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GENIE: AN INTEGRATED ENVIRONMENTAL INFORMATION AND DECISION SUPPORT SYSTEM FOR GENEVA PART I: AIR QUALITY

BY

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ABSTRACT

GENIE, the Geneva Environmental Information System, is a modular information and decision support system that is being developed at the University of Geneva under the auspices of the Centre Universitaire d'Ecologie Humaine in collaboration with: the Laboratory of Plant Biochemistry and Physiology, the HEC Logilab group, the Département de Géographie, the Groupe des Sciences de la Terre, the Conservatoire et Jardin botaniques de la Ville de Genève and Laboratoire Universitaire de biosystématique et floristique.

GENIE aims at providing an easily accessible and easy to use, but highly integrated repository of environmental information and decision support tools. Designed as a distributed system based on a flexible client-server architecture, it brings together various and distributed data and information resources. In addition to descriptive information, the system also provides tools for WHAT-IF analysis, supporting the design and analysis of scenarios of environmental planning, management and policy, by forecasting the impacts of potential actions. While the system will eventually address the full range of urban and regional environmental problems, the first implementation concentrates on air quality assessment and management, and the energy and transportation sectors as the main sources of emissions.

Key-words: environmental information system, decision support, GIS, air quality assessment, monitoring, ozone, energy planning.

INTRODUCTION

Regional development policies such as energy policy, transportation policy, land use and urban development, industrial development, tourism, and agriculture, all affect the natural and human environment, which in turn is the resource basis and life support

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system of our societies (FEDRA, 1994a). The complexities of interactions between the various physical, ecological, socio-economic and political aspects, components, and actors, pose a considerable challenge to planners, policy and decision makers, but also the general public, all stakeholders in our common environment.

Accurate and timely information is the basis of any planning and decision making. Decisions are always choices between alternatives, but in order to make a rational and informed choice, the alternatives must be known, and understood in terms of their respective costs and benefits. In an open and democratic society this information must be shared among all the actors and stakeholders in a problem. In the case of environmental decision making, this is complicated by the fact that environmental problems are inherently complex, spatially distributed, and dynamic, and any forecast is fraught with considerable uncertainties (FEDRA and REITSMA, 1990).

GENIE is designed as an information and decision support system for environmental planning and management. It has to support two major groups of tasks:

– As an information system, to provide timely and accurate information on the state of the environment, and related trends.

– As a decision support system proper, it must help to identify and design alternatives, evaluate them in terms of the objectives, criteria, and constraints of the respective decision problem, compare and rank the alternatives, and assist in the final selection of a preferred alternative.

The central elements of the underlying architecture are the integration of various information resources such as existing data bases or monitoring networks, the linkage of a number of methods of analysis, primarily simulation models and expert systems functionality, and finally a fully interactive, multi-media user interface that provides easy access to the systems functionality (FEDRA, 1995, 1996a, see Figure 1).

THE GEOGRAPHICAL SCOPE: CANTON AND CITY OF GENEVA

GENIE can address a hierarchy of spatial resolutions within a given geographical domain. Its regional geographical domain is defined by the area between latitude 46°02'55'' to 46°32'38'' and longitude 5°44'40'' to 6°29'00'', covering an area of 3136 km^2 (56 km x 56 km). Geneva is located at the end of the Lac Léman, at the junction of the Rhône (243 m^3/s) and the Arve river (84 m^3/s) coming from the Mt-Blanc area. The city is lying at the bottom of a quaternary and tertiary sedimentary basin surrounded by several mountains born during the building of the Alps: the Jura, the Salève, the Voirons and the Vuache. The geology of the area is both tectonic and from the ice-age. Altitudes range from 350 to 1720 m above sea level.

Since Geneva is under continental, Atlantic and Mediterranean influence, the climate can be described as transitional or "degraded oceanic" (GUICHONNET, 1982); there is also a micro-climate effect from the lake. The standard mean annual temperature and precipitation are respectively 9.2° and 930 mm (OCSTAT, 1995); minima

