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A GIS based Air Quality Management System

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Contents

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ABSTRACT

Based on a Geographical Information System (GIS) platform the Environmental Surveillance and Information System (ENSIS) have been developed to handle air pollution and water pollution problems. The main objective of a modern environmental surveillance platform is to enable direct data and information transfer and obtain a remote quality control of the data collection. The system combine monitoring, data presentation and modelling in one package, which enable the user not only to present and evaluate the present situation, but also to undertake environmental planning for a sustainable future. The GIS platform, on which the system is operated, provides easy access to the data and gives a perfect and easily understandable data presentation tool.

This paper describes briefly the air pollution module of ENSIS, AirQUIS, and gives references to different international applications of the GIS based system.

1 INTRODUCTION

One of the main challenges in today’s society is to have timely and appropriate access to relevant and good quality environmental data. The aim is to enable actions whenever environmental requirements and limits are violated. These were the challenges that a group of scientists faced when e new generation of GIS based monitoring and planning system was to be developed. The environmental information system will have to combine the latest sensor and monitor technologies with data acquisition; data base developments, quality assurance, statistical and numerical models and advanced computer platforms for data processing, as well as distribution and dissemination of data and model results. The modular total systems, which have been developed in Norway, are based on a Geographical Information Systems (GIS) as an important platform for the collection of data and presentation of the results.

These technologies are now being used in environmental management to support integrated pollution prevention and control. They can also be part of an emergency management system to support actions and crisis management during emergencies and accidents of various kinds. The content and operability of the system might be quite different in the two cases.

Users will have individual requirements ranging from simple measurement to full-scale abatement. The development of GIS based monitoring and planning systems may vary depending upon users requirements. Typical options may be:

1. A simple monitoring programme with user-friendly solutions for data handling, statistics and presentation of results.
2. A complete "Air Quality Management System" (AQMS) providing environmental management solutions based on combined monitoring and modelling for areas where air quality improvement is required to comply e.g. with air pollution standards and regulations

2 THE ENSIS SURVEILLANCE AND PLANNING SYSTEM

ENSIS is a management and decision support system for environmental issues. ENSIS has been developed by Norwegian Research Institutes and includes AirQUIS, which is an air pollution related module and WaterQUIS for water quality topics. The system can be used as a management tool for planners, as an information tool for the public and as an expert system for specialists.

The ENSIS system contains in addition to AirQUIS and WaterQUIS common modules that are shared by air and water specific parts of the program system. Important common parts are the measurement database, and the graphical user interface including the GIS (geographical information system).

