the ground and be removed by deposition. The concentration of hydroxyl has a marked gradient with height, with maximum in the layers where nitrogen oxides, hydrocarbons and sulphur dioxide are emitted. Nitrogen dioxide, sulphur dioxide and the hydrocarbons (ethane, *n*-butane, ethylene, propylene and *m*-xylene) accumulate throughout the night in the shallow nocturnal layer.

# APPENDIX D

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DATO: FEBRUAR 1983

# APPENDIX D

## EVALUATION OF AIR POLLUTION IN OSLO
## A SUMMARY

BY

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# EVALUATION OF AIR POLLUTION IN OSLO
# A SUMMARY

## 1 BACKGROUND INFORMATION

This project was undertaken in 1979 as a co-operative effort between the health authorities in Oslo and the State Pollution Control Authority in Norway (SFT).

The purpose was to quantify the population exposure to air pollution to provide data for an evaluation of health effects. The project was carried out by the Norwegian Institute for Air Research (NILU) with support from a project group with members from SFT, the Health Board of Oslo, and the Technological Institute of Norway (STI). Further, the Transport Economical Institute (TØI), Oslo Community, Institute of Geophysics, University of Oslo, and siv.ing. S.E. Riise have participated in the work.

The project was financed by SFT. Additional financial support was provided by NILU in resolving problems with calculation methods.

## 2 REPORTS

The results from the project have been previously published by NILU in the following reports (in Norwegian):

"Beregning av spredningss- og eksponeringsforhold for visse luftforurensningskomponenter i Oslo" ("Calculation of dispersion and exposure conditions for some air pollution components in Oslo", NILU OR 8/82). The results are given and discussed in the report. The input data and some results are given in appendix under separate cover.

The data on emissions are given in a separate report "Utslipp av luftforurensninger i Oslo-området 1979" ("Emission of air pollutants in Oslo 1979", NILU OR 10/82).

## 3 PURPOSE OF THE INVESTIGATION

- Map pollution distributions with different averaging times for concentration values that may be compared with air quality standards or guidelines,*
- Describe frequency distribution of air pollution concentrations in different parts of the area.
- Calculate the number of people exposed to doses higher than given values.
- Give the relative contribution to pollution concentration from vehicular traffic.
- Calculate the expected reduction in ambient concentrations as a result of 20%, 50% and 90% reduction in traffic emissions.

The investigation was carried out for the following air pollutants and averaging times:

| | |
|---|---|
| $SO_2$ | (1 hour, 24 hours and half year) |
| Particulate matter/soot | (1 hour, 24 hours and half year) |
| $NO_2$ | (1 hour, 24 hours and half year) |
| CO | (1 hour, 8 hours) |
| Lead (inorganic) | (3 months) |
| Benzene | (1 year) |
| Ozone | (1 hour) |

* The applied air quality guidelines (concentration values) are specified by SFT on basis of the SFT-report No. 38, "Air pollution. Effects on health and environment", and on the U.S. federal air quality standard for lead.

# 4 METHODS AND INPUT DATA

Emission data and data for dispersion conditions (meteorological data) were used for calculations of concentration distributions.

Figure 1 shows a map of the area for calculations. In calculating the population exposure, only the inhabitants of Oslo were considered and the population distribution is shown in Figure 2.

To calculate one-hour average doses, the distribution of people travelling, staying in their homes, or at work for each hour of the day was considered.

## 4.1 Emissions

The mass emissions of each pollutant for the Oslo area for 1979 were used. The following sources were included in the emission survey:

- vehicular traffic
- oil combustion
- industrial processes
- other sources, including incineration, aircraft at Fornebu airport, Oslo harbour, consumption of coke, wood, coal, distribution of gasoline, and use of solvents.

The emissions are given for each $km^2$, as shown in Figure 1, and for each of the major sources.

Calculations of emission were based on:

- number of km driven in each $km^2$ by vehicles using diesel oil and by vehicles using gasoline. The emission factors giving average amount of emission per km driven were provided by STI.