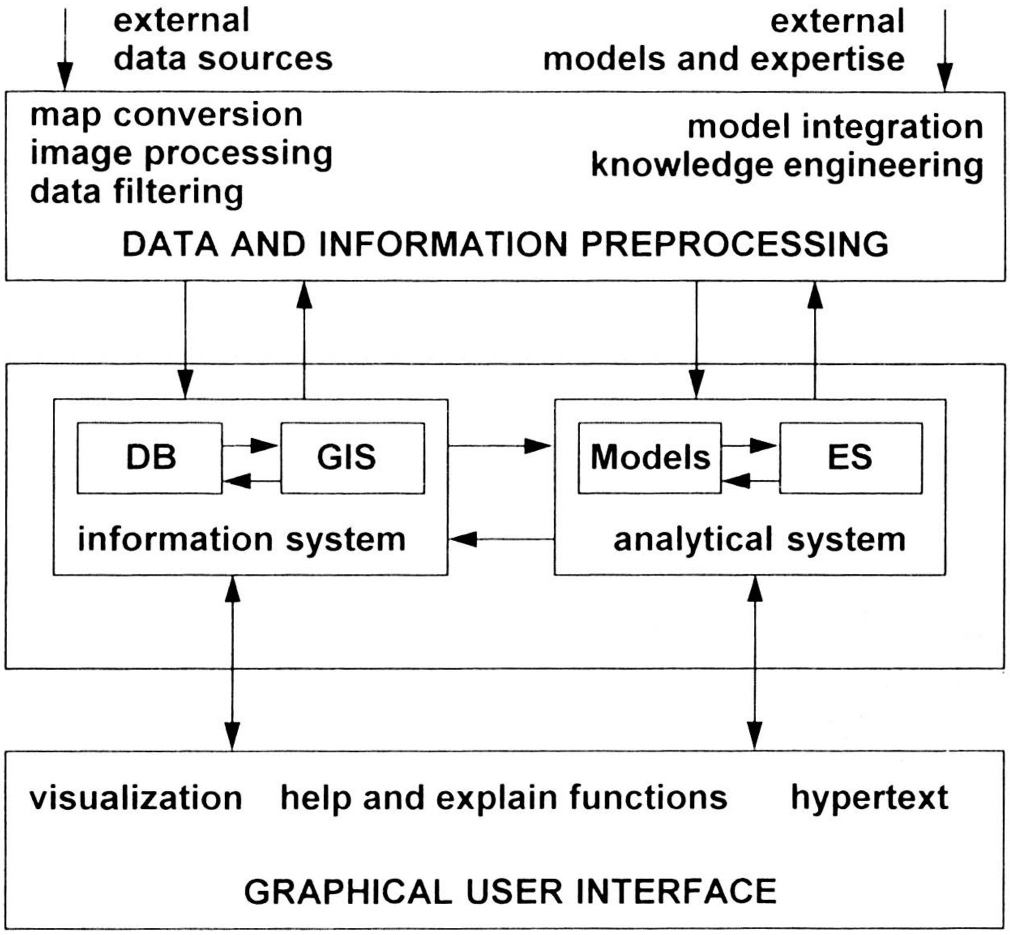


FIG. 1.

A generic framework and architecture for GENIE. DB: data base GIS: Geographical Information System. ES: Expert system.

are found in February for both temperature and precipitation, maxima occur in August for temperature and September for precipitation. The two main winds are coming from N-N-E (cold and dry) and S-W (warmer and wetter). In one year, the area has around 110 rainy days and between 1600 and 1900 sunny hours; there are many foggy days in winter because of the shelter effect of the topography (fog and cold air are locked in the basin, protection against west wind).

The domain is covering several administrative entities: 2 states, 2 French departments and 2 Swiss cantons and more than 300 municipalities. According to the latest federal census of 1990 the population reached 171042 inhabitants in the municipality of Geneva, 379190 in the canton and about 750000 for the entire domain. Most of the population is located in Geneva and in neighbouring municipalities, in a conurbation line oriented NW-SE and crossing the border (the French border towns of Annemasse and Gaillard have 38000 inh.). Other main towns in the domain are Thonon-les-Bains

(30000), Bonneville (10000) in the Arve valley and Bellegarde (10000), an important station on the TGV line to Paris. Despite the very dense population (2500 inh./km^2), more than 70% of the canton of Geneva is not in a built area.

SYSTEMS COMPONENTS

GENIE is a modular system, where any number of components and models can be integrated into a common framework, that provides the data bases and GIS, linkage to external information resources, and the user interface with its multi-media hypertext functionality. This common framework provides the integration of the various modules and components that can be configured to address a broad range of environmental problems.

A Common Framework: the information system

As a common framework to integrate data and information resources, GENIE uses a GIS and a set of linked data bases. The GIS combines vector and raster data, satellite imagery, scanned maps, and digital elevation models (Figure 2). The software provides interfaces and filters to import industry standard software formats, such as ARC/INFO, GRASS, and ERDAS.

The main GIS functionality is oriented at the display of spatial information including the input and output data of the spatial simulation models. Arbitrary selection of overlays and features, stacking sequence, choice of colours for individual attributes, zooming, and 3D display are supported. Switching from a single to four parallel map windows, and the animation of time-series of maps is also implemented under full interactive control. The GIS is accessible as a specific module, as well as an embedded set of functions in other systems modules, in particular, the spatial simulation models.

The maps and the images have been geo-referenced to the Swiss projection (oblique Mercator, units: meters). Five layers are now available for the domain:

- administrative boundaries (about 300 "communes")
- a topographic map in raster format (original scale 1:200'000, CN200)
- classified TM image (from Dr Jaquet, Groupe des Sciences de la Terre)
- DEM (Digital Elevation Model) from the Office Fédéral de Topographie (spatial resolution: 25 m, vertical resolution: 0.1 m).
- a Landsat-TM5 image of June 1995 (resolution 30 m).

These layers are shown in combinations in Figure 2 as following: Upper left, The topographic map CN200; Upper right, Swiss cantons (Geneva in green, Vaud in red) with the Swiss and French boundaries of "communes" and the classified TM image; Lower left, the Landsat image (TM453) together with the classified TM image; Lower right, CN200 with Swiss and French "communes" and the DEM map.

New layers, recently assembled by the Swiss land-planning office, are ready to be imported into the system:

