THE INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

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To promote international cooperation in solving problems arising from social, economic, technological, and environmental change

To create a network of institutions in the national member organization countries and elsewhere for joint scientific research

To develop and formalize systems analysis and the sciences contributing to it, and promote the use of analytical techniques needed to evaluate and address complex problems

To inform policy advisors and decision makers about the potential application of the Institute's work to such problems

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A COMPUTER-BASED APPROACH TO ENVIRONMENTAL IMPACT ASSESSMENT

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Foreword

Research on environmental problems, and the development of tools designed to understand these problems better and to solve them, are central components of IIASA's research agenda.

This report describes software tools for environmental impact assessment, merging IIASA's expertise in environmental problems with methodological developments in advanced computer and software technology. The paper was presented at a workshop on "Indicators and Indices for Environmental Impact Assessment and Risk Analysis," organized by the Institue for Systems Engineering and Informatics and the Environment Institute of the CEC's Joint Research Centre in Ispra, Italy.

The research described here draws on a series of research and development projects carried out by IIASA's *Advanced Computer Applications* group. Within the framework of environmental impact assessment, the paper addresses the issue of standards and indicators, and reviews methods and tools of impact assessment. It then describes a rule-based system for impact assessment, one of the tools developed at IIASA, and a number of interactive simulation models for air, surface, and groundwater quality for the prediction of environmental impacts.

The examples describe the integration of models and expert systems with various data bases and geographical information systems, as well as computer graphics for the visualization of information, problems and solutions that provide the basis for easy-to-use interactive software tools. The research results presented demonstrate the role and potential of advanced software tools in environmental systems analysis and impact assessment – key areas of IIASA's applied research.

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A Computer-Based Approach to Environmental Impact Assessment

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Keywords: Environmental Impact Assessment (EIA), Simulation Models, Expert Systems, Applied Artificial Intelligence, Environmental Modelling, Risk Analysis, Computer Graphics.

ABSTRACT

Human activities, in particular large-scale industrial, energy, construction, water resources, or agricultural projects, considerably affect the natural environment. Growing concern about these impacts and their immediate, as well as long-term, consequences, including risk involved with technological systems and the inherent uncertainty of any forecast, makes the prediction and analysis of environmental impacts and risks a task of increasing global importance.

Environmental Impact Assessment (EIA) requires the qualitative and quantitative prediction, assessment and evaluation of the impacts of human activities on the environment in terms of appropriate indicators. Various types of models are major tools for the prediction and analysis of these impacts. They must describe environmental systems in terms of those indicators that environmental law and regulations define and prescribe to evaluate the severity of impacts.

Numerical or symbolic simulation models and expert systems, implemented on computers, provide powerful and versatile tools for the assessment of potential impacts of planned policy or action. Designed to describe, simulate and evaluate impacts that are not yet observable or lend themselves to data collection, simply because the corresponding action is only in the planning stage and the impacts are thus in the future, models can also operate in data-poor situations, analyzing scenarios of sets of assumptions at least at a screening level. The ability to provide useful information in data-poor situations is especially valuable in developing countries where data collection programmes and monitoring schemes may just be starting and reliable background information is usually scarce.

Methods and procedures for EIA, the relationship between indicators, standards, and methods, and in particular the use of computer-based tools, models and expert systems, that combine traditional modelling approaches with new techniques of artificial intelligence (AI) and dynamic computer graphics, are demonstrated by a number of application examples in air, surface and groundwater modelling, as well as risk analysis. Drawing on application examples from Europe, the United States, China, India and Thailand, the paper discusses some general features and emerging trends in EIA.

INTRODUCTION

Human activities, in particular large scale industrial, energy, construction, general infrastructure, water resources, or agricultural projects considerably affect the natural environment. These impacts occur during the construction phase, the operational lifetime of a project, and in many cases, as with waste disposal sites, may continue after closure of a plant or site. Consumption of natural resources, including space, water, air, and biota, and the generation of wastes including the dissipation of energy and noise, usually lead to a degradation of the natural, and thus, directly or indirectly, the human environment.

Environmental considerations are becoming increasingly important components of planning, and environmental concerns and issues are increasingly shaping the political agenda on the local, national, and even global scale.

Many countries, pioneered by the 1969/70 *National Environmental Policy Act* (NEPA) of the United States, have introduced appropriate legislation calling for the explicit consideration of environmental impacts in the planning and decision-making process for large projects. For an international comparison of EIA procedures and examples from various countries, including developing countries, see, eg., Ercman, 1977 for Europe; Munn, 1979 for an international overview including the CMEA countries; Gresser, Fujikura and Morishima, 1981 for Japan; Clark, Gilad, Bisset et al., 1984 for developing countries, or the Asian Development Bank (ADB, 1988) for selected member countries.

The landmark legislation of NEPA contains three major provisions (Liroff, 1976):

1. It establishes environmental quality as a leading national priority by stating a national policy for the environment;
2. It makes environmental protection part of the mandate of all federal agencies, establishing procedures for incorporation of environmental concerns into agency decision making. In particular, it requires federal agencies to prepare an environmental impact statement (EIS) for major actions or projects that can affect the environment;
3. It establishes a Council on Environmental Quality in the Executive Office of the President to oversee and coordinate all federal environmental effort.

Environmental Impact Statements, as regulated by the act, must contain:

- a description of the proposed action, its purpose, and a description of the environment affected;
- relationship to land-use plans, policies, and controls for the affected areas;
- probable environmental impacts, positive and negative, direct and indirect, and possible international implications;
- discussion of alternatives;

- probable negative impacts that cannot be avoided or mitigated;
- relationship between local and short-term use and long-term considerations;
- irreversible commitments of resources;
- description of federal actions to mitigate and offset adverse effects;
- inclusion of comments from reviewers.