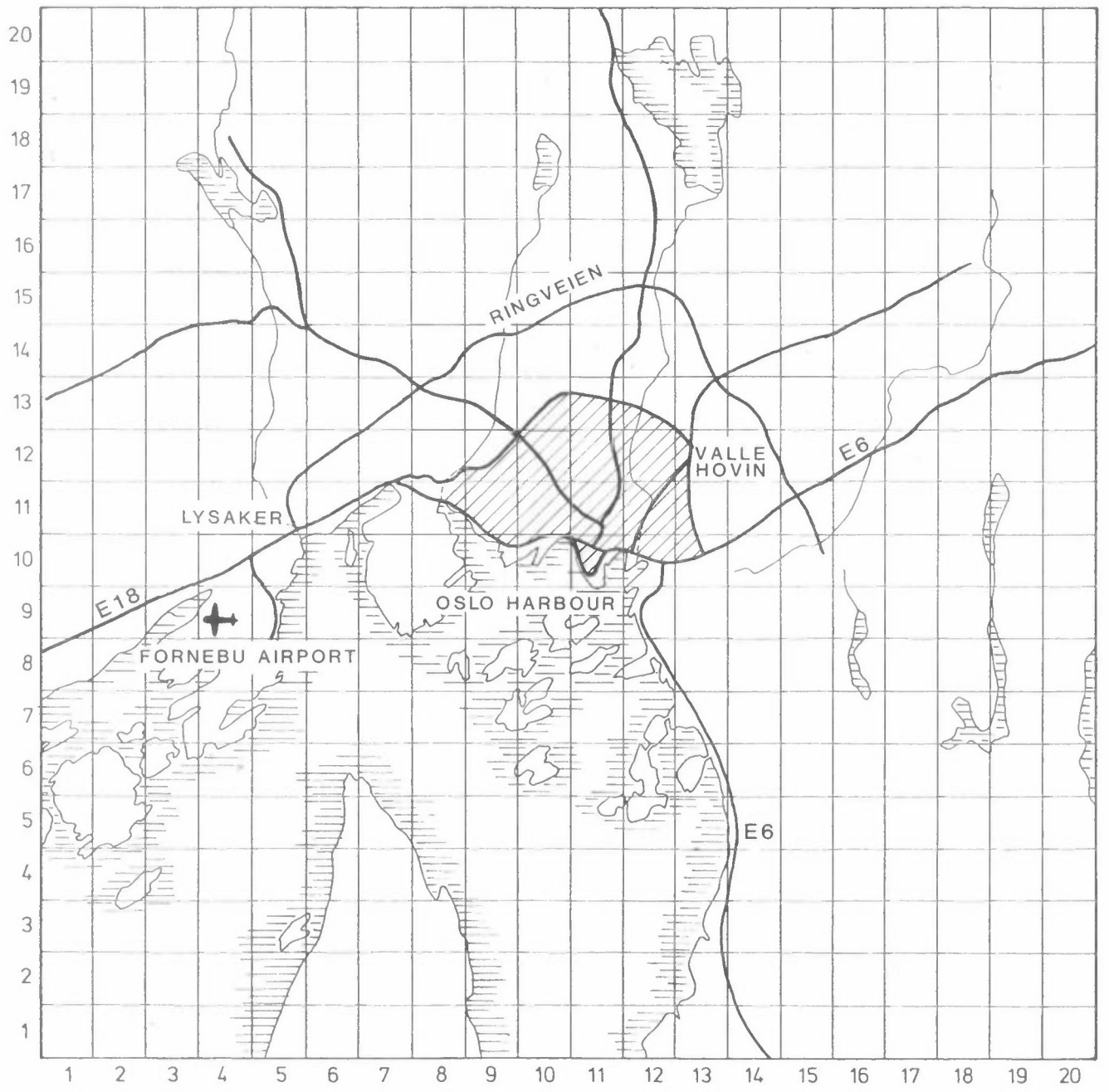


*Figure 1: Grid system ($km^2$) for the area of calculations.*

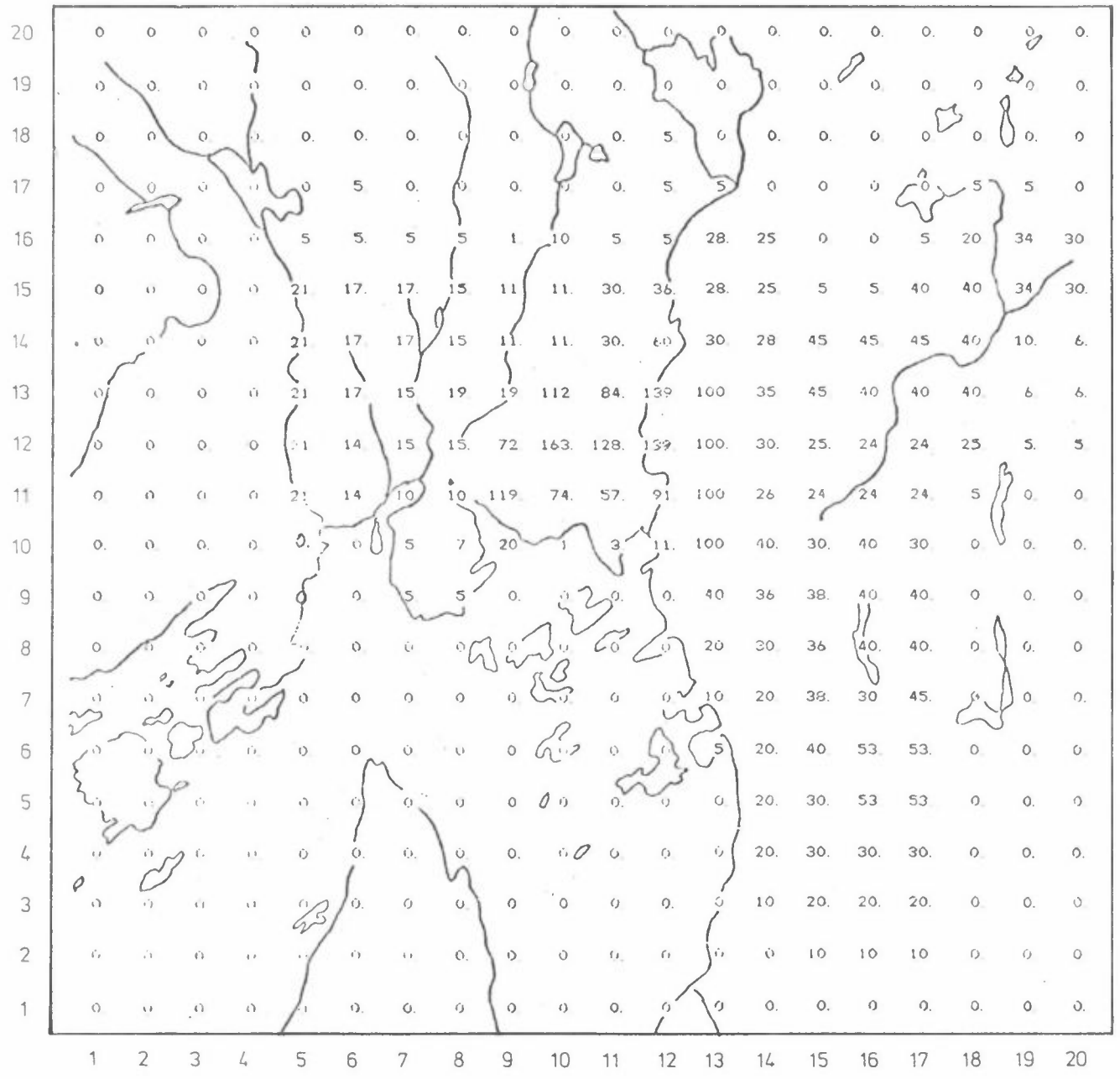


*Figure 2: Population distribution in Oslo (31.12.76). Unit: 100 persons/km$^2$.*

- data on consumption of different kind of oils for each $km^2$. For large sources a resolution of 100 m x 100 m was used.
- data from SFT on emissions from industrial processes.
- data on traffic density at Fornebu airport and in Oslo harbour.

Emissions from thirteen large furnaces and boilers, and from about 120 streets were treated separately. Table 1 shows the average total emissions from the different sources in the Oslo area.

## 4.2 Data on dispersion

In 1970-71, NILU made an extensive survey of the dispersion conditions in Oslo, with emphasis on the conditions during pollution episodes. Data from this survey is used in the calculations of ambient concentrations. Ten episodes were used to estimate highest hourly and daily concentrations.

Dispersion conditions and frequency of episodes vary from year to year. Only a few episodes, and even no episodes with extremely bad dispersion conditions, were observed during the winter of 1970-1971. To account for this, stronger inversion than observed was assumed in calculation of maximum hourly and daily concentrations. Wind measurements from Valle Hovin were used in the calculation of long term average concentrations.

## 4.3 Dispersion calculations

Concentrations in streets with high traffic density were calculated using a method that has been previously validated in Oslo. To calculate concentrations downwind of single sources, a plume dispersion formula was used describing the growth of plumes under different dispersion conditions.