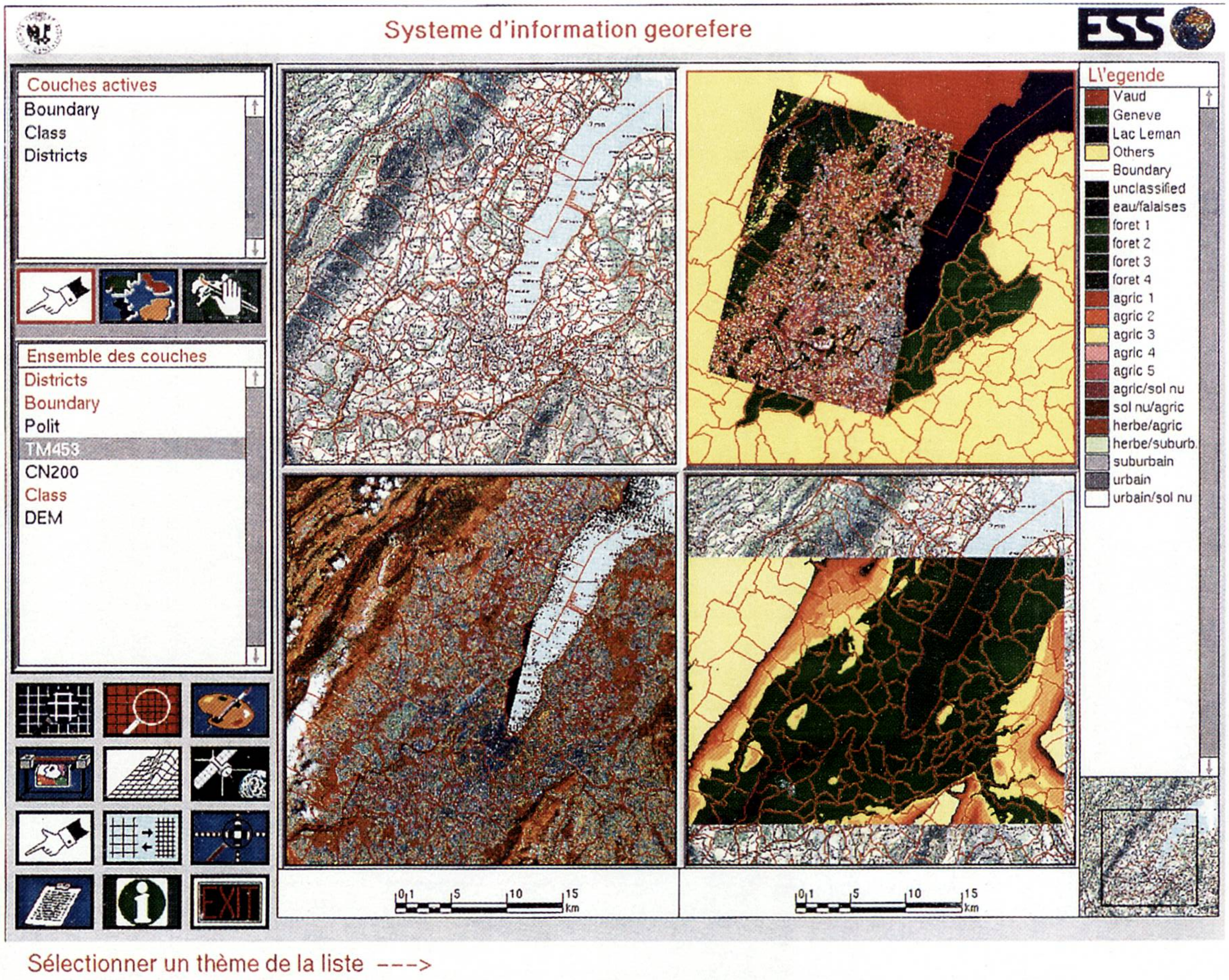


FIG. 2 - GIS example with overlays combining vector and raster data, satellite imagery, and a DEM (Digital Elevation Model). CN200 Map reproduced with the permission of the Office fédéral de topographie from 25.11.1996. See text.

– transportation network (roads, railroads, ...)

– hydrological network

– land cover types (this data is in Mapinfo format and will be available after 1997).

Other layers (not entirely covering the domain):

– rasterized "plan d'ensemble" from the "Système d'Information du Territoire Genevois" (SITG, original scale: 1:5000)

– URBA-CARTA from InterSurvey Consultants, digital map of streets at scale 1:10'000.

Spatially referenced data bases, like the object data base are linked to the GIS layer through the location or spatial extent of its objects. Typical objects are observations or monitoring stations (Figure 3), emission sources like industries, power plants, incnerators, road segments, city blocks, waste water treatment plants, etc. Objects can be selected for display and analysis from the map by picking the appropriate symbol, or by selecting the item from the corresponding list of names.

As an example, GENIE displays data from the air quality observation stations exploited and constructed by ECOTOX. This Institution, among other activities, monitors the air quality on Geneva with an observation network (ROPAG: Réseau d'Observation de la Pollution Atmosphérique de Genève) since 1989 (LANDRY & CUPELIN, 1989-1995, CUPELIN & ZALI, 1992). In 1994 and 1995 eight fixed measurement sites were running. The oldest site is at Ste-Clotilde. The most recent is located at Passeiry. The location of the other sites are: Ile, Wilson, Meyrin, Foron, Anières and Jussy. Collectively they have been chosen to be characteristic of Geneva with the following criteria: population density, sources of pollutants, local meteorology.

Three sites are localised in an urban environment:

– Wilson: it is situated between the lake and the city of Geneva (Les Pâquis). When the wind is blowing from the lake ("bise") it allows the monitoring of the quality of the air that enters the city. When the wind is blowing from south-west, it can monitor the pollution coming from the city.

– Ile: this site is located at the centre of the town where the car traffic is very dense (Mont-Blanc Bridge over 86000 car/day, Coulouvrenière Bridge about 65000 car/day).

– Ste-Clotilde: this site is typical of an urban environment with a high tertiary activity.