Numerous regulations or guidelines for environmental impact statements in many countries worldwide follow this basic pattern, with some variations. One of the more recent, is the Council Directive of the Commission of the European Communities (CEC, 1985). The Directive on the assessment of the effects of certain public and private projects on the environment (85/337/EEC, June 1985) requires comprehensive environmental assessments of projects and installations, which, by virtue of their nature, size or location, are likely to have significant effects on the environment. A list of projects that will require an impact statement include oil refineries, thermal power stations, radioactive waste disposal facilities, steel mills, asbestos-related industries, integrated chemical installations, motorways, long-distance railways, and airports (meeting certain size criteria), trading ports and inland waterways, and finally, waste disposal facilities A second list of about 80 project types, all industrial activities with less than a dozen non-industrial projects, specifies optional assessment "...where Member States consider that their characteristics so require". A broad analysis of the direct and indirect effects on people, environment, property and cultural heritage is foreseen and the evaluation of alternatives is required.

The Directive is typical of comparable legislation in that it provides a basic policy, a set of broad objectives, some generic instructions, in particular for which types of activities or installations an impact assessment is required, but very little specific guidelines, indicators, or hard and fast rules as to how to make an assessment. All that is required is that the assessment is made prior to consent and submitted to the competent authorities for a given project, but guidelines do not exist for the process of the assessment.

There is however, a large body of related legislation and guidelines that defines various standards, such as the various environmental quality standards and guidelines defined, for example, by WHO (eg., Koning, 1987), the EEC, and national institutions such as the USEPA. Each of them provide references and indicators against which predicted environmental impacts, but also project characteristics, may be compared: eg., Indian Standards (IS: 8829-1978, Government of India, 1987) define locational restrictions for thermal power plants (TPS): an exclusion zone around a TPS of 1.6 km is required (with the stack to be located in the leeward section with respect to the predominant wind direction) for residential/commercial developments, subject to "strict land use zoning". Further, a 25 km radius around a TPS should not include:

1. Metropolitan cities;
2. National parks and wildlife sanctuaries;

3. Ecologically sensitive areas such as tropical forests, biosphere reserves, national parks and sanctuaries, important lakes and coastal areas rich in coral formation.

It is interesting to observe, however, that environmental standards used in individual countries and also their definition, eg., of measurement or an averaging period, differ; since we must assume that no country is "right" and the others are "wrong", this adds an interesting perspective to the interpretation of indicators, guidelines and standards.

As an example, the table below summarizes national standards for one of the probably best researched and most regulated air pollutants, SO_2.

Country	Definition	value μgm^{-3}
Belgium	annual arithmetic mean of 24 hour means	100
Canada	maximum annual arithmetic mean	60
Denmark	97-percentile of 24 hour means	300
France	annual arithmetic mean	70
FRG	annual arithmetic mean of 1/2 hr means	140
India	long term mean (industrial and mixed use area)	120
	long term mean (residential areas)	80
	long term mean (sensitive areas)	30
Italy	maximum 24 hour mean (for licensing)	390
	median of 24 hour means (guideline)	80
	98-percentile of 24 hour means	250
Japan	24 hour mean of 1 hour means	106
Netherlands	median of 24 hour means	75
	95-percentile 24 hour means	200
	98-percentile 24 hour means	250
Spain	maximum 24 hour mean	400
	maximum annual arithmetic mean	150
Sweden	24 hour mean	300
	arithmetic mean for winter season	100
Switzerland	annual arithmetic mean	60
	95-percentile of 1/2 hour means	300
Thailand	annual geometric mean	100
	24 hour mean	300
United Kingdom	annual arithmetic mean of 24 hour means	60
	98-percentile of 24 hour means	200
USA	annual arithmetic mean	80
EEC	median of 24 hour means	80/120
WHO	annual mean	50
	24 hour mean	125

Sources: Meinl and Münch, 1985; WHO, 1987; Government of India, 1987.

On the other hand, for example, a substance such as cadmium is regulated by the EEC in at least 17 Directives, including limit values for the discharge from a number of industrial activities (von Moltke et al., 1985).

The lack, or the profusion, or the uncertainty of data, standards, indicators and indices that should be used for the assessment process, as well as the lack of clear guidelines for the procedure and the ultimate audience, leaves two major domains that will require further interpretation and special attention:

1. What to look for, what the potential significant impacts could be, and how these possible impacts should be predicted and assessed, ie., in terms of which indicators: what should be described, measured and predicted;

   the EEC Directive, for example, lists a a number of areas that need to be covered: population, fauna, flora, soil, water, air, climatic factors, material assets, including the architectural and archeological heritage, landscape, and the inter-relationship between these factors.

   In a listing quite similar to the NEPA's requirements the EEC Directive lists what needs to be described as follows:

   - the project itself in its physical characteristics, production processes, and wastes and emissions generated;
   - an outline of alternatives, if any;
   - the expected significant environmental impacts on the factors listed above;
   - a description of the likely significant effects of the project resulting from its very existence; the use of natural resources; emissions, nuisances, and wastes;
   - the Directive specifies that the description should cover direct and indirect, secondary, cumulative, short-, medium-, and long-term, permanent and temporary, positive and negative, or, in short, all effects of the project;
   - it also requires a description of the forecasting methods employed, as well as an indication of technical deficiencies or lack of know-how and general problems in the compilation of the assessment information;
   - a description of proposed mitigation measures.

2. How the impact statement is to be presented and results communicated. The purpose for which the information is to be used defines the requirements in terms of scope and coverage, presentation style, but also resolution, precision, and reliability, or, more generally, quality of information (for a discussion of some of these concepts see the papers of Funtowicz and Ravetz, this volume).

   Regarding presentation and audience, the EEC Directive makes a few specific provisions: it calls for a non-technical summary of the above points, implying that the basic assessment could or should be fairly technical in nature.

