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ENVIRONMENTAL SIMULATION AND IMPACT ASSESSMENT SYSTEM FOR THE MINING INDUSTRY

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ABSTRACT

This paper describes a European Commission Brite Euram project carried out by Imperial College, 1 nstituo Superior Tecnico, Outokumpu Zinc Tara Mines Ltd and Sociedade Mineira de Neves-Corvo S.A. The project developed an environmental simulation and impact assessment system in order to facilitate an understanding of the interaction between minerals extraction and the environment. The research partners investigated effective modelling techniques which allow for the temporal, spatial and uncertainty properties of environmental impacts and incorporated these techniques in an environmental impact modelling system. The system developed utilises a Geographic Information System (GIS) as its spatial database for input, output and spatial operations. Environmental impacts have both spatial and temporal components. As the temporal modelling capabilities of GIS are limited, numerical models for the simulation of environmental impacts were developed and integrated with the GIS. The environmental impact categories considered included air pollution, blasting vibration, groundwater quality, river water quality, and heavy metal contamination in soil and plants. A common Graphical User Interface (GUI) to input/output environmental data and to run the simulation models within GIS was also developed and integrated with the system.

INTRODUCTION

The minerals industry contributes to the economic growth, prosperity and quality of life of nations. However, notwithstanding their economic importance, the minerals extraction and processing industries are considered to be one of the biggest contaminators of the surrounding environment. This gives rise to adverse public opinion and, lack of public confidence in the mining industry's ability to protect and preserve the natural environment often results in the refusal of planning permission to mine valuable resources.

Ideally, environmental planning prevents the creation of pollution at source, rather than trying to counteract its effects later. This ideal may not always be attainable, and in such a case environmental planning should lead to the selection of the least environmentally harmful option. Such an aim is best achieved by taking into account the environmental impacts of a project at the earliest possible stage in the planning and decision making stages, In respect of new and existing projects, the mining industry needs to show that the damage to the environment will be minimised and that action will be taken to alleviate damage, by adopting, from the very beginning of the project, an approach that accounts for environmental protection throughout the lifetime of the project. This can be a costly process and may affect the feasibility of a project.

The current challenge for the minerals industry is to provide the supply of minerals and metals required to sustain social and economic growth without causing long-term degradation of the environment. This challenge can be met by adopting a well structured, systematic approach to environmental management, The best practicable technology in monitoring and modelling the behaviour of the environment should be implemented by the industry. The emphasis must also be on the use of best available sources of information, and on the presentation of this information in a form which provides a focus for public scrutiny of the project enabling the assessment of the importance of the predicted effects, and the scope of modifying and mitigating them.

The main objectives of the project described in this paper were:

1. To combine a geographic information system with simulation modelling techniques and advanced geostatistical methods with the purpose of developing an environmental simulation and impact assessment system,
2. To extend the model for use as an information tool so better environmental management can be achieved overall.

The main trust of this project was to develop *environmental simulation models,* combining the advantages and benefits of advanced geostatistics and numerical modelling techniques, and to *integrate* these models with a GIS to enable both spatial and temporal impact analysis. The environmental impact categories considered included air pollution, blasting vibration, groundwater quality, river water quality, and heavy metal contamination in soil and plants, A *common graphical user interface* to input/output environmental data and to run the simulation models within GIS was also developed. Managers at operating mines require a comprehensive and reliable set of environmental data in order to make informed decisions on environmental quality. The industrial partners of the project had already established a comprehensive environmental monitoring programme before the start of this project. These programmed were further strengthened through the purchase of same monitoring equipment to support the specific needs of this project and through the development of well structured *environmental data bases.* The upgraded monitoring systems and the data bases developed at each site were essential for the validation of the environmental impact modelling software developed and for demonstrating the overall environmental impact assessment concept based around the *GIS graphical user interface* developed.

Figure 1 illustrates the generalised structure of an environmental simulation and impact assessment concept which embraces the numerical models and the graphical user interface developed in this project. It is believed that the work carried out by the research partners and the system software developed has contributed a great deal towards providing one of the building blocks necessary for effective environmental management in the minerals industry.

GEOGRAPHICAL AND ENVIRONMENTAL DATABASE

The building up of the graphical and environmental database at the two mines served two purposes: (a) to prepare the industrial partners for the use of the system and improve the efficiency and effectiveness of the use of environmental data in environmental management and (b) to provide the necessary data for the validation of the impact simulation models to be developed. The map data for the two mines was acquired in DXF digital format; from the Army Cartographic Services (S.C.E.) and Aero-Topográfica, Lola. (ARTOP), originally produced at a scale of I :25000 and 1:10000 respectively, for Somincor and from the Irish Ordinance Survey, at a scale of 1:2500, for Tara Mines. In addition, specific information relevant to mining operations was digitized by the mining, survey and geological departments and transformed from local to national coordinate systems. The map data was converted into ARC/INFO internal format and the modifications to the database were carried out using ARC/INFO's manipulation and digitization tools.