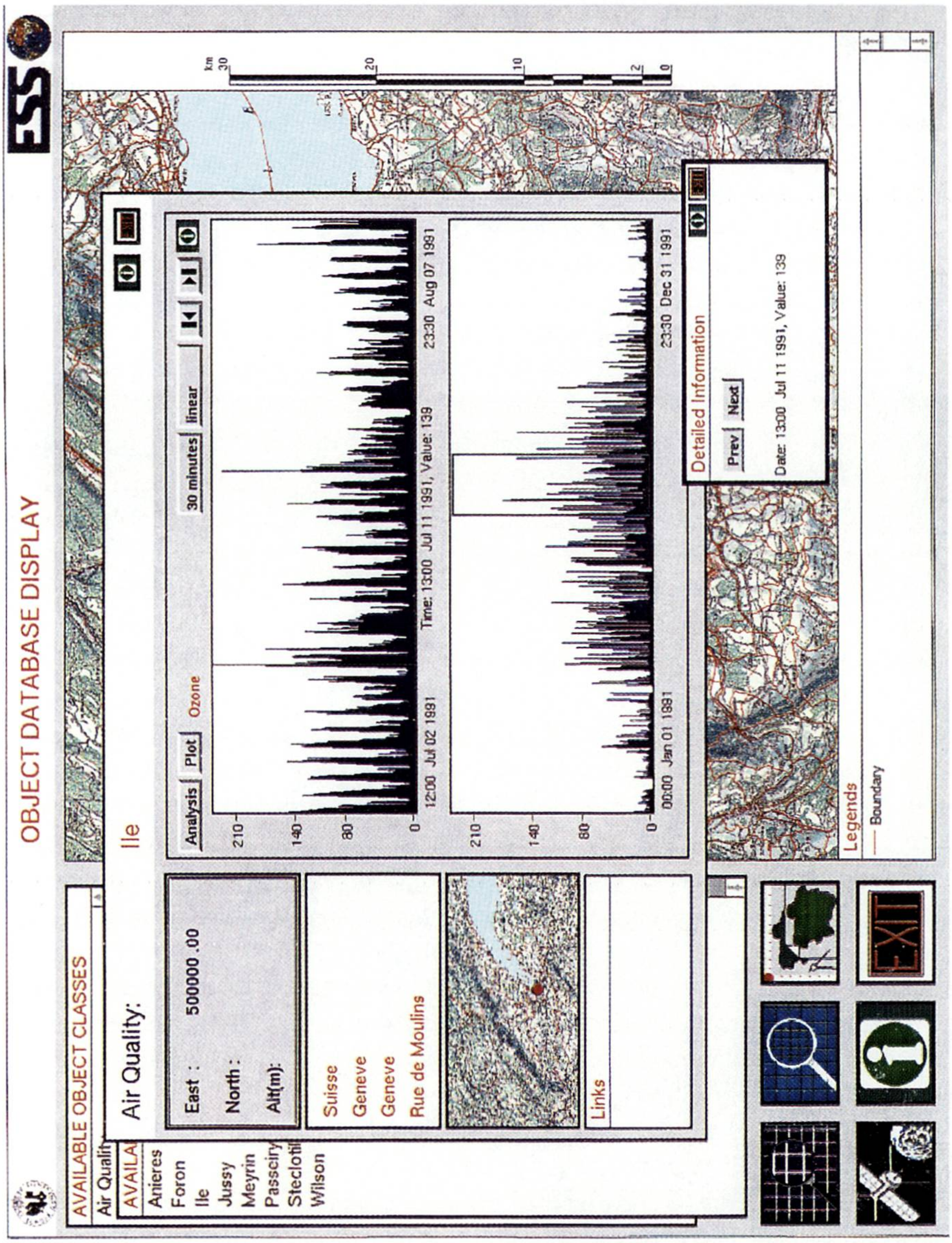
Two other sites of measurement are located in a suburban environment:

– Meyrin: this site is at the limit between an industrial area and the city of Meyrin.

– Foron: it is near the French border in a suburban environment with a high population density. It is also under the influence of the French city of Annemasse.

In the country area two sites allow an evaluation of the sources of pollution by the city depending on dominant winds (Anières and Passeiry). A last site is localised in the Jussy forest, it allows a monitoring of the quality of the forest in relation with air quality.

The concentrations of pollutants are measured in accordance with the recommendations of the OFEFP (Office Fédéral de l'Environnement, des Forêts et du Paysage,



Ozone data source: ECOTOX Geneva

FIG. 3 - Time series display with different levels of temporal aggregation.

OFEFP 1990). Ozone is measured with an ultra-violet absorption technique (UVAbs). Measurements are taken every 5 sec. Data is averaged over a 30 min period in order to be stored for further analysis. Other air chemical components are also monitored (SO_2, NO_2, NO, THC = total volatile hydrocarbons, CH_4, CO, PS = suspended particles), together with physical parameters like temperature, relative humidity, light intensity, wind direction and wind speed.

A station can be selected for analysis and display by simply picking it from either the map or the list of station names. The object display will then show the time series of raw data, at various levels of temporal aggregation, selected interactively by the user (Figure 3). Meta-data describe each monitoring station, its location and neighbourhood, variables measured, and the monitoring and analytical methods used, etc. The meta-data are stored in hypertext multi-media format as defined in the HTML 3 standard, including the possibility to access remote information resources on the INTERNET through their URL (uniform resource locator).

For the observation station objects, some basic statistical analysis is provided together with the time series display functionality. This includes the computation and display of basic statistical parameters describing the time series. The user can select different time windows and layers of temporal aggregation, also related to the availability of synoptic data from neighbouring stations. In addition to a number of statistical tests (e.g., for daily and seasonal patterns, trends in mean and variance, spatial homogeneity and compliance with air quality standards) the system also offers spatial interpolation of the observation values in terms of colour coded map overlays, including the animation of the time series data. Different display styles, choice of colour schemes, isolines, and pseudo 3D display of the concentration surface can be selected by the user.

The examples displayed on Figures 4 and 5 show the interpolated ozone situation in Geneva at 06:00 h and 09:30 h for Thursday, July 11, 1991, before and after the morning traffic peak of the day. The mean daily ozone level was 110.8 $\mu g/m^3$ with a minimum of 2.98 $\mu g/m^3$ at the Foron site and a maximum of 314 $\mu g/m^3$ at the Jussy station. The dynamics of ozone concentration declined in the night at all sites and started to rise at 06h to 08h am. The dynamical changes in ozone are particularly important in summer (see also Figure 3). Peaking was between 11 h am to 02 h pm. This was one of the highest level of ozone reached in the year 1991. Weather conditions were: high temperature (mean daily temperature over the eight ROPAG measurement sites: 27.2°C, with a minimum at 16.6°C and a maximum at 40.1°C). Due to the presence of the Azores anticyclone the day was sunny and clear (mean light intensity 295.2 W/m^2, min 18.1 and maximum at 843 W/m^2). Wind speed was low (mean 0.683 m/s, min 0.04 m/s and max 3.09m/s) with no clear dominant direction.