   It also indicates that while the developer has to prepare the impact assessment and make it available to the competent authorities, the public concerned should be given the opportunity to express an opinion before the project is initiated. The specific rules for this information and consultation process are the responsibility of the member states, which may determine *inter alia*, the way in which the public is to be consulted and informed; methods listed include bill-posting, publication in local newspapers, and the organization of exhibitions with plans, drawings, tables, graphs, and models.

While the first problem domain, what to assess, is a more scientific one, the second, how the results should be presented, is largely in the realm of politics and applied psychology. It does, however, have considerable influence on the first one, determining the scope and and level of detail of the assessment. Both depend on the descriptors and indicators used, and in turn, define or imply what should or could be used for the assessment and its presentation.

Impact Assessment: Methods and Tools

Environmental Impact Assessment (EIA) requires the qualitative and quantitative prediction, analysis, and assessment of the impacts of human activities on the environment. Ideally, an integrated part of planning from the earliest stages, environmental considerations should be given equal weight with economic and technological considerations, including the often long-term environmental, and thus social, costs in a project's assessment, and the minimization and mitigation of environmental costs as part of the design.

Depending on the regulatory framework, the reason and the objectives of the EIA (see, for example, Frieden, 1979 for a more critical evaluation of uses and abuses of EIAs) it has to describe the project and its environment, which is usually rather easy and straightforward; it also needs to predict significant impacts on the environment, which is neither easy nor straightforward, and in fact already presupposes an assessment of the significance of an impact, which is only in part a scientific problem.

For any major development project, and industrial development in general, impacts on the environment include:

- land use and pollution during the construction of a project or an industrial plant, including temporary secondary problems caused by construction teams, transportation, equipment, etc.;
- pollution of the environment during operation of the industry due to emissions of wastes and byproducts to air, water, and soils, possibly causing environmental and human health hazards, as well as due to the transportation of raw materials and finished goods to and from the industrial site;
- pollution of the environment and acute hazards to man during abnormal operating conditions and accidents such as explosions or toxic spills;
- environmental degradation due to the consumption of renewable and non-renewable natural resources required for the production process;

- secondary environmental impacts due to changes in land use, population density, and the socio-economic structure around an industrial plant;
- secondary environmental impacts due to the use and eventual discarding of the industrial product.

Comprehensive impact assessment, however, should also look at the positive impacts, ie., environmental improvements that are possible directly (eg., material substitution) or indirectly (due to increased revenues) as a consequence of a new industrial activity. Further, impact analysis should be a comparative, not an absolute assessment–alternatives should be compared.

Methods for the assessment of environmental impacts range from simple checklists and qualitative impact matrices to much more complex computer-based approaches using, eg., simulation modeling and optimization, geographical information systems, or expert systems techniques. However, the legal, procedural and institutional components are very important aspects that may differ widely from country to country and from project to project.

Methods that do have a track record of repeated use, and have been described in the respective literature, include, for example:

- Graphic overlay methods (McHarg, 1968; Dooley and Newkirk, 1976)
- USGS Matrix (Leopold, Clarke, Hanshaw et al., 1971)
- Network Analysis (Sorensen, 1971; Sorensen, 1972)
- Cross-impact Simulation (Kane, 1972)
- EES Environmental Evaluation System (Dee et al., 1973)
- HEP Habitat Evaluation Procedures (US Fish and Wildlife Service, 1976)
- Decision Analysis (Keeney and Raiffa, 1976)
- WRAM Water Resources Assessment (Solomon, Colbert, Hansen et al., 1977; Richardson, Hansen, Solomon et al., 1978)
- EQA Environmental Quality Assessment (Duke et al., 1977)
- METLUND Landscape Planning Model (Fabos et al., 1978)
- Goals Achievement Matrix (Hill, 1968)
- WES Wetland Evaluation System (Galloway, 1978)
- AEAM Adaptive Environmental Assessment (Holling, 1978)
- EQEP Environmental Quality Evaluation Procedure (Duke, 1979)

- CBA Cost–Benefit Analysis and related methods; numerous authors
- Interactive Systems Analysis and Decision Support (Fedra, Li, Wang et al., 1987; Fedra, Karhu, Rys et al., 1987).

In terms of causality considered, methods are based on checklists or questionnaires, cross impact matrices, or complex network analysis involving second and higher-order effects and feedback. In terms of formats they range from narrative and qualitative descriptions to various attempts at quantification and formalizations, from monetization to graphical methods. In terms of procedures, they may involve experts or expert teams and panels, workshops, or public hearings to court proceedings. In terms of tools, they may be based on guidelines and manuals or involve computer-based tools. Usually, any practical impact assessment involves a combination and mixture of several such components.

EIA procedures and approaches are often organized around checklists of data collection and analysis components (eg.,De Santo, 1978; Munn, 1979; Bisset, 1987; Biswas and Qu, 1987). Basic components of the assessment process are:

- a description of the current environment, which usually includes such elements as rare or endangered species, special scenic or cultural components;
- a description of the proposed project or activity, covering technological, socio-economic, and administrative and managerial aspects;
- a description of expected impacts, with emphasis on irreversible change and the consideration of mitigation strategies and project alternatives, including the alternative to not undertake the project;
- and, depending on the mandate given, a comparative evaluation of options.

Obviously, the prediction of future impacts, and deciding which of them are to be considered significant, is the most difficult part. Approaches range from purely qualitative checklist-based matrix approaches (Leopold, Clarke, Hanshaw et al., 1971), expert panels and workshop techniques (Holling, 1978), system diagrams and networks, to various computer-based modeling techniques (for more recent surveys see Gray and Stokoe, 1988; Fedra, 1988a) and any combination of these approaches. However, most of the accepted and routinely used tools of EIA are not based on the use of computers, but on more-or-less formalized qualitative assessment procedures. Also, while most methods are somewhat general, they were usually developed in a rather specific context. Few of the methods listed above are associated with concrete tools: they are approaches rather than tools, and where tools have been developed, they have been adapted to very specific applications.