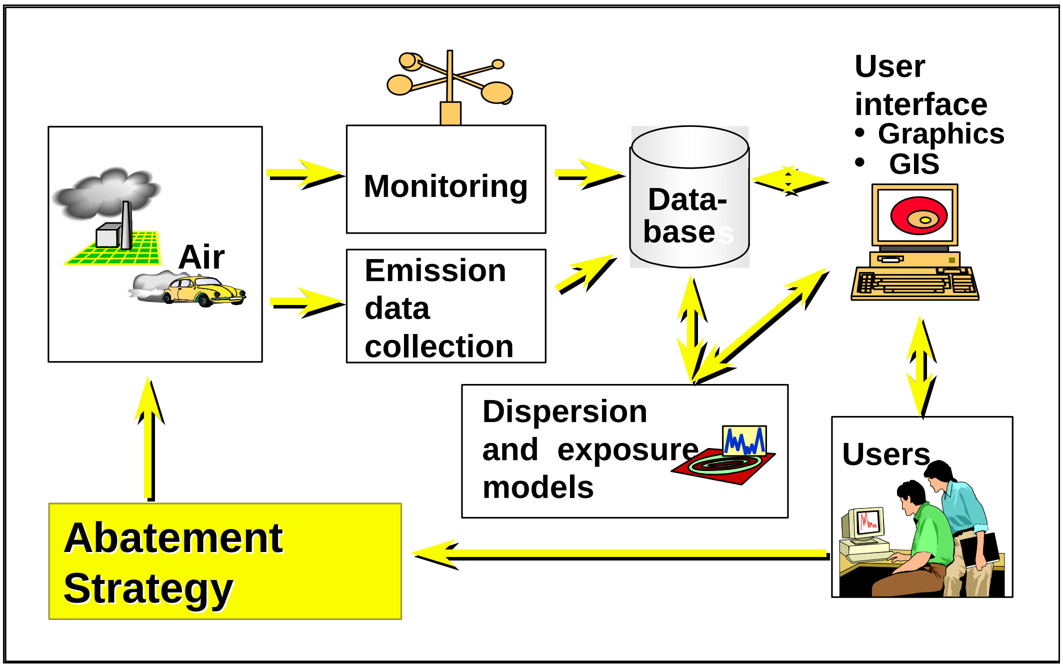

Figure 1: *The AirQUIS surveillance and planning system*

The user interface is to a large extent a map interface from which spatial distribution of pollution sources, monitoring stations, measurements, model results and other geographically linked objects can be presented. The map interface can also be used as an entrance for making queries to the database.

2.1 The GIS Functionality

The GIS (Geographical Information System) functionality of the ENSIS system is designed to offer several possibilities for understanding the problems of air pollution.

- The GIS makes it easier to place the air pollution sources at the correct location, for example by making it easy to display the total network of road links in a city.
- GIS presentation of area-distributed consumption of fossil fuels and direct emissions gives a good overview of where to expect high impact of air pollution.
- Viewing the measurement stations on a map with the pollution sources will give an idea of what concentrations one may expect to find at the stations for a given wind direction.
- The GIS makes it easier to search for geographically linked data in the database.
- Displaying results of model calculations as a map can be used for public information on pollution levels at different parts of a city.

There are three types of data that can be displayed on the map: shape themes, ENSIS themes and data set.