Ozone interpolated maps were obtained from the data of the 8 fixed sites of measurement by the inverse distance weighting with power 2 method. The GIS interpolated ozone map at 06:00 am shows a uniform low distribution of ozone over all the canton (2-10 μg/m3) with the exception near Jussy and Meyrin area (~30 $\mu g/m^3$). At 09:30 h am a high ozone level is obtained over all the canton (84-173 $\mu g/m^3$). However,

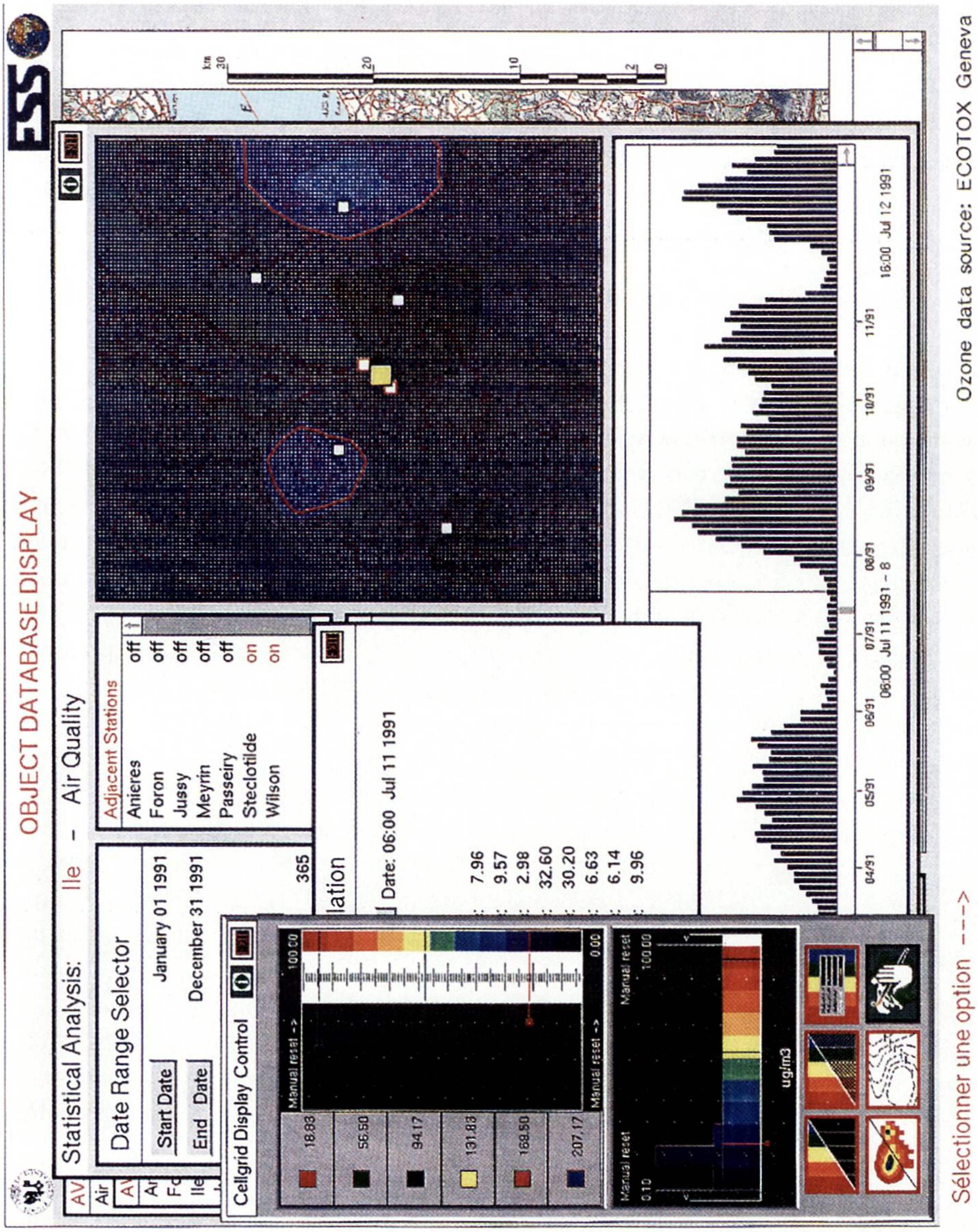


FIG. 4 - Spatial interpolation: ozone, July 11, 1991, 06:00 am.

it can be noted that at this time the lower levels are observed in the centre of the canton (Figures 4 and 5).

Other typical objects provide the linkage to the various models, like the point sources of emission to the air quality models, and the linkages to the energy and transportation sectors. Model scenarios themselves are represented as objects. They include a set of boundary conditions and driving forces like meteorological conditions, as well as sets of decision variables and control parameters, for example, referring to the emission scenario in terms of technology choices, control measures, etc.

Air Quality Management: from GENIE to AIDAIR

Air pollution is an important environmental challenge for the society (e.g. RABINOWITZ & GREPPIN, 1996). A central component of GENIE is the domain of air quality assessment and management. The current prototype system allows its users to:

– display and analyze air quality and meteorological monitoring data through the observation stations objects described above (compare Figures 3, 4, 5).