One of the most flexible and universal tools of impact assessment are certainly models and related information and decision support systems, implemented on computers. In a number of countries, and covering a broad range of project types or applications areas for environmental impact analysis in a broad sense, IIASA's *Advanced Computer Applications* (ACA) project has developed or adapted and implemented models with an interactive, graphical user interface, integrated with data bases and geographical information systems, and using embedded AI technology. Selected examples are described below in more detail. They demonstrate the potential of more modern, computer-based tools and approaches to impact assessment in a wide range of institutional and regulatory settings.

The use of computers as a major tool for EIA is by far not as common as it could or should be. Problems, in particular in developing countries, range from the availability of the necessary computer hardware to the expertise in developing, maintaining, and using more-or-less complex software systems (eg., Ahmad and Sammy, 1985). Further, lack of quantitative data is often cited as a reason for not using computers and simulation models.

However, the availability of increasingly powerful and affordable computers grows rapidly (Fedra and Loucks, 1985; Loucks and Fedra, 1987), and so does computer literacy among technical professionals. Even very powerful super-micro computers have become easily affordable, and technical workstations are approaching the price class of personal computers. And many of the reasons cited for not using computers in environmental assessment are in fact problems that the computer can help overcome. Experience shows, however, that the general level of technical development of a country is not necessarily an indicator of the potential use of computer-based methods. It still appears to be institutional and also to a large degree, personal attitudes that determine the use of modern information technology in impact assessment. Any institutional change needs a long time, and needs a champion within the institution. However, with increasing computer literacy, more and more people gaining access to computers at their workplace, and with the emergence of more easy-to-use smart software, computer-based methods are becoming accepted tools for environmental impact assessment in many countries.

Assessment, Prediction and Communication

A classical tool, and probably, including all its offspring, one of the most widely used ones, is the Leopold matrix (Leopold, Clarke, Hanshaw et al., 1971); it is based on a matrix of 100 actions or project elements versus 88 environmental conditions that might be affected.

In addition to being unwieldy however, it requires considerable expertise on the part of the user to determine which (usually rather small subset) of action–environment combinations will be relevant, and what the expected impact might be.

Clearly, this can be improved upon by a computer implementation that:

- shows only relevant action–environment pairs, depending on the project characteristics and the location of the project;
- offers help in determining whether or not a significant impact can be expected for a given combination, based on the various project and environment characteristics the user might have information on.

A rule-based impact assessment system

The system described below has been implemented as a rule-based expert system, using hierarchical checklists to perform environmental impact assessment; the current system is geared towards the assessment of river development projects. The structure of the assessment process is based on the Asian Development Bank's Environmental Guideline Series (ADB, 1988). The indicators used to assess a given project are based on checklists of items specific to the project type, covering environmental as well as selected socio-economic topics, each indicator being rated on a qualitative scale, from not significant to major.

In the current prototype a system of hierarchical checklists is used with a rule-based deduction process including a recursive explain function WHY to assist in the assessment, as well as the possibility to use the rule-based deduction in a tutorial mode to check user-defined answers with CHECK HYPOTHESIS. A top-level summary, using weights on the individual subproblem assessments, ie., indicator scores, to generate a summary structured as eight basic strategic indicators, has also been implemented (Figure 1).

As an alternative entry point to the system, a projects data base, where project descriptors can be edited directly, is accessible from the top level. As an important feature of the system, all environmental or project descriptors can be represented either in numerical or symbolic form: depending on the amount and quality of information available, the analyst can use either representation form, with defaults coupling the numerical representation in terms of ranges with the symbolic, linguistic description (Figures 2 and 3).

In addition, basic elements of overlay methods, based on an implementation of geographical data bases and dedicated GIS functions, have been implemented. The GIS coupling also allows direct use of spatial data in the inference process.

The expert system proper is entered via a problem selector. Available projects, as well as an empty template New Project are offered. The analysis can be started in two different ways: via the project summary evaluation option, or through the basic problem class-oriented subproblem checklists. Either way can be chosen, and both approaches are fully interchangeable, so that the analyst can switch from one mode to the other.

At the project summary level, for any specific project (one of a project type or class), the expert system establishes a number of strategic goals or questions for the overall environmental review criteria that the system uses to summarize the assessment for a given project. The summary evaluation criteria or indicators implemented in the river basin development application are:

- Unwarranted losses in precious natural resources
- Unwarranted accelerated use of natural resources