Long term average concentrations were calculated for the mid-point in each $km^2$, as shown in Figure 1. The contributions from point sources and area sources in each $km^2$ are additive.

*Table 1: Average hourly emissions of air pollutants in Oslo, 1979. Unit: kg/h.*

| | $SO_2$ | Part./soot | CO | HC | $NO_x$ (as $NO_2$) | Local | Benzene |
|---|---|---|---|---|---|---|---|
| Winter | | | | | | | |
| Oil combustion | 520 | 110 | n* | 20 | 290 | - | n |
| Vehicle traffic | 40 | 140 | 6400 | 440 | 390 | 7.6 | 34 |
| Other sources | 190 | 140 | 1200 | 540 | 100 | 0.8 | 12 |
| Sum | 750 | 390 | 7600 | 1000 | 780 | 8.4 | 46 |
| Summer | | | | | | | |
| Oil combustion | 320 | 60 | n | 10 | 170 | - | n |
| Vehicle traffic | 40 | 120 | 5500 | 400 | 380 | 6.9 | 31 |
| Other sources | 90 | 40 | 300 | 440 | 50 | 0.8 | 3 |
| Sum | 450 | 220 | 5800 | 850 | 600 | 7.7 | 34 |

*n: negligible.

Air pollution accumulation in the Oslo area during episodes have to be considered under conditions of stagnating wind to estimate the highest concentrations. The highest concentration values, as a result of data from 10 selected days, are referred to as maximum concentrations in Oslo. If the emission survey used is reasonably accurate, higher concentrations will be very seldom recorded.

# 5 RESULTS

## 5.1 Pollution maps

A number of maps have been drawn for Oslo, showing pollution concentrations for different averaging times extending from 1 hour to 6 months. Two figures are selected as examples. The $SO_2$ concentrations, shown in Figure 3, demonstrate the dispersion of pollutants mainly from area sources (e.g., domestic heating).

Dispersion of lead, originating mainly from vehicular traffic, is shown in Figure 4. The results are based on a content of lead in gasoline of 0.4 g/l. The allowable lead content in Norway will be reduced after 1 February 1983 to below 0.15 g/l. Thus, it can be expected that the concentration values will be reduced accordingly.

In order to use the results to improve the living environment in Oslo, the local authorities wanted to know the levels of pollution in individual streets. Concentrations in street canyons were calculated for about 120 blocks with high traffic density and buildings on both sides. Concentrations can also be high in streets with buildings on one side, or even lacking buildings, but then high traffic density is necessary (e.g., E6, E18, Ringveien). The highest concentrations occur in street canyons in the urban centre with buildings on both sides.