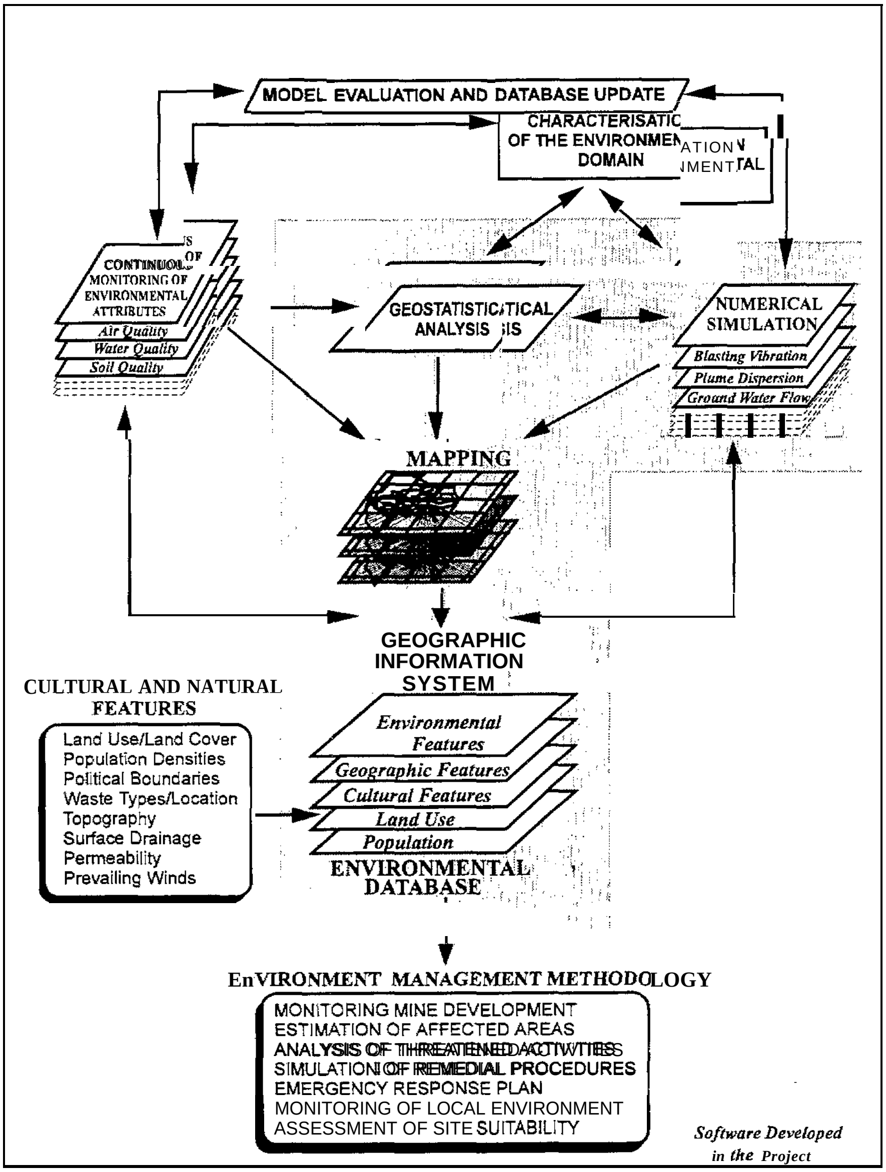


Figure 1: Structure of the environmental simulation and impact assessment system

A large database of spatial data relevant to mining operations and monitoring activities were also added to the data base in order to enable the analysis of environmental impacts and to relate these to the geographical, cultural and natural features of the area. The following sets of data was collected for each mine site, digitized and stored as the spatial database of the geographic information system used:

- Topography
- Geographic features
- Road and rail transport routes
- Urban and rural settlement areas
- Land use and land cover
- Mine sites and buildings
- Infrastructure
- Waste types, disposal sites
- Water, air, soil, noise, vibration and biological monitoring sites

The geographic data was cataloged and classified according to the type of information represented, and each kind of major geographic feature was organized into workspaces. Each information level included in a workspace is represented by several graphical entities (features). In order to optimise the access to the information. Each type of graphical entity was stored as a different coverage. The data was used in conjunction with the simulated, modeled and predicted environmental attributes in mapping and overlay analysis for impact assessment.

The project has been instrumental in initiating a system, at each mine site, where a master database holding all the monitored environmental data was developed. These records are stored under a common structure, ready to be treated by geostatistical methods/prediction models and to be incorporated into the GIS. A database system using Microsoft Access was implemented for management, storage and retrieval of the information resulting from the environmental monitoring programme.

Six main groups of environmental data, namely the Aquatic, Atmospheric, Meteorological, Noise, Vibration and Soil and Herbage Data were considered at the two mine sites. Each group was then subdivided into several sub-groups until the most elementary level is formed by the tables. Each of these tables represents a very specific set of data about a certain theme or a particular type of analysis, also identified by the sampling rate (periodicity) at which the information was collected at the stations (Figure 2). At Tara the main problem in developing the environmental database was the use of the large quantity of historical data that has been collated since 1971. Historical data plays a large role in the decision making process at Tara, therefore, it was important that all of this data was integrated into the database. Steps were also taken to validate the historical data to ensure its accuracy and relevance to currently monitored parameters. Figure 3 illustrates the composition of the soil and herbage data base at Tara. Both Tara Mines and SOMINCOR have developed an integrated environmental database that facilitates or utilises the transfer and storage of information to and from the GIS (ARC/INFO).

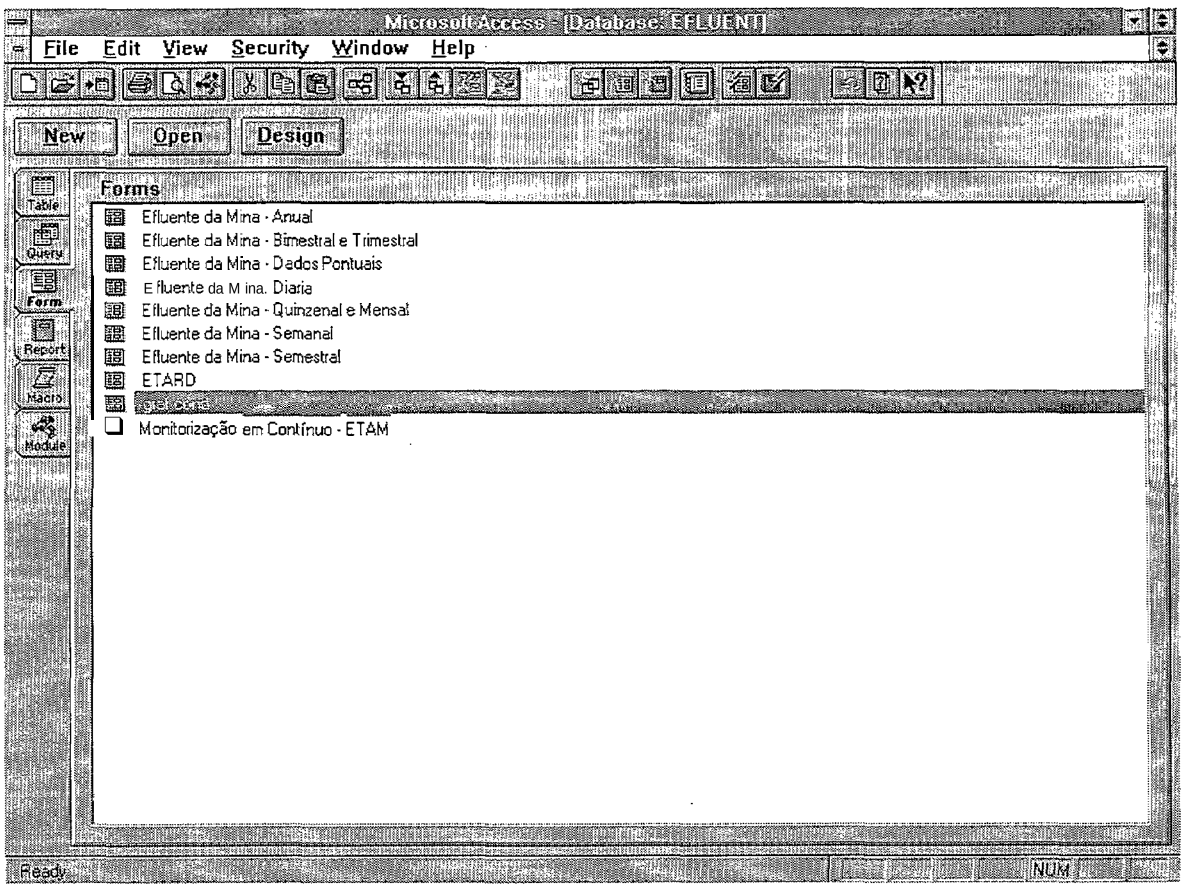


Figure 2: Example of the menu that accesses the tables related to the mine water discharges at Somincor.

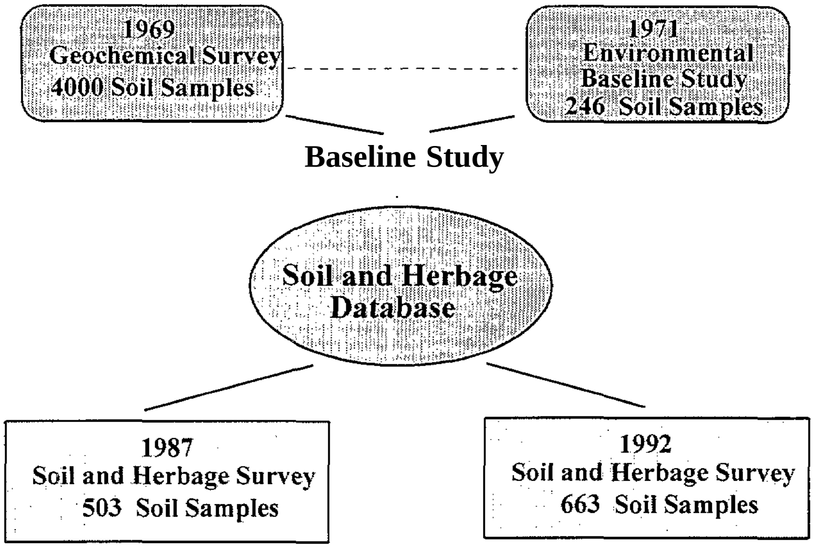


Figure 3: The soil and herbage database, Tara mines.