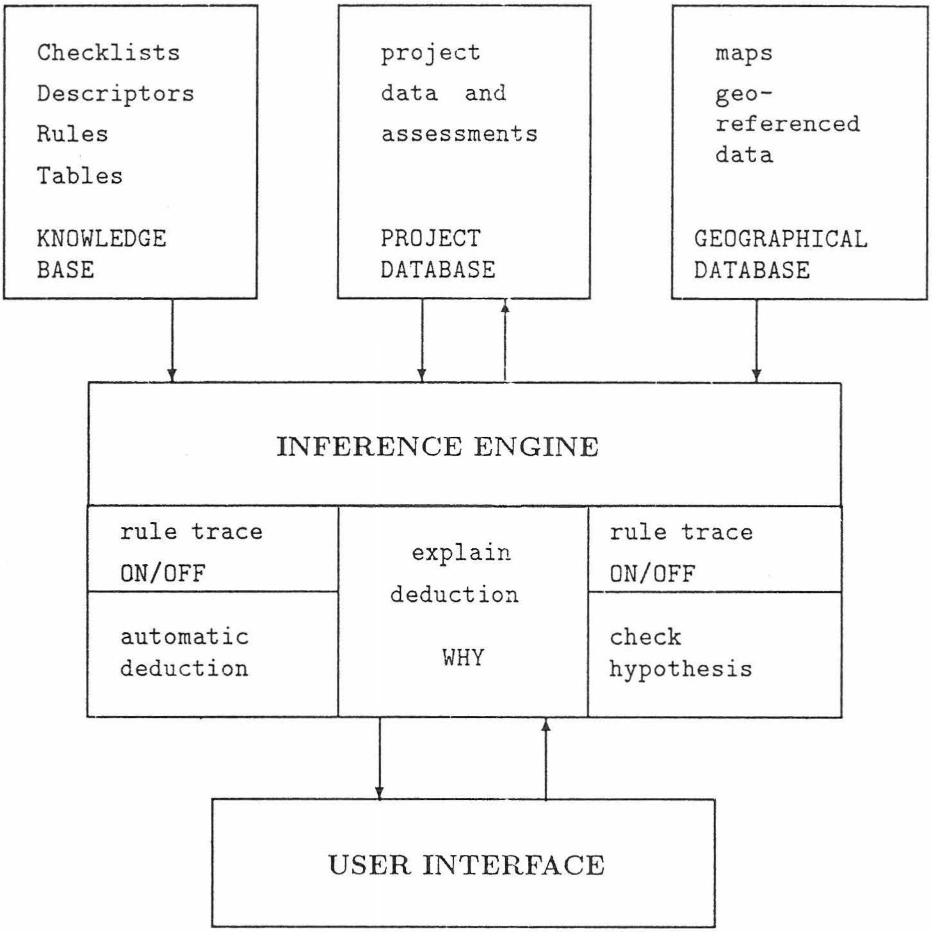
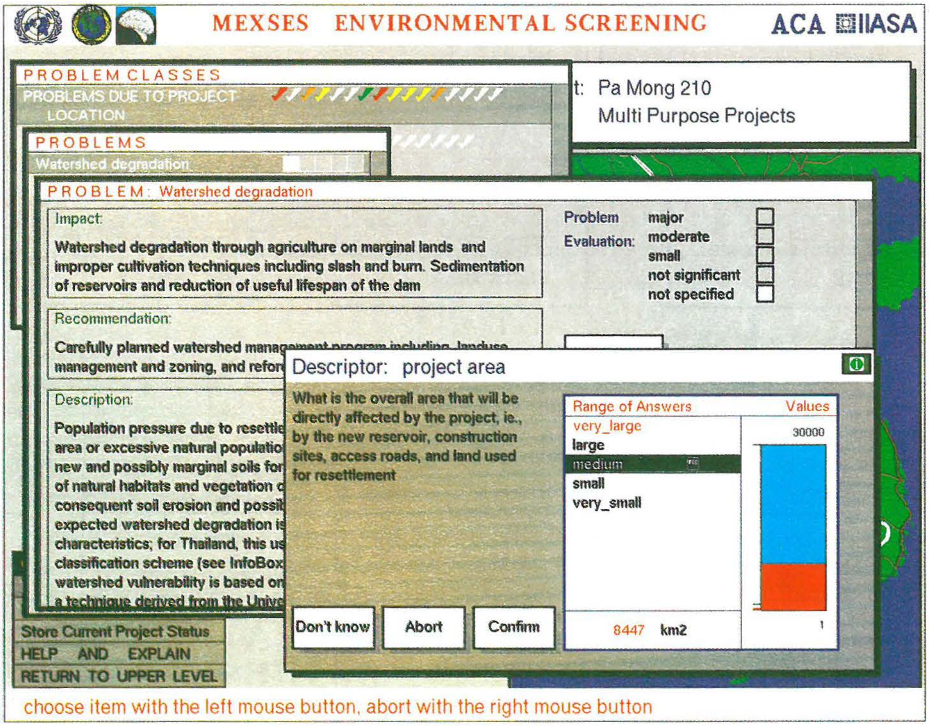


Figure 1: Structure and functions of the rule-based impact assessment



t: Pa Mong 210
Multi Purpose Projects

PROBLEM: Watershed degradation

Impact:

Watershed degradation through agriculture on marginal lands and improper cultivation techniques including slash and burn. Sedimentation of reservoirs and reduction of useful lifespan of the dam

Recommendation:

Carefully planned watershed management program including landuse
management and zoning, and refor

Description:

Population pressure due to resettle
area or excessive natural populatio
new and possibly marginal soils for
of natural habitats and vegetation c
consequent soil erosion and possib
expected watershed degradation is
characteristics; for Thailand, this us
classification scheme (see InfoBox
watershed vulnerability is based on
a technique derived from the Unive

Problem Evaluation:
major ☐
moderate ☐
small ☐
not significant ☐
not specified ☐

Descriptor: project area

What is the overall area that will be directly affected by the project, ie., by the new reservoir, construction sites, access roads, and land used for resettlement

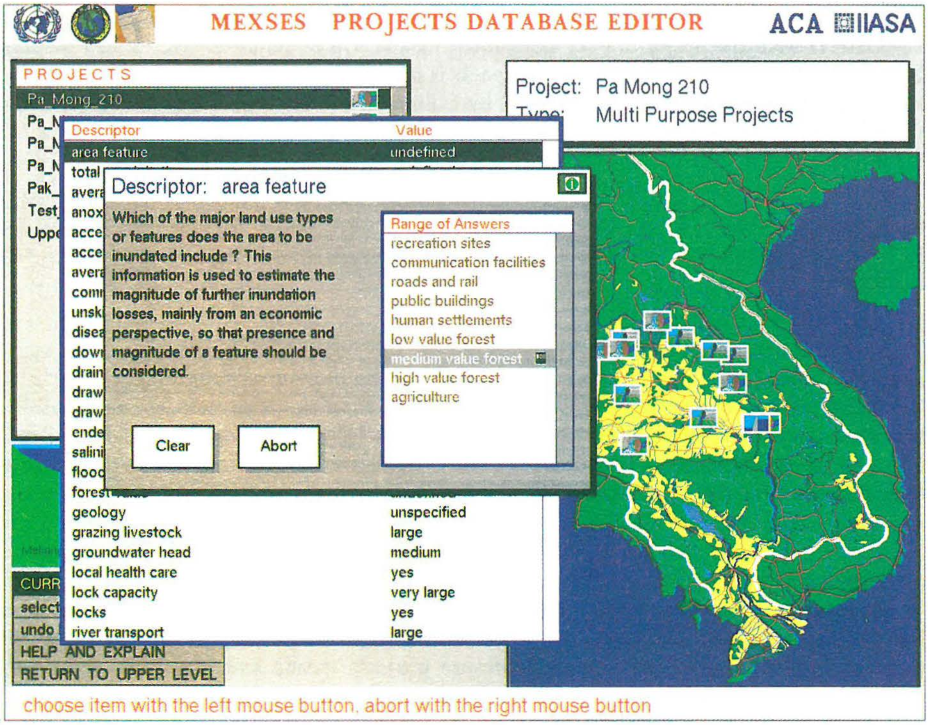
Range of Answers	Values
very_large	30000
large	
medium	
small	
very_small	1
8447 km2	