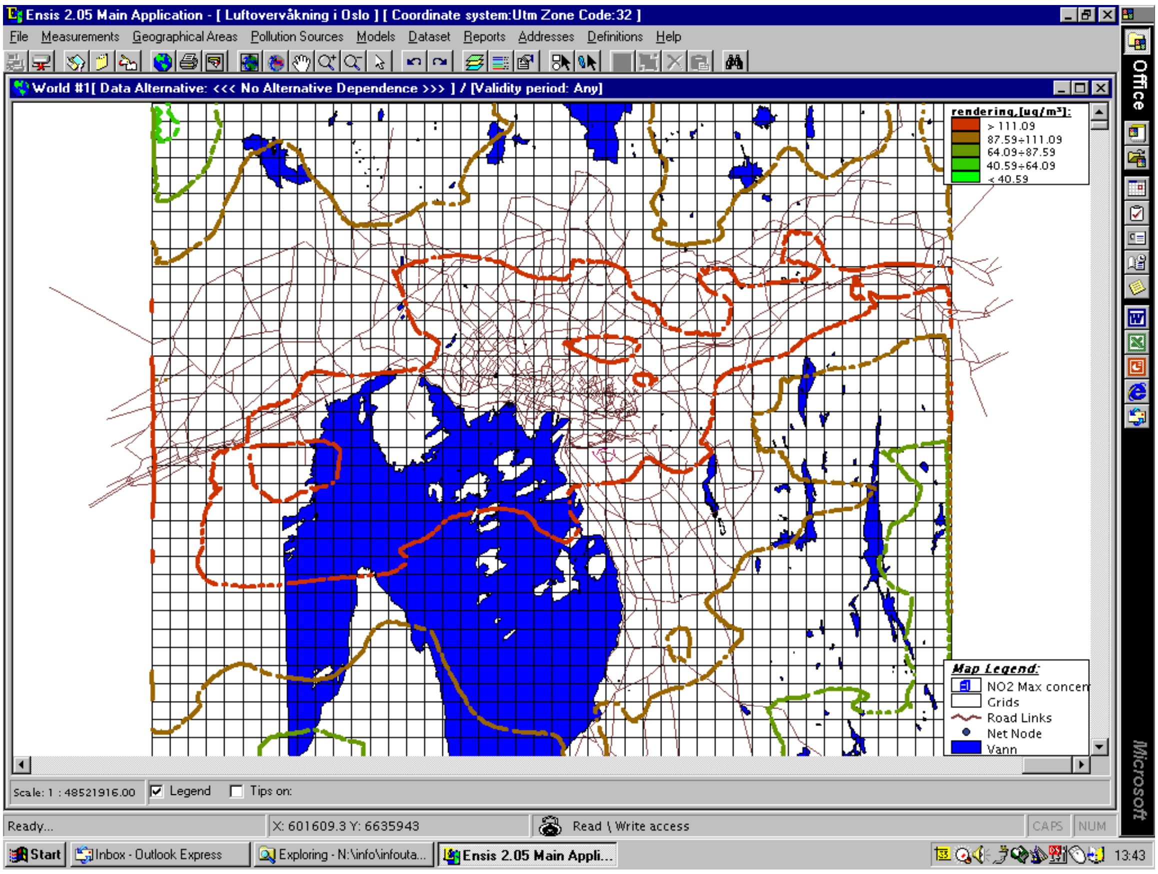

Figure 2: ***Different map themes can be used as background for presentation of measurement results or as in the example model results. Contour lines indicate model estimated average concentrations of NO2 in Oslo on top of a 1 km grid, water and main roads.***

Shape Themes

The Shape Themes are themes that are not connected to data in the ENSIS database. Examples of shape themes may be coastlines, lakes, parks, borders, or anything that will make the map look better and be easier to understand. The user decides which shape themes to display by selecting from a list of available themes. The available themes may be different for different projects. This is organised through the User Manager.

ENSIS Themes

The ENSIS Themes are the GIS representation of the data in the ENSIS database, for example administrative regions, air pollution sources, road links, stations, receptor points. The user decides which themes to display by selecting from a list of all ENSIS themes. All ENSIS themes will be available for all projects, and may be shown on the map, provided they contain data.

Data Set

All data set in the database can be viewed on the map. This may be data distributed on administrative or user defined regions (region data set), data distributed in grids (field data set), data distributed on lines (line data set) or data distributed in points (point data set). The data set may have been entered into the database manually or by import, or the data set may be results of model calculations.

3 AirQUIS

AirQUIS consists of six components and makes use of an Oracle database. The system has integrated forms and maps, was developed in VisualBasic and MapObject (GIS) and works well on an ordinary NT-server. The different components consist of:

- A manual data entering application,
- An on line monitoring system,
- A module for online data acquisition and quality control,
- A measurement data base for meteorology and air quality,
- A modern emission inventory data base with emission models,
- Numerical models for transport and dispersion in air of pollutants,
- A module for exposure estimates and population exposure assessment,
- Statistical treatment and graphical presentation of measurements and modelling results,

All objects described above are integrated in a map and menu oriented user-friendly interface with direct link to the databases for measurements, emissions, modelling results and presentation tools. Advanced import/export wizards allow the user to transfer data easily to and from the AirQUIS system.

3.1 The databases

The database is designed to be a tool for storing all the necessary data for conducting an environmental survey or impact analysis for a city or region. For air quality this means that the ENSIS database takes care of emission related data, such as fuel consumption, emission factors, physical description of stacks and processes, dynamic traffic data etc. It also takes care of ambient air measurements and meteorological data, including descriptions of the methods and the measured values. The results of the emission, dispersion and exposure model calculations are also stored in the database.

Both emissions, measurements and model results are geographically linked and can be viewed through the GIS interface. The use of a common database ensures consistency of the data. Data are entered into the database via standard graphical menus, or special import functions.

3.2 The Models

The AirQUIS models include an air emission calculation model, a meteorological model, an air dispersion model and different ways of calculating population exposure. The models provide the possibility of identifying the results of alternative planning scenarios as well as describing the present situation.

The atmospheric dispersion models, which presently are part of the AirQUIS monitoring and surveillance system, have been presented for evaluation, discussions and model comparisons within the European Environmental Agency (EEA). At present these models are being further developed to match the user requirements, and to adequately meet the need for user friendliness. The models are already part of the models approved by Norwegian Authorities. They have also been used in several countries in Europe

The EPISODE model is a mass-consistent, 3-layer (in the vertical) model solving the basic transport-diffusion equations. Based upon spatially distributed and time dependent input data of emissions, wind and turbulence, the model gives time-dependent concentrations in any receptor point within the modelling area.