The basic system is further developed in an ongoing EUREKA project (EU 1388 EUROENVIRON, An integrated decision support system for air quality management: AIDAIR); the primary objective is to extend the core functionality by adding a real-time linkage to data acquisition systems; add a set of air quality models, primarily by providing models that can better represent complex terrain and valley situations; and by representing the main sources of air pollutants, namely the energy and transportation sector, explicitly. New functionalities in AIDAIR as compared to GENIE will allow users to:

– maintain emission inventories for major point sources with the help of a rule based expert system;

– simulate air quality for a range of meteorological and emission scenarios for basic pollutants such as SO_2, NO_x, and dust for individual episodes as well as over longer periods, e.g. to simulate average annual conditions based on the USEPA Industrial Source Complex model ("ISC": USEPA, 1979); and of ozone, based on the USEPA Photochemical Box Model (SHERE & DERMEJIAN, 1984); major developments are foreseen in enlarging the basic set of models, for example by adding dynamic 3D extensions as well as near-field, street canyon models as well as models of accidental spills.

– design and optimize investment strategies for pollution abatement on the basis of ISC long-term scenarios.

From a technical point of view, the extension into a distributed client/server system (Figure 6) is a major objective of the EUREKA project.

Air pollution problems involve, and regulations address:

– a set of different compounds or pollutants. The recent EU Directive on air quality assessment and management COM(94)109 lists: sulphur dioxide and black smoke, including suspended particulate matter, nitrogen dioxide, lead and ozone and as recent additions: Carbon monoxide; Cadmium; Acid Deposition; Benzene; PolyAromatic Hydrocarbons (PAH); Arsenic; Fluoride; and Nickel.

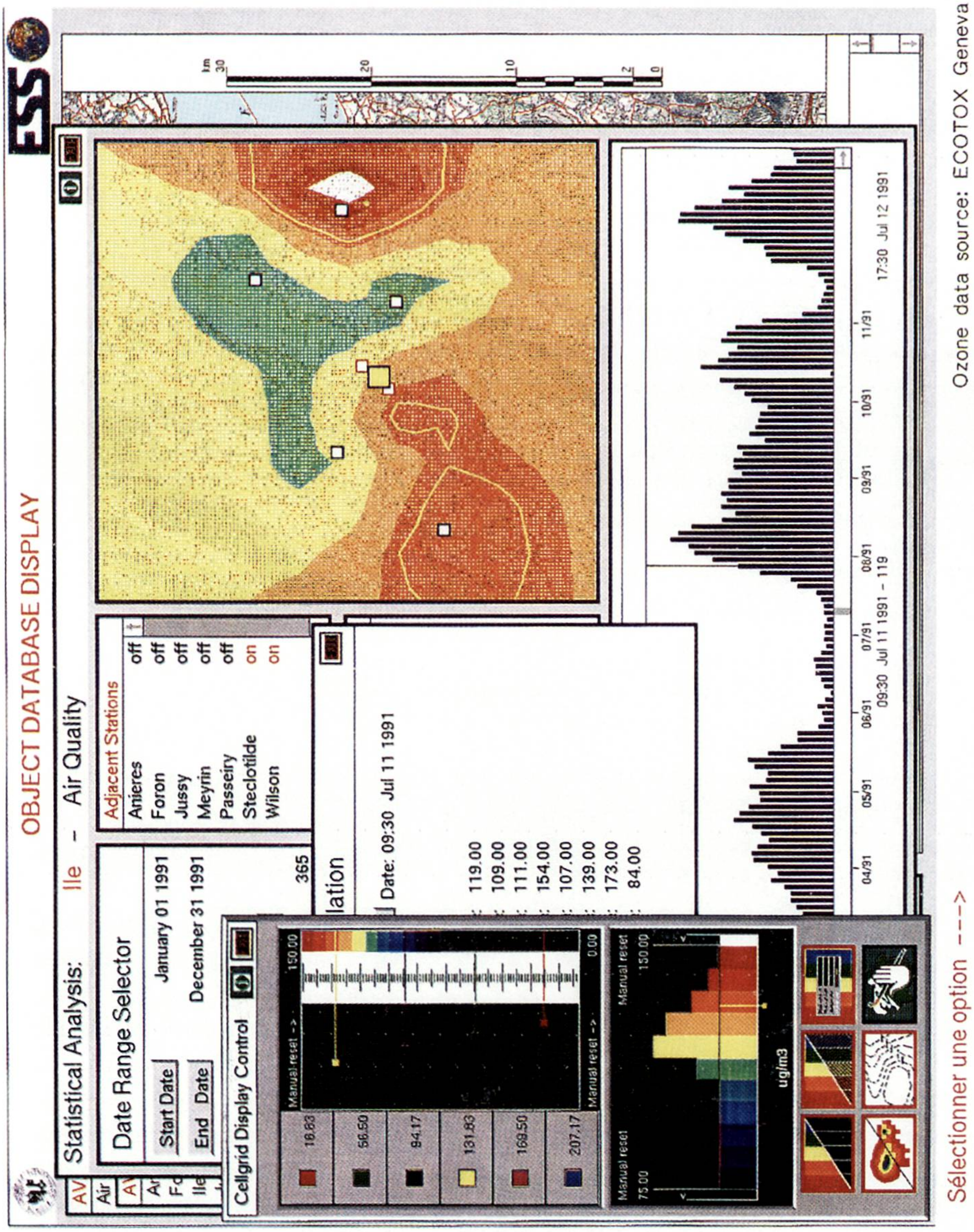


FIG. 5 - Spatial interpolation: ozone, July 11, 1991, 09:30 am.