THE DESIGN AND IMPLEMENTATION OF ENVIRONMENTAL MONITORING SYSTEMS

There are several techniques of gathering and monitoring environmental data. The basic techniques include:

- Grab sampling techniques with periodic data analysis
- Automated sampling techniques with periodic data analysis
- Automated continuous monitoring and data analysis
- Biological monitoring systems

A variety of factors have to be appraised in the design of an environmental monitoring system. Primarily the environmental variables that will be monitored, and secondly the frequency at which these variables can be evaluated. Following the review of all the environmental monitoring equipment and monitoring technologies available in the market and considering the needs of the project and the industrial partners, some monitoring units and data collection techniques were upgraded at the early stages of the project, The environmental monitoring programme implemented at the two mine sites is summarised in Table 1.

Table 1: Environmental quality indicators monitored at two mines during the project.

River Water Quality	Ground Water Quality	Noise	Vibration	Meteorology	Air Quality	Soil and Herbage	Biological Surveys
Turbidity	Piezometric Pressure	L_{eq}	ppv	'Wind Direction	Ambient Dust	Metals	Bio Diversity
PH	pH	L_{max}	frequency	Wind Velocity	Gaseous	Nitrates	Bio Population
Dissolved Oxygen	Dissolved Oxygen	L_n	waveforms	Rainfall	Emissions	Sulphides	Metals
Temperature	Heavy Metals	L_{10}		Sunshine hours	Composition	Organic Content	General-
Heavy Metals	Conductivity			Temperature		PH	Condition
Conductivity	Temperature			Humidify		Bio Diversity	. . .
Flow Rate	Chemical Content					Bio Population	
Water Chemistry	Water Chemistry					Metal Content	
... .	BOD					- -	
	COD						

Atmospheric monitoring in both mines is carried out using dust deposition gauges and high and low volume air samplers for suspended solids. In addition to these monitoring techniques, Somincor initiated a biological monitoring programme using lichens as biological indicators of atmospheric pollution. Research so far established a specific lichen species - *unsea sp* - as a high capacity Cu indicator and the monitored data was utilised to develop a monitoring/modelling methodology for the estimation of the spatial variation of Cu values from possible sources of pollution.

At Tara Mines, pHOX series 200 multiparameter data logging water monitor's were installed at three locations; the clear water discharge pond, upstream and downstream of the diffuser on the River Boyne. At Somincor, same monitors have been working at two selected sites since September 1993 on the River Oeiras. Somincor implemented a hydrobiological survey programme to complement the chemical monitoring in the river. Groundwater hydrochemistry and levels around the mine site and at the tailings pond area are monitored through piezometric wells at both mines. Tara Mines has been using a Grundfos sampling pump to assist this work.

Noise monitoring at Somincor is carried out using portable monitors at seven monitoring sites. Tara mines have installed four computerised Larson Davis monitoring units with integrated meteorological monitoring capability to replace the existing monitoring system. Continuous monitoring of wind average speed, wind maximum speed, wind direction, temperature and humidity is carried out at an hourly interval using the new integrated noise and meteorological stations. Somincor monitors the meteorological conditions using a climatological station located on the mine site.

The analysis of soil and herbage samples for metal levels is carried out in both mines periodically. The initial survey carried out in 1971 at Tara Mines was a trace element survey of soil and herbage determining the existing concentrations of chemical elements in the soils and grassland of the general area of the proposed mine. This information, together with the 1969 geochemical data is used as the baseline (background) data against which any possible changes due to mining operations could be measured. Current soil and herbage surveys are based on a National Grid network around both the Mine site and Tailings dam structure yielding 663 samples in 1992. At Somincor the monitoring programme involves sampling along the road where concentrate was transported until July 1992 (60 samples) and along the new railway line Neves Corvo - Ourique (42 samples). Soi Is around the mine complex are also sampled (32 samples), annually and biannually.

A schedule identifying specific stopes and blast vibration monitoring locations at Tara was prepared for the purpose of the project. This includes near field and far field monitoring to coincide with the four permanent monitoring stations located along the periphery of the mine site. Eight Instantel continuous monitoring units were purchased, four were installed to replace the existing fixed station monitoring system, the remaining four units are used as portable monitors allowing for near and far field monitoring of selected stopes in support of the vibration modelling research.

ENVIRONMENTAL SIMULATION AND IMPACT ASSESSMENT SYSTEM DEVELOPMENT AND VALIDATION AT MINE SITES

Essential to understanding and analysing an environmental system is to capture its evolution through time and its distribution across spatial regions, as well as the dependency of variables involved, which is particularly important because of interaction of climatic, pollutant, and biotic influences. Main constraints associated with modelling environmental systems are:

i. Observational or measurement constraints, such that one or more of the system elements are not measurable. Lack of monitoring and measurement standards resulting in random and systematic measurement errors and in observational data rather than data from designed experiments.

ii. Theoretical constraints associated with the limitations of current modelling techniques so that they can only be applied after certain assumptions are made.

Further constraints are introduced by various sources of disturbance or stochastic elements, such as non-linear behaviour of the environmental pollutants, caused by aberrant values, either real unusual occurrences or just bad data, seasonal fluctuations and complex cause-and-effect relationships. In summary, environmental data sets are characterised by a high degree of imprecision, subjectivity, incompleteness, high noise content and/or presence of clusters. All this coupled with spatial and temporal variability of various pollutants makes environmental modelling a particularly complex task.

Simulation modelling gives an approximation over a time period of behaviour of the real world system. The use of simulation models by the engineers and environmental scientists in the minerals industry has the following objectives:

- to understand the pollution mechanisms around the industrial site,
- to predict the environmental impacts associated with the production activities both as an EIA tool and as an environmental management and control tool during production, and
- to provide and/or improve input data for the simulation models used.

The modelling procedure usually takes the form of characterizing/defining the model led domain; selecting a modelling technique; defining the boundary conditions; providing the input data; modelling impact and validating the methodology with observed/monitored environmental data. All these stages involve the use of spatially referenced data and material properties/variables that can be stored in a data base such as the one a GIS uses. The spatial data analysis techniques provided by a GIS together with their graphical representation capabilities make them an excellent candidate for operating an integrated environmental management system.

The environmental simulation models developed in this project utilised an integrated approach in the application of geostatistical techniques, numerical models and GIS for each environmental impact category considered. The Instituto Superior Tecnico developed several advanced geostatistical methodologies and techniques to characterize the spatial and space-time dispersion of soil pollutants, river water quality parameters and groundwater properties. For groundwater data, two separate geostatistical methods were developed. The first produces the estimation of hydraulic heads to define the boundary conditions and the second provides quality indices by coupling multivariate statistics and geostatistics. Researchers at Imperial College developed numerical models for the prediction of air quality; groundwater flow and pollutant transport; and blasting vibration around mine sites and related structures.