choose item with the left mouse button, abort with the right mouse button

Figure 2: Text-oriented user interface to the environmental screening expert system

- Unwarranted hazards to endangered species
- Unwarranted environmental degradation
- Unrealized resource utilization potential
- Undesirable land use development, urbanization
- Increased environmental hazards and vulnerability
- Widening of affluent/poor income gap
- Impacts on the overall food production and trade balance situation
- Unrealized socio-economic enhancements.

The overall indicators cover physical and ecological, as well as socio-economic aspects. Overall review criteria are established as a weighted average of a set of lower-level checklist results deemed of relevance in the context of the overall criteria. Each lower-level checklist



Project: Pa Mong 210
Type: Multi Purpose Projects

Descriptor: area feature

Which of the major land use types or features does the area to be inundated include ? This information is used to estimate the magnitude of further inundation losses, mainly from an economic perspective, so that presence and magnitude of a feature should be considered.

Descriptor	Value
area feature	undefined
geology	unspecified
grazing livestock	large
groundwater head	medium
local health care	yes
lock capacity	very large
locks	yes
river transport	large

choose item with the left mouse button, abort with the right mouse button

Figure 3: Defining a descriptor value at the project data base level

can contribute to more than one of the review criteria, and it can contribute to each or any of them to a different degree. This degree is expressed as a simple weighting factor, that specifies the relative contribution a given assessment result for a specific checklist will have on the overall review criteria.

These aggregated indicators or environmental review summary criteria are evaluated in terms of qualitative impact levels, namely

not significant — small — moderate — major.

Depending on the result of the aggregation and top-level evaluation procedure (which is based on the completed analysis of the lower-level checklists and problems discussed below), various concluding recommendations are offered, again derived from a set of rules based on the intermediate assessment results:

For example, if more than one of the eight top-level criteria are found to be a major problem, a complete and detailed environmental impact assessment with special emphasis on the criteria with the major impact assessment results will be required. No further display of the criteria with moderate or small impacts is provided at this level. The lower-level assessment results, however, can be viewed by calling up the respective subproblem listings for each of the top-level criteria. If only one of the top-level aggregated impacts is major, a complete and detailed assessment for this topic is recommended. This is combined with a recommendation for a more detailed assessment of all categories with a moderate impact level. In the associated information box, a listing of all recommendations referring to the subproblems that contribute significantly to the respective top-level evaluation are displayed.

If the evaluation of these subproblems, however, has not yet been completed, the summary evaluation level can be used as an entry into the individual subproblem checklists. The same evaluation mechanism can be entered via the **Environmental Checklists** option, this time organized by problem classes: They include **Problems due to Location**, **Planning and Design Problems**, **Problems during the Construction Phase**, **Problems during Project Operation**, and finally, **Environmental Enhancement Measures**, which looks at possible enhancement or mitigation strategies.

This second tier of assessment is based on an adaptive checklist approach, again specific to the project type. Project types covered in the prototype are, eg., reservoirs and dams, hydropower projects including transmission lines, irrigation projects, fisheries and aquaculture, and could also include infrastructure projects (roads and highways, sewerage, water supply, etc.), navigation, erosion control, etc. The checklists are designed to elicit more detailed information about the project and its expected environmental impacts, in an attempt to deduce answers which can ultimately be aggregated into the top-level questions and review criteria.

Subproblems or basic indicators covered in the checklists include, for example, impact from or in terms of:

resettlement;

watershed degradation;

encroachment upon precious ecosystems;

encroachment on historical/cultural values;

watershed erosion;

reservoir siltation;

impairment of navigation;

changes in groundwater hydrology, waterlogging;

seepage and evaporation losses;

migration of valuable fish species;

inundation of mineral resources/forests;

other inundation losses and adverse effects;

earthquake hazard and

local climatic change.

Where the necessary answers to the items on the checklist cannot be provided by the analyst directly with sufficient certainty ie., choosing one of the impact descriptors ranging from not significant to major, the third level of assessment is triggered. This starts a set of rule-based assessment tools that attempt to provide the analyst with a system-generated answer. Thus, unsatisfied goals at any level are decomposed into a set of sub-goals at the next lower level, which are then analyzed in an attempt to satisfy the respective higher-level goal.

The analyst can choose/set a value and then ask the system to check his "hypothesis". This triggers a backward chaining inference system that will attempt to establish all the necessary preconditions to the specifications formulated by the analyst as the hypothesis. If the required "facts" can not be confirmed, the inference procedure will ask the user the necessary questions. As a final result, the user's assessment will either be confirmed or rejected. Alternatively, the analyst can start a forward-chaining inference procedure, where the system will reason from the available data to arrive at a classification of impacts. Again, missing information will have to be supplied by the analyst in a question–answer dialog (Figure 3).