Area-distributed sources (domestic, small industry, etc.) are treated within a grid system of typically 0.5-1 km. Superimposed on this, road traffic and point sources are treated in separate sub-grid models (Gaussian line-source dispersion of traffic emissions, and puff-trajectory model for point sources). Winter-type NO-NO_2-O_3 chemistry is included, and summer-type photochemistry calculation schemes are being introduced into the model.

The road network model CONTILINK, developed by Norwegian Institute for Air Research (NILU), calculates emissions from a defined set of line sources. For each hour total concentrations of CO, NO_x and PM_{10} are estimated along a predefined the road system.

ENSIS has tools for graphical presentation and control of data, and tables for numerical presentation of data and statistical summaries. The information system provides a report generator and the possibility of exporting data and map images.

3.3 AQMS and Action Plans

The basic tool represented by AirQUIS can be applied for air quality management at different levels of sophistication:

Surveillance and Management. The AirQUIS emission inventory systems and advanced dispersion models may link and compare measurement data to model estimates. Model results may give spatial concentration distributions, which add information to the measurement data. The contribution to the pollution from different source categories, such as industry, traffic and domestic heating can be calculated based on emission or fuel consumption data. In this way the system can be used as a tool for evaluating and comparing different measures to reduce air pollution. The models may also estimate exposures of the population and of materials and ecosystems.

Impact assessment. The AirQUIS exposure estimates may be combined with dose-relationships to evaluate impact and to perform a complete impact and damage assessment. Estimates can be performed for health, material and vegetation impacts.

Optimal Abatement Strategies and Action Plans. Based on defined abatement options and scenarios, cost-benefit analyses can be used to evaluate the best possible options to reduce the air pollution load seen from an economic point of view. The results of such analyses again may lead to the development of Action plans.

4 THE AIR QUALITY MANAGEMENT STRATEGY SYSTEM (AQMS)

The basic concept for an Air Quality Management Strategy contains the following main components:

- Air Quality Assessment
- Environmental Damage Assessment
- Abatement Options Assessment
- Cost Benefit Analysis or Cost Effective-ness Analysis
- Abatement Measures
- Optimum Control Strategy

The 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 final result of this analysis is Optimum Control Strategy.

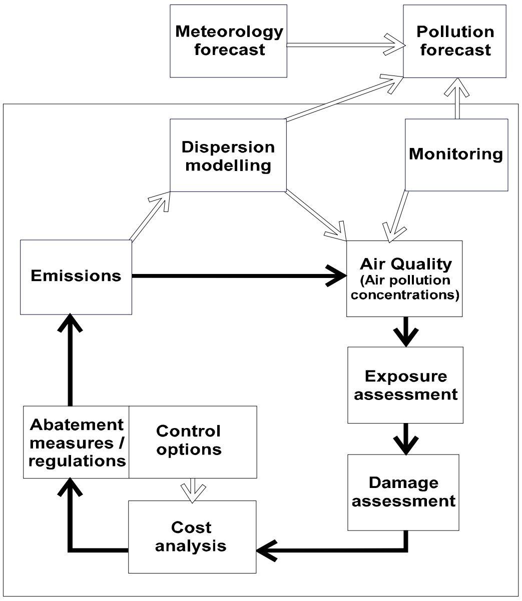

Figure 3: The modelling concept of an Air Quality Management Strategy system

A system for air quality management requires continuing activities on the urban scale in the following fields:

- Inventorying of air pollution activities and emissions
- Monitoring of air pollution and dispersion parameters
- Calculation of air pollution concentrations, by dispersion models
- Inventorying of population, materials and urban development
- Calculation of the effect of abatement/control measures
- Establishing/improving air pollution regulations

The environmental data are usually linked to geographical sites. In particular when monitoring data are supported and supplied by model estimates of spatial concentration distributions and impacts, it is suggested that the presentation of the results would involve the use of maps or digitalized Geographical Information Systems (GIS).