Environmental impact categories and the examples of model applications presented in this paper are selected to give the reader an overall view of the modelling techniques developed and their application to cases selected from one of the two industrial partners' sites. The numerical models and the geostatistical techniques developed were integrated under a common Graphical User Interface (GUI) developed at Imperial College. ARC/INFO, the Geographic Information Systems development platform selected for this project, was used to create the GUI using AML programming. The model results reported in this section give an insight into the output capabilities of the integrated system. More detailed description of the user interface is presented in the relevant section.

i) Modelling of the Spatial Distribution of Heavy Metals in Soils

One of the objectives of this project was to develop a methodology through which the spatial distribution of the soil and herbage metal contents can be modelled. The estimated metal levels can then be used to assess the extent of the impact using graphical display and data manipulation capabilities of GIS.

Methodologies implemented for the modelling of metal contents in soils are based on kriging theory, derived from geostatistics. Namely, if measurements have been made at scattered sampling points and the form of variogram is known, it is possible to estimate the value at any unsampled location by applying a kriging method. The geostatistical technique developed by the Instituto Superior Tecnico to estimate the shape of a plume of a soil contaminant is based on a two step approach:

i) creating an indicator variable related to a given threshold value of metal by indicator kriging in the area covered by the soil samples,
ii) obtaining morphological maps with an algorithm that assures local and global probabilities of the experimental data.

ii) Minerals Industry Air Quality Models

Table 2 shows possible sources of air pollution from minerals extraction activities, including processing of minerals, classified by spatial extent. This listing is not intended to be exhaustive or definitive. The air quality impacts from these sources occur at what is defined as a local scale in air quality modelling, primarily distances up to 10km. Air pollutants at this scale are contained within the boundary layer of the atmosphere.

Table 2: Sources of air pollution from minerals extraction.

Point	Line	**Area**
Ventilation outlets Transfer points Processing plants Drilling, and loading	Truck haulage routes Conveyor haulage routes	Tailings dams Blasting Storage areas Spoil heaps

Conceptually, the methodology for modelling the dispersion of an air pollutant can be thought of as having two basic components, an atmospheric flow or meteorological model and a transport and diffusion model. The flow model is used to provide a description of wind fields, atmospheric stability and turbulence. Two gaussian plume models, one for point emissions and one for area source emissions, for short and medium range prediction of air pollution from minerals extraction were developed. This work was complemented with the development of a meteorological pre-processor which can be used by both models. In this section, the models are described and their use as an environmental impact assessment tool in GIS is demonstrated.

The Meteorological Pre-processor: All air quality models require an input of meteorological parameters in some format suitable for use in the model. This is conventionally achieved through the use of a meteorological pre-processor. Most meteorological pre-processors have very strict requirements in the format of its input data, being tailored to use data in a format supplied by the U.S. N. W.S (U .S E.P.A, 1993). The meteorological measurements usually required are wind speed, wind direction, temperature, cloud cover, cloud ceiling and boundary layer height. Nevertheless, even some of these meteorological measurements may not be available, particularly cloud ceiling and, more importantly, boundary layer height. Therefore, to retain flexibility in the application of both air quality models described here, a meteorological pre-processor has been developed at Imperial College. As an absolute minimum, the pre-processor will provide input parameters for the air quality model based on wind speed, wind direction, temperature and cloud cover only.

The meteorological pre-processor uses the Pasquill-Turner method (Turner, 1964) to estimate Pasquill-Gifford stability categories. The meteorological measurements that form the basis of this method are wind speed, cloud cover and cloud ceiling, combined with time of day and solar altitude. In the absence of cloud ceiling measurements, an assumption has to be made as to whether a low or high cloud ceiling exists for the entire period. A low cloud ceiling is taken as below 2133.6 metres, to agree with the 7000 feet limit in the Pasquill-Turner method. The amount of insolation in the Pasquill-Turner method is a function of solar altitude. The altitude of the sun depends on the day of the year, the time of day and latitude and longitude on the Earth's surface, and can be calculated from known Earth-Sun relationships.

Air Quality Model for Point Source Emissions: Features incorporated into the model developed at Imperial College are:

1. basic requirements in terms of the input meteorological measurements;
2. a wind speed profile using the power law;
3. modification of the effective plume height allowing for stack tip downwash, and plume rise using Briggs' formulae (Lyons and Scott, 1990; Briggs, 1975);
4. the use of the Pasquill-Gifford method to determine the dispersion coefficients (Gifford, 1976);
5. the Pasquill-Turner method of resolving stability categorisation (Turner, 1964);
6. deposition using the tilted plume method.

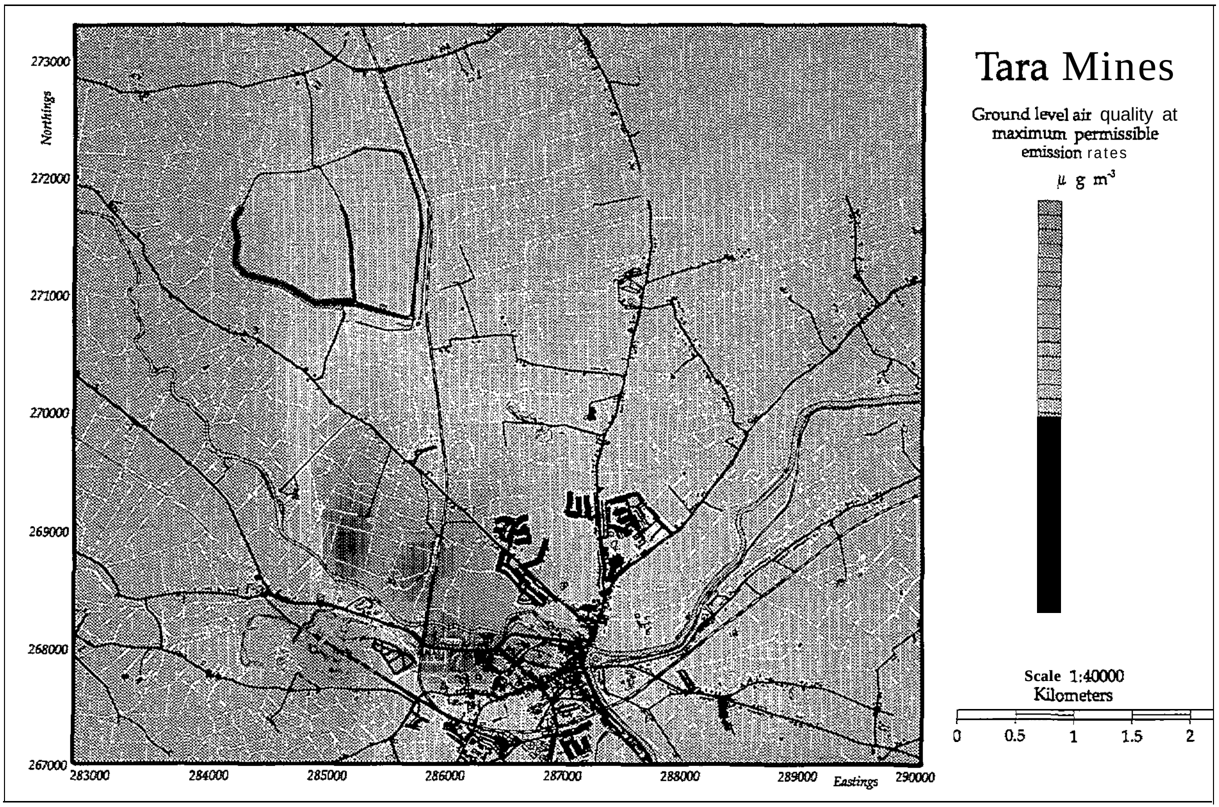


Figure 4: Predicted ground level air quality at maximum permissible emission levels.