The answers the analyst provides to the various questions posed are taken from a menu of possible answers, offered by the system from its knowledge base. Most descriptors or variables used can be symbolic as well as numeric, and the user can choose the appropriate format depending on the information at hand; defaults associated with the various symbolic labels are offered, and an additional layer of context-sensitive help, explaining the various terms and concepts as well as the background for each question, the range of possible answers, and illustrative examples are provided in the graphical interface.

Using information that is likely to be available at an early project state, the system will attempt to determine the expected severity of a given subproblem such as, eg., watershed erosion, by using rules that, for example, consider climatic and topographic data, soil and slope conditions, vegetation cover and land use, management practices, etc.

Auxiliary software also includes basic data manipulation, analysis, and display facilities, including topical map drawing and processing for overlay analysis techniques, based on a DLG (USGS Digital Line Graph) derived data representation compatible with Arc/Info data formats.

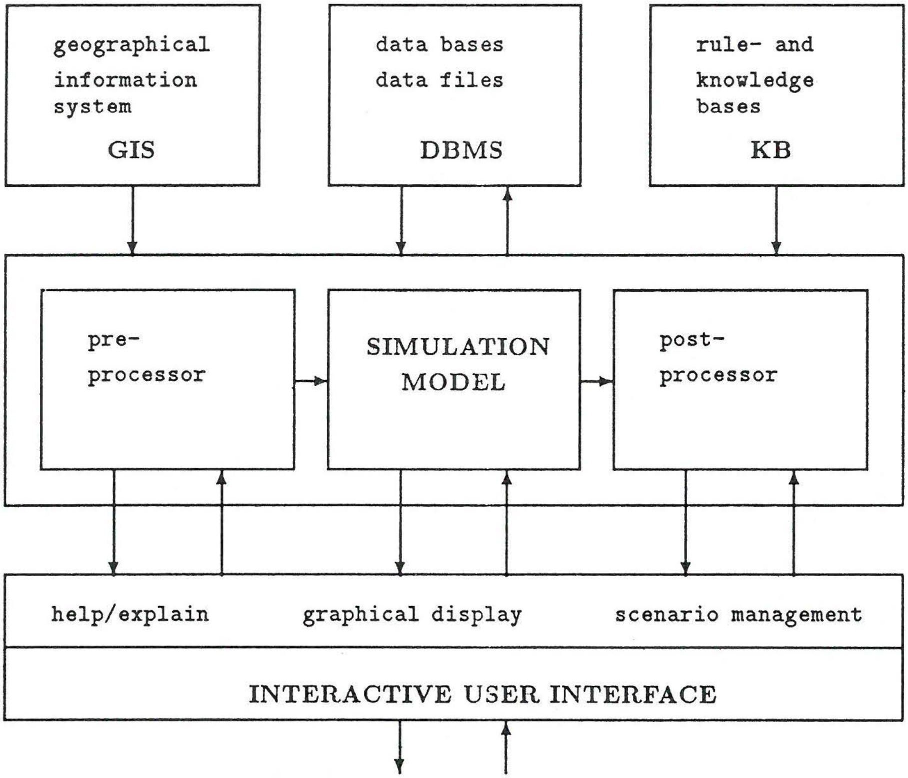
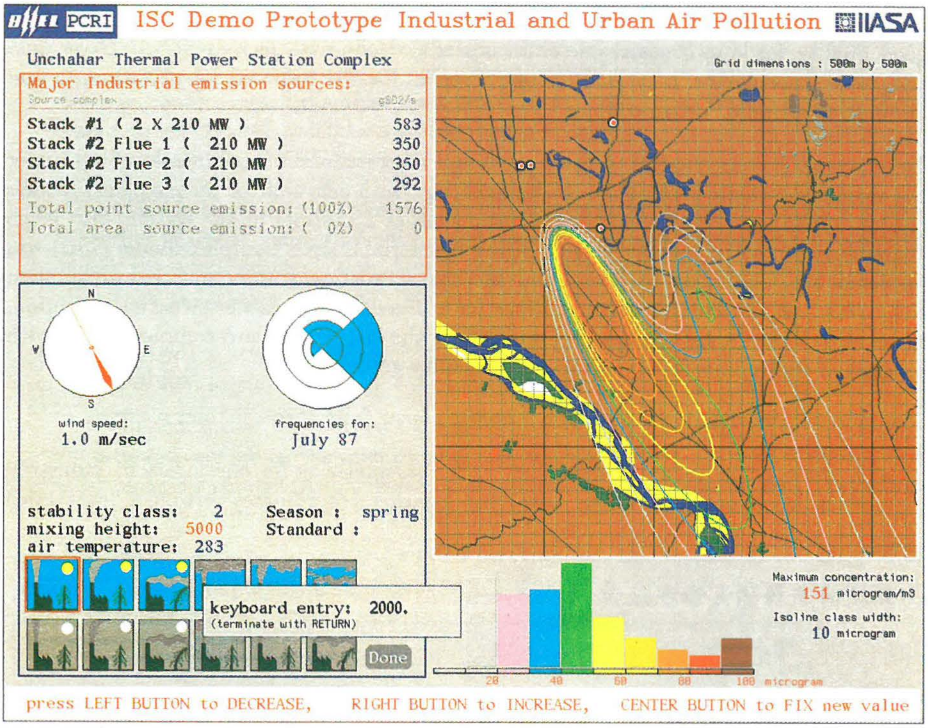


Figure 4: An integrated framework for interactive modeling

Simulating Environmental Impacts

Once the individual problem areas have been defined at the screening level, individual impacts may need to be predicted using somewhat more detailed numerical methods and simulation tools. Using concepts of *embedded AI* coupled with more traditional methods of *applied systems analysis* and *operations research*, these simulation and optimization tools are designed to provide easy and direct access to scientific evidence, and allow the efficient use of formal methods of analysis and information management by *non-technical* users as well. The application examples from Europe, the United States, People's Republic of China, India, and Thailand discussed below, cover air, surface and groundwater modeling (Figure 4).