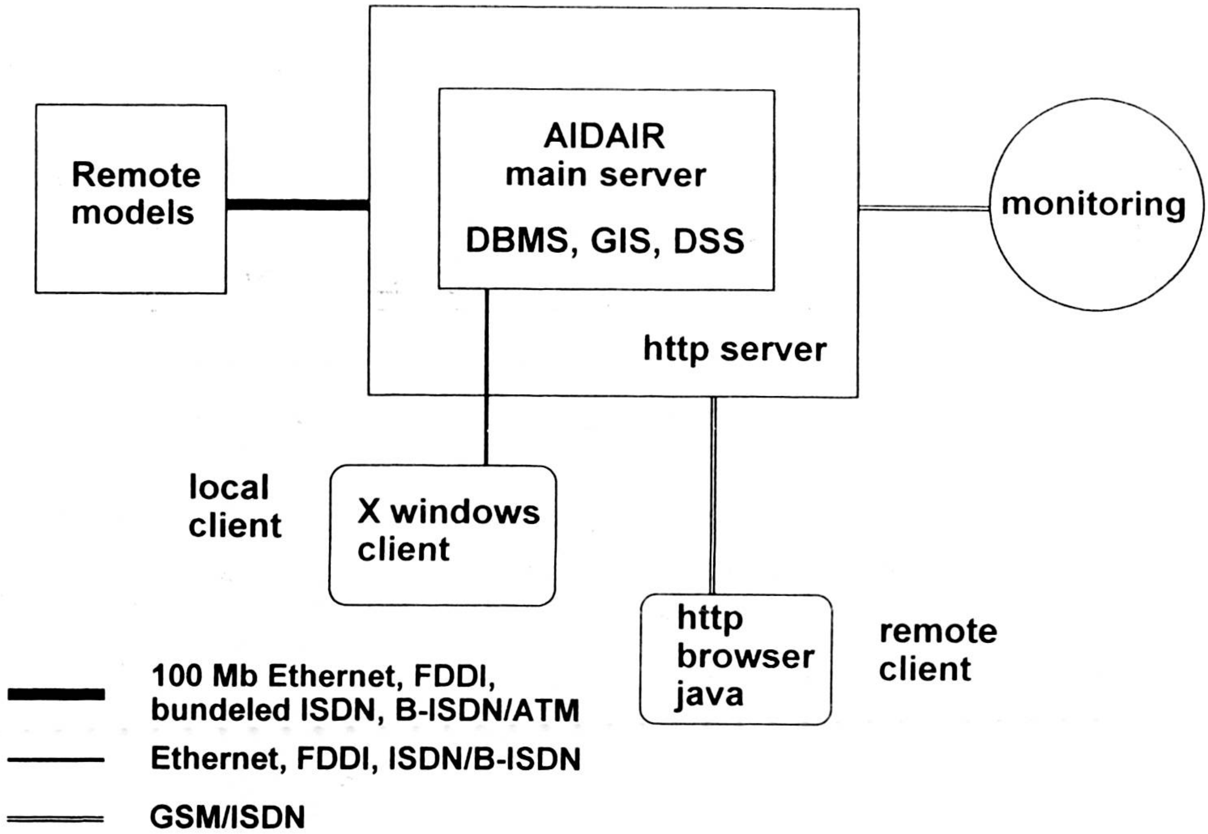


FIG. 6.

EUREKA client server architecture diagram.

– a range of time scales: short term (hourly) episodes including accidents, daily cycles, and long-term (seasonal, annual) average exposure;

– a range of spatial scales: from street canyons to large cities and their environs, i.e., several thousand km^2.

While these aspects all require different models and representations, they also need common, shared data for a consistent and efficient analysis, and a common, consistent user interface:

– Integration of data analysis and modelling with decision support tools to provide explicit support and directly relevant information for regulators, planners, and decision makers in a directly useful format;

– Integration of state-of-the-art modelling and analysis methods, including 3D dynamic photochemical models, expert systems, automatic learning, and neural networks;

– Integration of an environmental information and decision support system with modern information technology, based on a client/server architecture for a distributed implementation including high-performance computing resources;

– Integration with a multi-media interface and scientific visualisation tools, including animated display of data and model results, a 3D GIS, hypertext/hypermedia capabilities and remote access through WWW browsers.

Modelling the transport and dispersion of air pollutants has a considerable tradition, and is, in fact, included in many regulations world wide. To make models useful tools for planning and decision support, however, they need to be linked to the two main elements of regulatory control, to observation and monitoring of ambient air quality (the assessment side) as well as to the control of the main sources of emissions (the management side).

Energy and Traffic

Air pollution in cities is mainly due to three categories of activities:

– traffic and transport in general
– space heating
– industrial production.

For the more recently recognised problems of summer smog (ozone), this is complicated by the numerous and dispersed sources of volatile organic compounds (VOC), that together with the NO_x form ozone in the presence of solar radiation. In Geneva, for example, a study made in 1988 (Plan de mesures OPAIR, SLPO 1991) showed that the transport, space heating and industrial sectors were responsible for 71%, 15%, 14%, respectively of NO_x emissions. The emission of classical air pollutants is in a large part associated with the combustion of fuels in the different technologies adopted to provide the needed services, the useful energy demand. Therefore a large part of air pollution emissions is directly related to the combination of the two following factors:

– demographic and economic growth influencing the demand for energy services (useful energy demand)

– technology choices for delivering these energy based services.

One of the most interesting analysis of the energy systems, based on a relatively detailed description of the technology choices, has been the MARKAL modelling effort (see Fragniere & Haurie, 1996 and references cited therein). The approach is based on linear programming (LP), and the objective function in the LP model is the discounted sum over the time horizon considered of investment, operation and maintenance costs of all technologies plus the cost of energy imports. If one assumes that the demand for energy services (useful energy demand) is price-inelastic, then the minimization of this objective function subject to the constraints describing the energy system simulates a competitive market equilibrium.

The quality of the modelling and of the scenarios analyzed in a MARKAL framework depends crucially on the building of a comprehensive and accurate techno-economic data base. The data collected for every technology (existing or new) consist in costs (investment, operating, maintenance), efficiency (inputs and outputs of energy carriers or other resources), life-duration, availability factors, date of availability (if the technology is new), residual capacities (i.e. the planned decommissioning of capacities already installed at the initial period). This data must also contain a set of exogenous parameters such as price forecasts and availabilities for imported energy carriers, useful demands projections and anticipated environmental constraints.