The model was validated using Tara Mines site as the test case. Predicted ground level concentration of total solids (and metals) were found to be in good agreement with the observed **values** for the dust gauges around the mine site. Figure 4 illustrates the ground level concentration distribution of total solids for assumed emission rates at the maximum permitted level of total solids over a modelling period of one year.

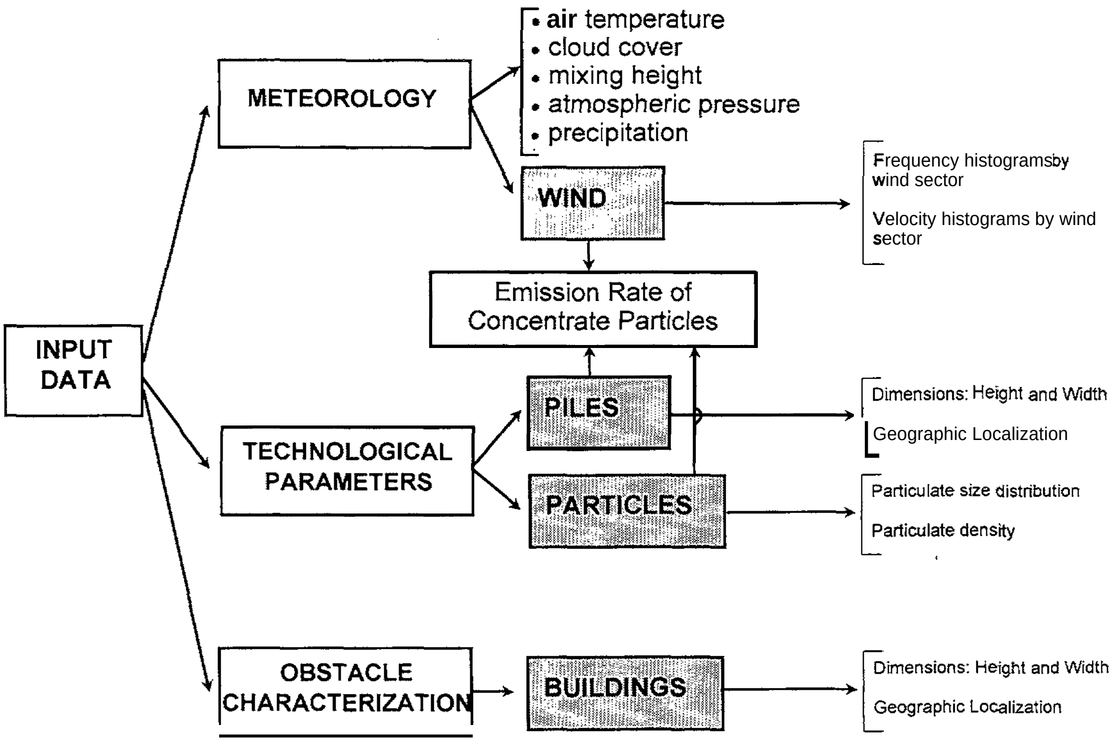


Figure 5: Data input for long term dispersion model for area source emissions.

Air Quality Model for Area Source Emissions (Fugitive Dust Model): In order to model the fugitive emissions from concentrate stockpiles, a gaussian long term dispersion model which calculates dry deposition was developed at Instituto Superior Tecnico and was integrated with the system under the Graphical User Interface (GUI) developed at Imperial College. The model was used to assess the area source emissions in mining and was validated at Somincor. This model uses two types of input data: meteorological data ('joint frequencies of occurrence for particular wind speed classes, wind direction sectors, and stability categories) and technological parameters (pollutant source characterization), Figure 5.

The meteorological data has been classified into joint frequencies of occurrence for particular wind speed classes, wind direction sectors, and stability classes. The emission rate of particles depend on wind speed, particles size distribution, precipitation and stockpile dimensions. The procedure recommended by the United States Environmental Protection Agency for total suspended particulate emission factor was used to calculate the concentrate emission rates.

iii) Groundwater Modelling

The groundwater modelling approach in this project aimed at developing systems where the quality and the piezometric level of groundwater around mine sites and associated structures can be modelled utilising geostatistical and numerical techniques. Historical data, together with monitored data for the purposes of this project, were used to test the validity of the following models developed:

- a coupled multivariate statistics and geostatistics model for the analysis of groundwater hydraulic heads and quality developed at Instituto Superior Tecnico, and
- a three dimensional finite difference model for the analysis of groundwater flow and solute transport developed at imperial College.

The model integration with GIS illustrate the enhancements, in terms of the quality of inputs and analysis of outputs, provided by GIS to the modelling process. Also, the potential of the modelling techniques to improve spatial data representation in GIS is demonstrated by using spatial covariance structures derived from data itself, avoiding unrealistic assumptions associated with traditional spatial interpolation methods. Figures 6a and 6b illustrates the comparison of simulated 1982 and 1989 hydraulic head data at Somincor. The maps were produced by kriging, where the variables are interpolated in space according to their autocorrelation. The estimated values, transferred to GIS, refer to a dense 100 x 100 m grid. The variograms of the variable for each time horizon were calculated. Using these variograms as structural models of the variable autocorrelation, a kriging estimation was performed and mapped. The results of the kriging models, when integrated with GIS, resulted in the enhanced display capability shown in the Figures, These figures show a GIS map where the groundwater piezometric surfaces in 1982 and 1989, in GRID and contours, were draped with the surface structures. Here, the piezometric surface was exaggerated, by a constant scaling factor, to present a powerful visual image. The absolute value of the piezometric levels, resulting from the mining activities, can be evaluated through sections graphed along an axis as shown in the figures. The figures also show the areas of high and low piezometric surfaces in relation to the surface structures, rural settlements, etc. providing an excellent environmental impact assessment tool.

iv) Stochastic Simulation of River Water Quality Parameters

The main objective of this element of the project was to develop methodologies to simulate the behaviour of some water quality indicators of a river resulting from mine effluent discharge, in order to enable the prediction of extreme scenarios for the entire system. A sequential simulation technique was implemented to draw correlated realizations in time and space of a random function, based on a data driven approach. Two different simulations were implemented:

i) a conditional simulation in which the input is the real time series of the first station corresponding to a mine effluent, and
ii) a non-conditional simulation where all time series were simulated.