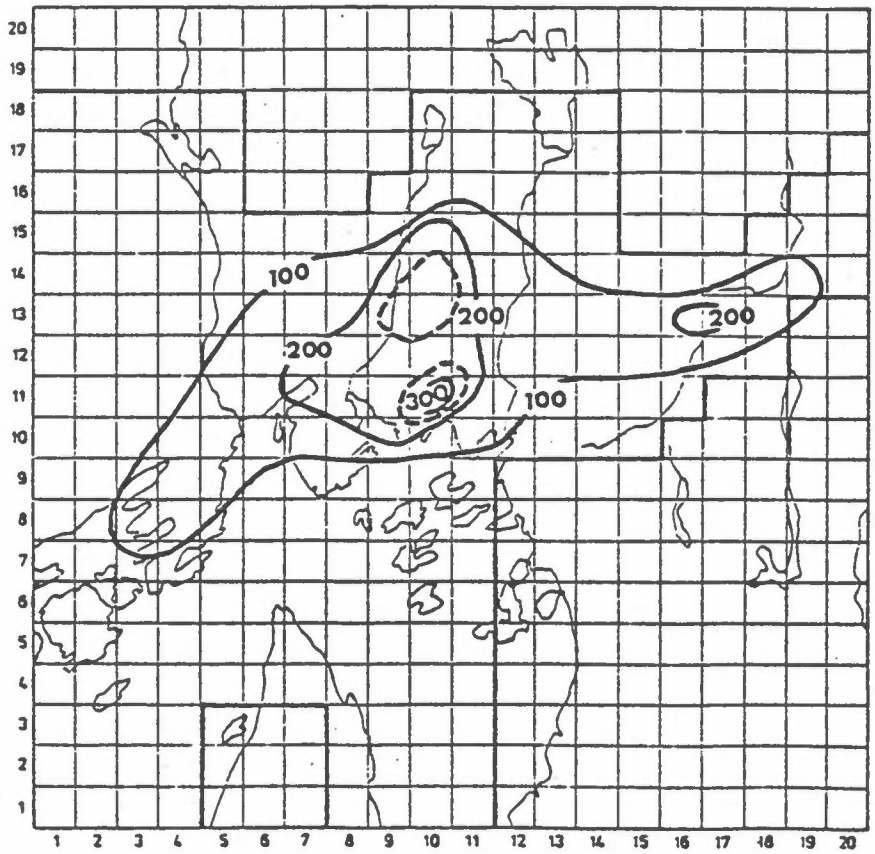


*Figure 3: Maximum 24 h $SO_2$ concentration.*
*Unit: µg/m³.*
*NB: In some episodes the maximum values will also occur in other parts of the urban area.*

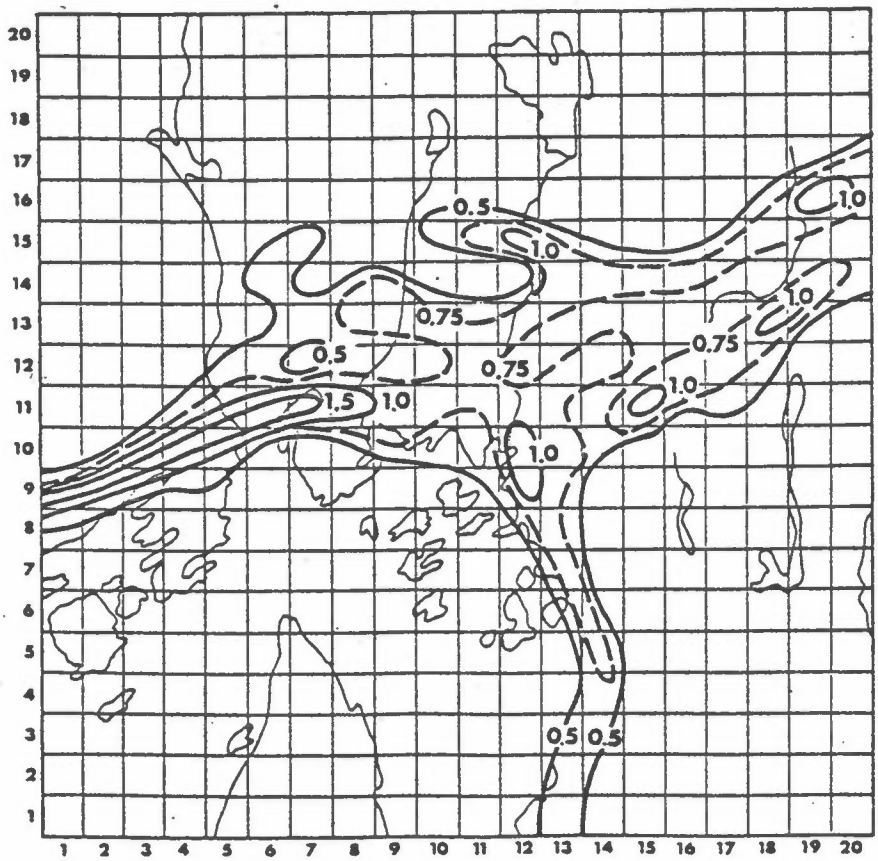


*Figure 4: 3-month average for lead.*
*Unit: µg/m³.*
*The calculations are based on a lead content in gasoline of 0.4 g per liter gasoline.*

For particulate matter/soot (24-h and 6-month averages), $NO_2$ (1-h and 6-month) and CO (1-h and 8-h values) it was found that one or several of the guidelines were exceeded by a factor of two in many street canyons. As an example, a map for 8-h average CO values is shown in Figure 5.

Tables 2 and 3 show a simplified view of the highest values occurring on the pollution maps presented in the main report. These values may be compared with the air quality guidelines.