Community-based regional energy-environment planning models have been recently proposed in Sweden and in the Geneva canton. These models which extend the standard MARKAL modelling approach, permit an assessment of the interplay between energy conservation, fuel switching, new technologies, combined heat and power production, and emission management. In MARKAL-Geneva a possibility has been introduced to model discrete choices, e.g. in the development of centralized production equipment.

The energy submodel in AIDAIR/EUREKA will serve in the computation of pollutant emissions due to energy uses, and also to the long term simulation and optimization of the evolution of the energy system in order to satisfy some global emission constraints. For the first usage, the data must keep their geographical reference; indeed the pollution dispersion model needs as input the location of different sources. In the second type of utilisation, the model will be used in an aggregated manner; here the total installed capacities of different types of equipments will be taken into consideration, without a precise reference to the location. Once the optimization is performed, the resulting *scenario* should be displayed on the city map and this will require a disaggregation step.

Linkage to the air quality models is through the spatially explicit emission scenarios resulting from the MARKAL model runs.

DISCUSSION

The main objective of GENIE is to integrate a broad range of data and information resources relevant to environmental planning, together with powerful yet easy to use tools for assessment and analysis.

Integrated environmental information systems are tools to support environmental planning and policy making (FEDRA, 1992). To do this effectively, they have to filter large volumes of raw data into useful information. They are designed to bring the best available knowledge to bear on decision making processes, reach a broad audience, be easy to use and understand, and help generate and explore a large number of options to choose from. They provide direct access to large volumes of data, including as a central element, spatial data, and a set of tools for their analysis and interpretation, including scenario analysis and model based forecasts and assessments (FEDRA, 1995).

Spatially distributed data play an improtant role in environmental problems, and GIS functionality is an important, and by now common and expected component in any environmental information system. Levels of integration vary widely, and with them the complexity, sophistication, but also the price of the tools. Large volumes of data are often available in data bases, from paper maps and from satellite imagery, and from sensors and data acquisition systems. Much of these data are increasingly accessible through global networking. To turn these data into useful and directly usable information is a major challenge, and it requires the integration of basic GIS technology with numerous other tools and methods to make integrated information resources directly accessible to a fast growing and in fact global user community (FEDRA, 1994b, 1996b).

The most important aspects of this new approach to providing environmental information for planning, management and policy making but also for environmental education and training are:

Immediacy and real-time nature; any change in the underlying data, any new information through the on-line linkage with monitoring and data acquisition systems becomes immediately effective in the conclusions and interpretations. The systems can be used continuously, with continuous updates, that is on demand, rather than on schedule.

Openness; by directly and explicitly coupling data and conclusions, and making the methods of assessment and interpretation an integral part of the information, open for inspection and possibly subject to choice; by making key assumptions, in particular in the evaluation, open to inspection but also accessible to the user for substituting his own set of values, responsible participation rather than passive reception by the user becomes the key concept. Users can also structure output formats to their liking and better understanding. Reliance on largely graphical and symbolic formats supports an intuitive understanding of complex relationships, trends and patterns in time and space. Openness also implies that alternative tools and methods can easily be incorporated to add new points of view and address specific requirements.

Flexibility and versatility; providing multiple formats and tools to generate alternative presentations, support alternative interpretations, and allow the user to explore the information and structure it to his own need allows the system to address new, and different questions rather than offering only a predefined fixed set of answers.

Accessibility; giving the system a friendly interface, access to the information, data, and tools becomes easy. Users can find what they look for much easier than in a book of many hundred pages, using efficient search and retrieval methods that go far beyond the usual table of context and subject index of a book.

Open access also means that through an integration with wide-area networks like the INTERNET, the system can be used to provide publicly accessible environmental information.

As a decision support system, GENIE provides background information and context, including tools to analyse the available monitoring data. Integrating several layers of data and information, the system supports a broad view of environmental problems. It then assists in the design and scenario analysis of policies and specific management options in the areas of emission control and energy and traffic policies, offering simulation and optimization models. Finally, alternative feasible scenarios can further be analysed with a discrete multi-criteria optimisation tool (MAJCHRAZAK, 1988) based on the reference point approach.

Future development steps will enlarge the set of environmental models integrated in GENIE, including aspects of water quality, noise, and perceived environmental quality.

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RÉSUMÉ

GENIE (Geneva Environmental Information System), est un système modulaire d'aide à la décision en développement à l'Université de Genève sous les auspices du Centre Universitaire d'Ecologie humaine et des Sciences de l'environnement en collaboration avec: le Laboratoire de Biochimie et Physiologie végétales, le groupe Logilab des HEC, le Département de Géographie, le groupe des Sciences de la Terre, le Conservatoire et Jardin botaniques de la Ville de Genève et le Laboratoire de biosystématique et floristique.

GENIE est un système avec une interface d'utilisation conviviale et qui a pour objet de fournir un accès à de l'information liée à l'environnement, ainsi que d'être un outil d'aide à la décision dans ce domaine. Il est conçu comme un système distribué et basé sur une architecture flexible de type client-serveur, le système réunit différentes sources et moyens d'information. En plus de ces capacités descriptives, il fournit également des instruments d'analyse du genre "que se passe-t-il si...?", qui permettent de concevoir et d'analyser des scénarios de planification, de gestion, et de politique de l'environnement grâce à la prévision des impacts d'actions potentielles. Bien que le système ait pour ambition finale de traiter l'ensemble des aspects urbains et/ou régionaux de l'environnement, la première réalisation est centrée sur la qualité de l'air et sa gestion, ainsi que sur les secteurs des transports et de l'énergie en tant que principales sources des émissions.

Mots-clés: système d'information, aide à la décision, SIG, qualité de l'air, ozone, planification énergétique.

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