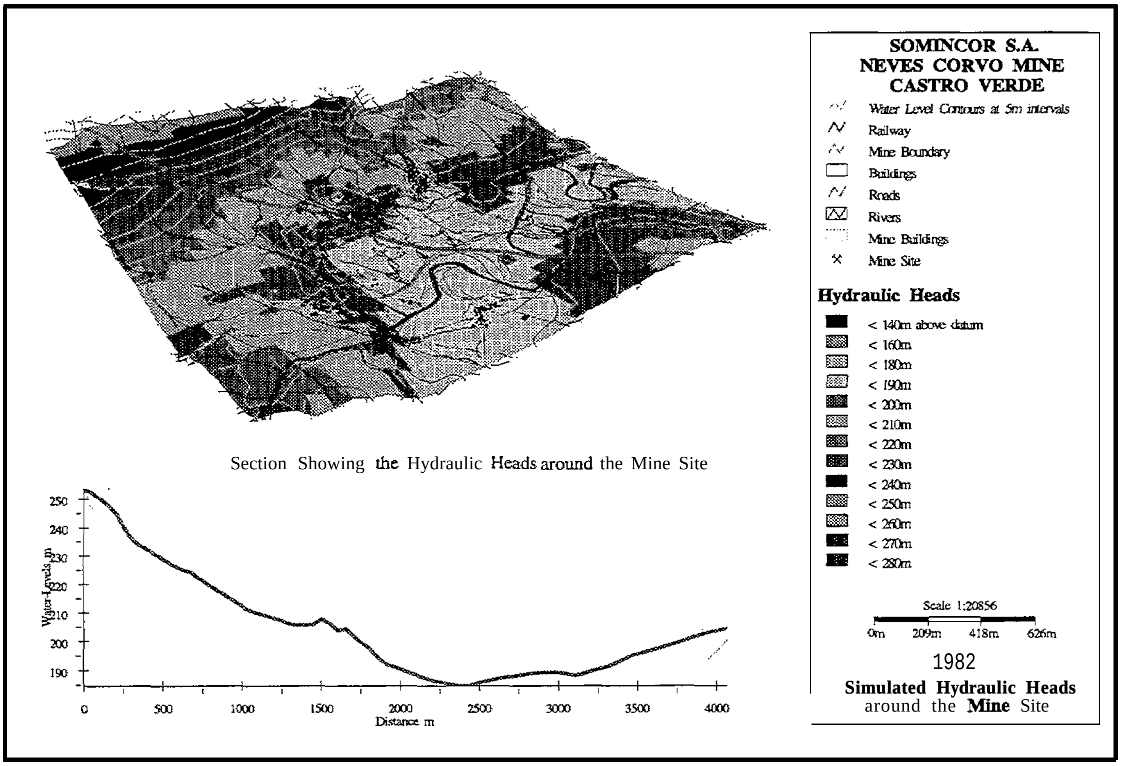


Figure 6a: GIS map showing the exaggerated groundwater piezometric surface, in GRID and contours, draped with the surface structures at Somincor in 1982.

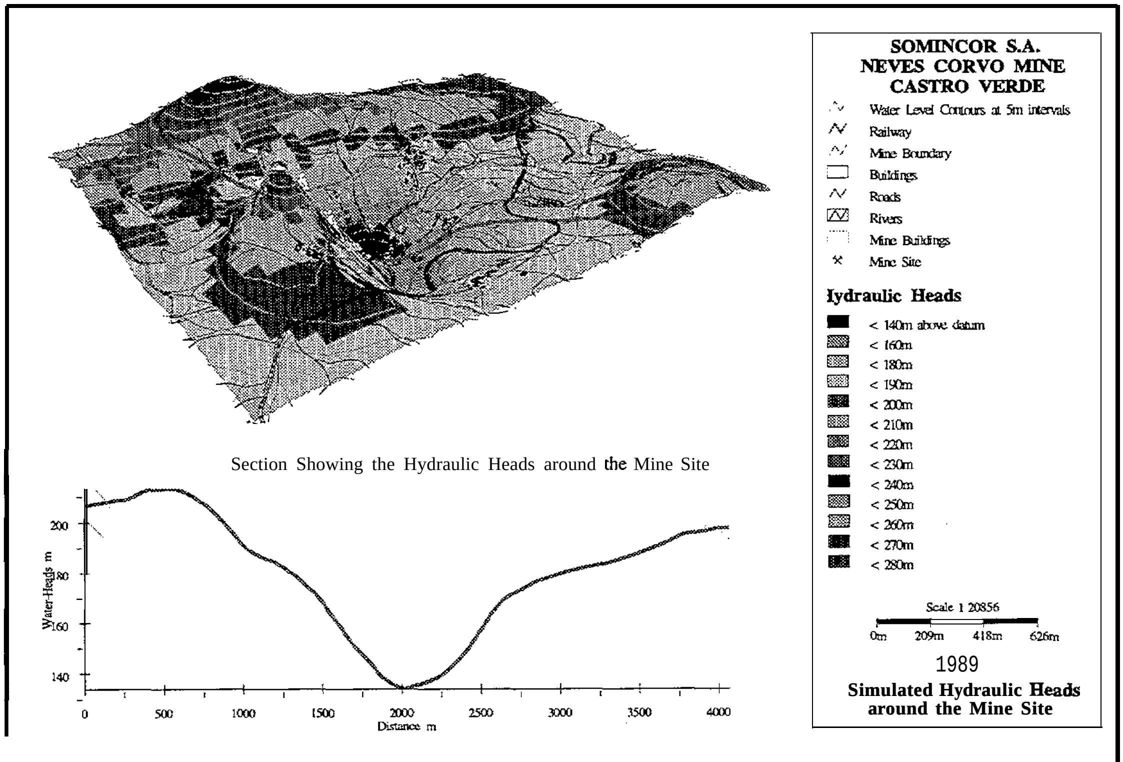


Figure 6b: GIS map showing the exaggerated groundwater piezometric surface, in GRID and contours, draped with the surface structures at Somincor in 1989.

The data set used to develop and validate the stochastic simulation consisted of monitored values of pH, dissolved oxygen and conductivity at a selected number of monitoring stations on Oeiras River at Somincor. The model was developed by the Instituto Superior Tecnico using 1992/93 river quality data and was validated with the new data monitored along the river from October 1993 to September 1995. The model was used to assess "good" and "bad" scenarios regarding extreme situations and comparing these with monitored data throughout the project period.

v) Blasting Vibration Modelling

Blasting vibration is caused by the imperfect utilisation of explosive energy released during blasting operations, leading to the radiation of the unused energy through the surrounding rock mass in the form of stress - strain waves. When these waves come into contact with a free face, physical motion results, as the energy induces oscillation in the ground surface. Over the last 30 years, increased environmental awareness and public complaints have introduced legislation to limit the maximum levels of vibration permitted by explosive operations, particularly for mining operations located adjacent to urban areas. Thus improved, predictive, and management control techniques are required.

The mechanism and nature by which explosives break rock is unproved, due to the character of the physical changes in the strain regime around the borehole as the explosive detonates. The extreme physical conditions, adjacent to the borehole, effect not only the nature of the seismic wave pulse but also effect the physical properties of the surrounding rock media and consequently the characteristics of the seismic source. Empirical, numerical and hybrid models have been used previously to estimate the nature of the radiation emitted from explosive columns in an elastic material.