*Table 2: Calculated maximum long term concentrations.*

| Component, averaging time | Standard $\mu g/m^3$ x | Calc.max.value $\mu g/m^3$ | Extension |
|---|---|---|---|
| $SO_2$, ½ year | 40-60 | 70 | Area |
| Part/soot, ½ year | 40-60 | 40 | Area |
| $NO_2$, ½ year | 75 | 40 | Area |
| Lead, 3 mo. | 1.5 | 1.0 | Area |
| | | 2.5 | Local (industry and street canyons) |

x: Air quality standards.

*Table 3: Calculated maximum short term concentrations.*

| Component, averaging time | Standard $\mu g/m^3$ | Calc.max.value $\mu g/m^3$ | Extension |
|---|---|---|---|
| $SO_2$, 24h | 100-150 | 300 | Area |
| Part./soot 1 hour | 100-150 | 150 | Area |
| $NO_2$, 24h | 100-150 | 90 | Area |
| CO, 8h | 10 000 | 7 000 | Area |
| | | 25 000 | Local (street canyon) |
| $SO_2$, 1h | | 300 | Area |
| Part./soot 1 hour | | 400 | Smaller area |
| $NO_2$, 1h | 200-350 | 180 | Area |
| | | 500 | Local (street canyon) |
| CO, 1h | 25 000 | 15 000 | Area |
| | | 45-60 000 | Local (street canyon) |
| $O_3$, 1h | 100-200 | 200 | Suburbs |

About 4000 persons living or working near street canyons may be exposed to maximum hourly $NO_2$ concentrations within the range given for $NO_2$.

High ozone concentrations over eastern Norway will be reduced over Oslo as a result of local emissions of NO. New formation of oxidants as a result of emissions from Oslo may in some episodes expose a few thousand people (10.000-50.000) to higher ozone levels than specified by the guidelines.

## 6 EFFECT OF REDUCED EMISSION FROM CARS IN OSLO ON THE MAXIMUM LEVEL OF EXPOSURE FOR PARTICULATE MATTER/SOOT, $NO_x$, CO, LEAD AND BENZENE

The following effects can be expected:

a) Reduction of emission from each vehicle will result in corresponding pollutant concentration reduction in the streets with high traffic density. A 50% reduction is necessary for CO concentrations to meet the guidelines in these streets.

b) Traffic regulations may be used to improve the pollution situations in single streets. Improved flow of the traffic will also reduce total emissions.

c) In episodes, 20-90% reduction in the emissions from motor vehicles should give the following average reduction in the pollution levels over the central area:

2- 8% reduction in the $SO_2$ concentrations
10-44% reduction in the particle/soot values
18-82% reduction in the CO concentrations
12-53% reduction in the HC concentration
11-57% reduction in the $NO_x$ concentration
19-85% reduction in the lead concentration
17-76% reduction in the benzene concentration.

## 7 RELIABILITY OF THE CALCULATIONS

Estimation of vertical exchange of pollution is probably the most important source of uncertainty in the calculations. The uncertainty in the vertical exchange is particularly important when the relative contributions from car traffic (emission close to the ground) and from home heating (emission above the roof level) are evaluated. The assumptions applied in this study should be tested by tracer experiments.

Data from the literature may be used for guidance on the expected uncertainty. Often the uncertainty in calculated average concentrations is estimated to be lower than 20% for long term average values, and to about 25% for daily mean values during shorter episodes.

The calculated exposure levels for the Oslo population will most probably occur. Type and frequency of different pollution episodes will vary from one year to another, and the maximum values are therefore difficult to quantify. Uncertainties may be reduced by improved data from further measurements.

# *APPENDIX E*

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| Air quality assessment and surveillance programmes | B. Sivertsen |
| | NILU PROSJEKT NR.<br>Q-301 |
| FORFATTER(E) | TILGJENGELIGHET*<br>A |
| | OPPDRAGSGIVERS REF. |

OPPDRAGSGIVER (NAVN OG ADRESSE)

Norsk institutt for luftforskning

3 STIKKORD (à maks. 20 anslag)

Assessment | measurements | A.Q. programmes

REFERAT (maks. 300 anslag, 7 linjer)
Rapporten gir en oversikt over de nødvendige elementene i luftkvalitetsmåleprogrammene, og har i vedleggene informasjon om NILUs kompetanseområder.

TITLE

ABSTRACT (max. 300 characters, 7 lines)

The necessary elements in air quality and surveillance programmes are discussed. A presentation of NILUs project and experience is given in Appendices.

*Kategorier: Åpen - kan bestilles fra NILU A
Må bestilles gjennom oppdragsgiver B
Kan ikke utleveres C