Geographical information systems based on advanced raster/vector technology has been developed to handle maps, networks, symbols and various objects. They can handle both geographical information and technical documentation and present this in graphical form. The GIS user can easily organise selected data from various databases. Thematic maps can be produced combined with time series graphical presentations and results from model calculations. The system will display the results of planned actions based upon simulation models and thus act as a more user-friendly decision support system.

5 APPLICATIONS

5.1 Air surveillance and management system

The software system AirQUIS has been adapted to meet the needs of different clients. The system normally includes data retrieval, databases, and data presentations, modelling and air quality management systems. A complete AirQUIS system is supplied according the client specifications.
This also provides the development of emission inventories, dispersion models and exposure assessment. Measurements of air quality and meteorology together with model results may be presented to evaluate the contribution from different sources to the air quality of the selected area. The system has been applied in this mode in Oslo, Sarpsborg/Fredrikstad and in the Telemark region in Norway, in Yantai, China in Botswana and is being developed for Haifa, Israel, Stockholm Sweden and for the Saudi Electric Co. in Saudi Arabia.

The system may present hourly, daily and monthly concentration distributions, as well as next-day predictions, forecasts and early warnings based upon population exposure. The user-friendly planning tool may, for example, estimate the change in air quality impact if a road is closed or transport composition and patterns are changed, or a factory reduces or changes its emissions.

5.2 Impact assessment

Regulatory risk assessment in air pollution management includes a consideration of hazard identification, exposure-response relationships, exposure assessment and quantitative risk characterization. Numerical models, which are part of the AirQUIS system, may estimate the exposure of harmful pollution to human health, materials and the ecosystem.

Dose-relationships are being used to evaluate the impact and to perform a complete impact and damage assessment. For the environmental impact on buildings and building materials (Our Cultural Heritage) a sub module of AirQUIS, CorrCOST has been developed. The system was used in Norway to evaluate the economic impact of air pollution on building material in Oslo and in other areas of Norway. NILU is working in co-operation with other research institutes within the field of environmental impact assessment.

5.3 Cost-benefit analyses

The Cost-benefit analyses (CBA) are a highly interdisciplinary task. The CBA should provide a benefit-cost ratio based on monetarised costs and benefits, and be accompanied by a description of the non-monetarised items that also should be considered.

Monetary valuation of control actions, and of the effects on health and the environment, may be different in concept and vary substantially from country to country. NILU has conducted such CBA of possible measures for reducing the extent of pollution damage in several major urban areas in Asia. The World Bank project “URBAIR” was a forerunner for these analyses. All the various possible measures are cost estimated and put together in relation to calculated reductions in air pollution and the consequences for damage impact.

5.4 AQMS

An Air Quality Management and Planning System (AQMS) was established in the city of Guangzhou (6 mill. inhabitants) in South China. The core of the system was the GIS based AirQUIS system. The system is applied to develop action plans for air quality improvement in a cost-efficient manner. The project was a co-operation effort between the NORCE consortium of Norwegian institutes (with NILU as the leading institute) and research and municipal government institutions in Guangzhou. The nature of the project was "knowledge and tools transfer.

6 CONCLUSIONS AND RECOMMENDATIONS

An integrated surveillance and planning tool is needed to select the right decisions in order to protect human health as well as materials and the ecosystem from an increasing impact of pollution. Heavily populated and industrialised areas experience a change in impact that is difficult to handle. Not only is the amount of pollution increasing in many areas, but also the composition and complexity is becoming more difficult to monitor, understand and solve.

The GIS based surveillance and planning tool presented in this paper is one step towards obtaining the adequate and relevant information in order to select the right actions in the process of preventing too large damages. The GIS based on-line monitoring and warning system can predict the impact of selected scenarios for the future, and thus make it possible to implement the best available solutions. It is recommended that the monitoring, modelling and planning tools included cost/benefit analyses are used in order to get as much benefit out of the investments as possible.

The AirQUIS system represents one of these GIS based platforms that enable direct quality assurance of the input data, which are essential for understanding the problems and in the next phase select the most cost effective solutions to avoid damages from environmental impacts.

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About IRENIE: http://www.norgit.no/irenie/index.html

Air Quality Oslo: http://www2.vegvesen.no/luftkvalitet/oslo/sentrum.stm