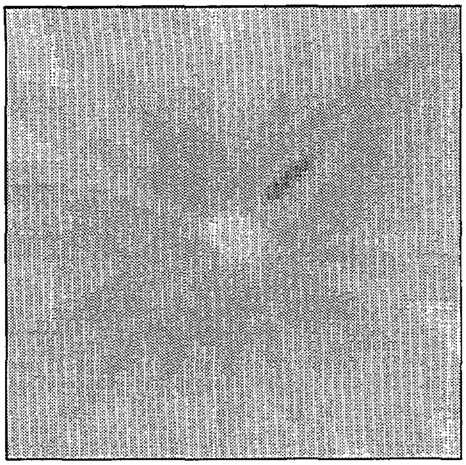
The thrust of the work carried out at Imperial College was based around measurement and numerical description of blast vibration, the analysis of this data and understanding, numerically, the effects of the signal path. A hybrid model that utilises monitored seismic data to estimate the spectral emission of a blast providing both frequency and magnitude information was developed and validated utilising the monitoring program at Tara which supplied valuable field results and measurements,

The main strength of the modelling concept introduced is the reduction in the amount of data required to produce results. Factors such as the local geology, on a macro scale, and explosive confinement can easily be accounted for. This is ideal in the case of Tara as the properties of the orebody, in which all the blasting occurs is similar, while the general layout and blast pattern (burden, hole diameter, explosive type, pattern etc.) all remain constant, The model directly allows for the following factors:

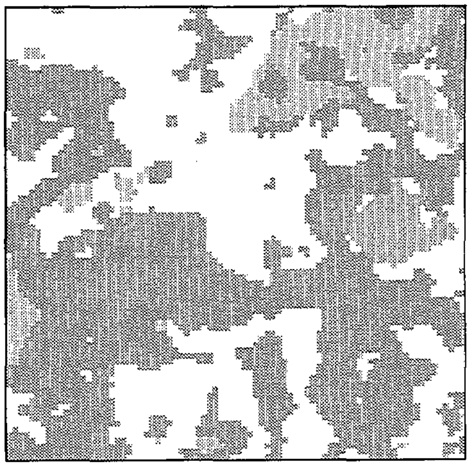
- Statistical timing variation
- Blast pattern induced directionality
- Local geological conditions
- Variation of seed charge weight
- Variation of blasthole charge weight

THE GRAPHICAL USER INTERFACE DEVELOPMENT AND SYSTEM INTEGRATION IN GIS

Recent developments in computer graphics and database management systems created the platform for the development of integrated environmental management systems. The spatial data handling and storage capabilities of Geographic Information Systems coupled with their ability to transform the original spatial data held in order to answer different queries has enabled the researchers at Imperial College to develop an environmental impact management system which integrates the simulation models developed in the project with a GIS under a Graphical User Interface (GUI).



(a)



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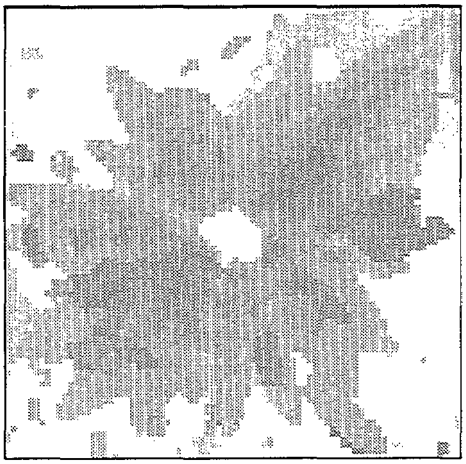

(c)

(a) Concentration contours in intervals of 0.2 g m^{-3}
(b) Index of vegetation sensitivity to air pollutant, 1 to 8
(c) Combined index of vegetation sensitivity with air pollutant levels, 1 to 50

Darker areas represent higher values

Figure 7: Air pollution - land use interaction analysis in GIS

The spatial data storage, manipulation and display capabilities of a GIS is best illustrated by an example such as that shown in Figure **7.** Here the continuous emission of gaseous particles from an elevated point source for a period of thirty days is modelled and displayed in GRID (Figure 7(a)). Figure 7(b) shows the relative sensitivity rating of vegetation to the particular pollutant studied and Figure 7(c) shows the relative levels of pollution impact predicted for the study area determined by map overlay analysis.

A Graphical User Interface is a spatial and object based interface with on-screen graphical representations of the available facility. It allows the user to utilise one or more 'models' integrated within a system, which would otherwise seem highly complicated at a basic command line level. The research team at Imperial College used ARC/INFO as the platform to develop the "*graphical user interface*" which drives the numerical models and facilitates environmental impact analysis. The GUI development was carried out using ARC Macro Language (AML), a programming language provided with ARC/INFO (Environmental S ystems Research Institute Inc, 1993).

Another ARC/INFO module used in producing the GUI is GRID. This is the raster data structure which divides the world into discrete uniform units called cells. Each cell represents a certain specified portion of the earth, such as a square kilometre and has a value corresponding to the feature or characteristic that it describes. The location is not defined as an attribute, but is inherent within the storage structure. The cells are organised into a Cartesian Matrix consisting of rows and columns as shown Figure 8. GRID allows the effective storage, manipulation and analysis of a continuous surface, i.e. pollutant concentration. Therefore, this method of storage is highly suited to output the results of the numerical models developed in this project (air quality, groundwater flow and quality, etc.). Besides the grid data, all other displays, such as maps and graphs are in vector format. These are all drawn using commands from the ARC/INFO ARCPLOT module.

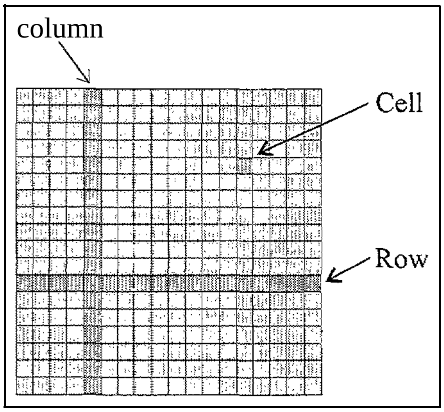

Figure 8: The Arc/Info GRID structure

The main objective of the GUI was to facilitate a seamless integration of a number of different simulation models with ARC/INFO ensuring that the GUI;

- allows the user to easily run any of the models, inputting the required data via menus, which may otherwise seem highly complicated,
- is able to produce a variety of outputs suitable for the results produced by different models,
- allows the user to view model results in an understandable, clear and precise way,
- allows access to data files from previous model runs,
- enables the graphical comparison of the results of several runs of the same model,
- makes it possible to manipulate results and view them in different ways, where possible, e.g. by reclassing the results, and
- provides help to the user all the way through, via help menus, so they can easily use the models to produce valid and meaningful results.

The *main menu* driving the environmental management system, together with the *map options* menu, displaying the *point source emissions* model results overlaid on Somincor map data using the GUI is presented in Figure 9. The environmental impact analysis tools provided in the GUI developed include grid display and manipulation tools; grid interrogation tools such as histograms, cell values, scattergrams, cell statistics; grid stacking and interrogation tools. An example use of the GUI tools for impact assessment is given in Figure 10. Here, the change in groundwater quality at a given level section over four years (or the change in groundwater quality with depth) modelled using the solute dispersion model developed at Imperial College is displayed using the *grid stacks* tool. The data presented in these stacks can be analysed for environmental impact using the *histogram*, *scattergram* and *composite graph* tools developed. For example, the use of the cross-hair and the composite graph tool will yield a line-graph representing the change in the selected grid value over time or in space within the stack displayed.

CONCLUSIONS AND FURTHER RESEARCH

This paper described the main components of an environmental simulation and impact assessment system developed under the EC Brite Euram Research Programme. The system utilises a Geographical Information System as its spatial database for input, output and spatial operations. A number of models for the analysis and modelling of blasting vibration, soil, groundwater, river and air quality were developed and integrated under a dedicated graphical user interface developed in ARC/INFO. Models developed were validated using field data from the partner mines.

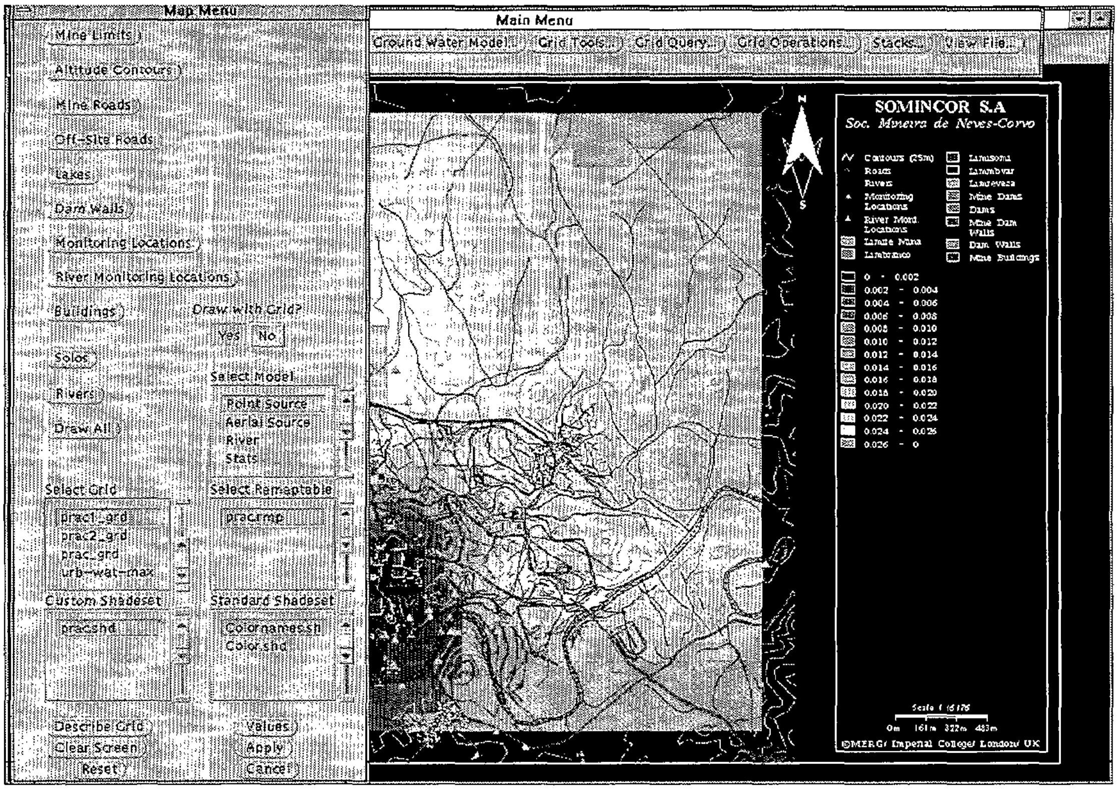

Figure 9: The graphical user interface illustrating the main menu and the map options menu which are used to access and display the air quality model results stored as ARC/INFO grid files together with the site map data.

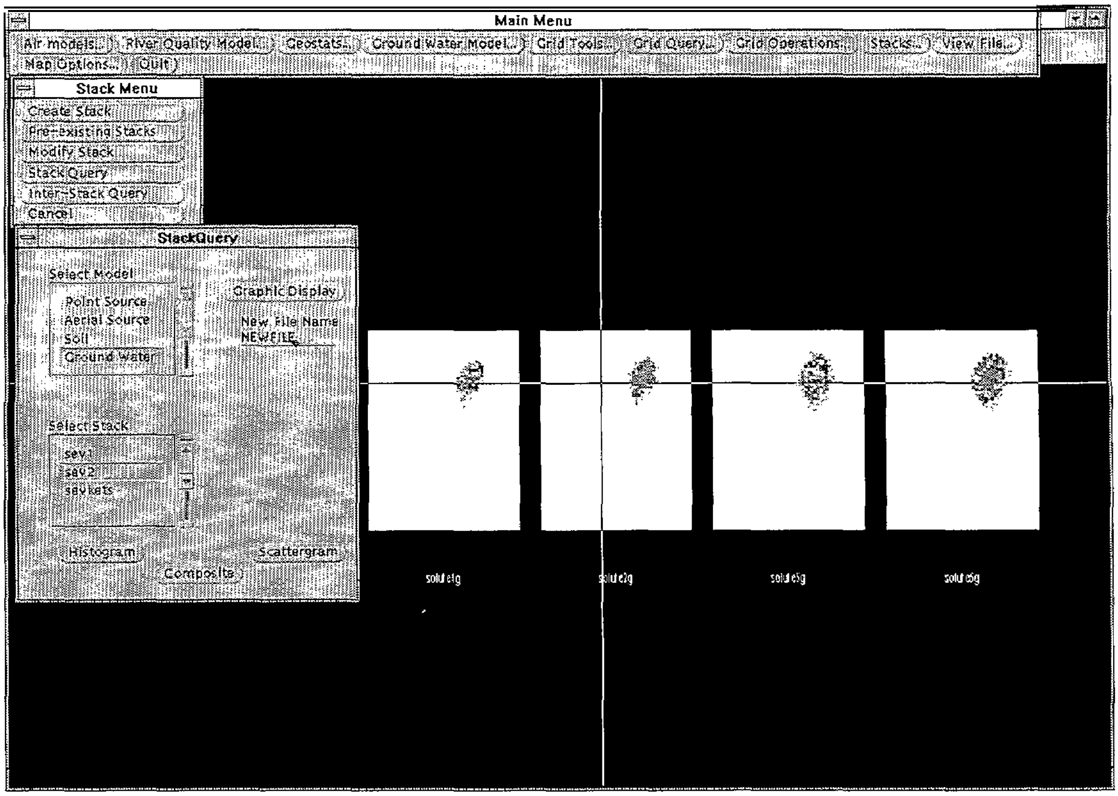

Figure 10: The use of GUI tools for the analysis of the change in groundwater quality in space and time: Solute dispersion model results displayed using the grid stacks tool.

Examples of different fields of application for the system developed are:

- Prediction of the temporal nature of environmental impacts using numerical simulation and the analysis of the interaction between spatial and non-spatial environmental attributes.
- Optimisation of location of plant, machinery and industrial activities.
- Interactive analysis of monitored environmental data.
- Preparation of comprehensive environmental impact statements, identification of critical areas, definition of preventative measures.
- Preparation of emergency action plans based on predictions, Quick reaction to cases of emergency through interactive analysis of environmental variables.

During the execution of the project, the partners identified a number of new research areas which would address the technical limitations of both hardware and software technology currently available to the mining industry. These areas of research areas follows:

1. The development of new generation water quality sensor systems which would adress the requirement to investigate innovative in-situ cleaning and anti-fouling measures in order to produce robust, small diameter and cost effective monitoring systems for piezometric wells.
2. The development of a robust and standardised sensor data acquisition and communications architecture suitable for wide area networks which would enable the installation of comprehensive and low cost of-the-shelf monitoring systems in small mines to meet the legislative requirements.
3. Research into Artificial Intelligence techniques for short term prediction of river water quality in order to overcome the limitations of stationary stochastic models and to enable automation in real-time river quality prediction and effluent discharge control. This area of research would involve fundamental, underpinning research into artificial intelligence techniques, downstream of industrial research projects.

The work required to address the problems described above was beyond the scope of this project (or the Workprogramme) as they are mostly associated with the environmental monitoring hardware technology, requiring considerable input and research by monitoring systems hardware manufacturers. However, it is believed that by addressing these issues in the future, the industry will improve upon the availability and reliability of environmental data which is one of the essential ingredients of an environmental management system *front end software* such as the system developed in this project. The development of such systems would complement the work carried out in this project and will provide the opportunity to establish totally automated real-time environmental monitoring and control systems for pollution prevention.

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