The indicators used in the various simulation models, are, at this more technical level, usually well defined in the respective regulations and legislation (compare the table on SO_2 air quality standards above). They are either directly computed by the individual



ISC Demo Prototype Industrial and Urban Air Pollution

Unchahar Thermal Power Station Complex

Grid dimensions : 500m by 500m

Major Industrial emission sources:

Source complex	gSO2/s
Stack #1 (2 X 210 MW)	583
Stack #2 Flue 1 (210 MW)	350
Stack #2 Flue 2 (210 MW)	350
Stack #2 Flue 3 (210 MW)	292
Total point source emission: (100%)	1576
Total area source emission: (0%)	0

wind speed: 1.0 m/sec

frequencies for: July 87

stability class: 2

mixing height: 5000

air temperature: 283

Season : spring

Standard :

keyboard entry: 2000.
(terminate with RETURN)

Maximum concentration: 151 microgram/m3

Isoline class width: 10 microgram

press LEFT BUTTON to DECREASE, RIGHT BUTTON to INCREASE, CENTER BUTTON to FIX new value

Figure 5: Air quality modeling: isoline display of ground-level concentrations

models in terms of environmental concentrations of pollutants over space and time, or derived from these computed values.

Air Quality Models:

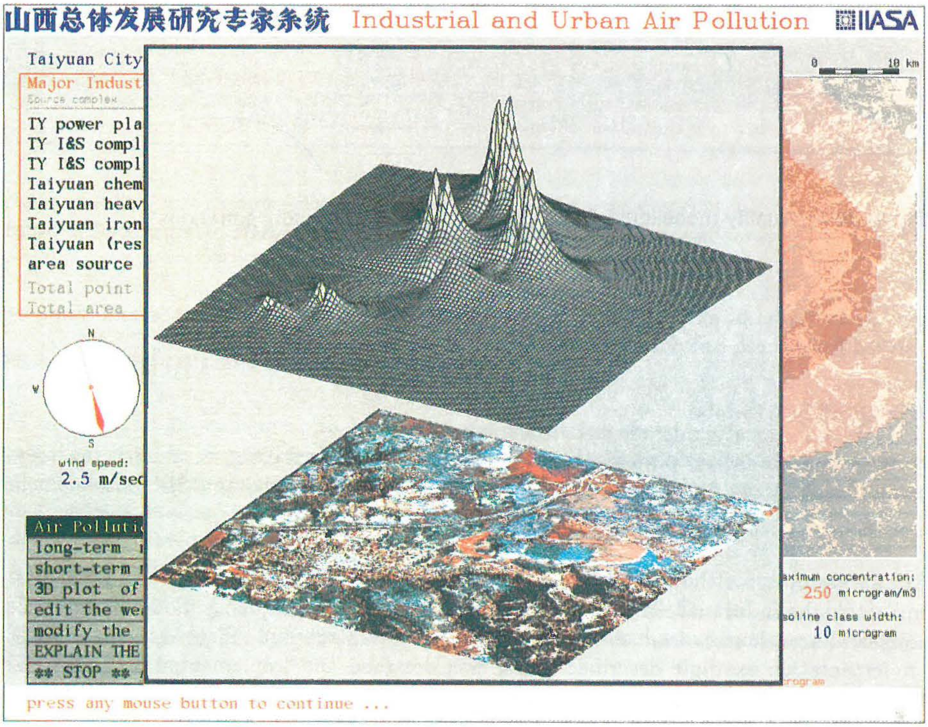
A number of atmospheric simulation models, including several Gaussian models for buoyant or heavy gases and dust, local Lagrangian and box models, and 2D finite-element models have been developed and implemented in several case studies.

As one example, for the regional to local scale, and for continuous rather than accidental emissions, the Industrial Source Complex model, a Gaussian air quality model for multiple point and area sources from the UNAMAP system, was adapted (Figures 5 and 6). The implementation example described below was designed and implemented for industrial centers in the People's Republic of China. Another implementation of the same model with a modified interface and specific handling of local meteorological data was developed for the City of Vienna, and a similar version, including a deposition model for particulates, was implemented for the Pollution Control Research Institute (PCRI), Hardwar, India, and applied in a number of Indian examples. The extensive use of fossil fuels, even of good quality, leads to considerable emissions of air pollutants such as SO_2, NO_x or dust and, as a consequence, may lead to high levels of local or regional air pollution, in and around industrial or urban centers.

To analyze the consequences of the current and increased use of coal or other fuels under the various development scenario as designed, eg., with economic or technological models (Fedra, 1988b), or for a specific installation such as a thermal power station with given characteristics, an interactive version of the Industrial Source Complex Model (ISC) was implemented. The model translates emission characteristics for these sources into ambient SO_2, NO_x, or particulates concentrations for a user-defined weather situation or period, eg., a most likely or a worst-case assumption, or the last winter, and compares them with predefined environmental standards or air quality guidelines.

The model input defining a pollution scenario comes from three distinct sources:

- A site-specific library of data files, each characterizing for one location (industrial installation or zone, urban area) the location (coordinates within a local grid)



wind speed:
2.5 m/sec

aximum concentration:
250 microgram/m3
soline class width:
10 microgram

press any mouse button to continue ...

Figure 6: Long-term air quality simulation: a 3D representation of SO_2 concentration over a regional map

of the individual sources as well as the default values of emission characteristics. These include the yearly amount of fuel burned for each source, fuel characteristics, boiler and emission control parameters, stack height or height above ground for area sources, stack diameter, exit velocity, and exit temperature, and width of area sources. Where available, a background map from an appropriate Geographical Information System (GIS) is used;

- Embedded in the code, the definition of a (generic) weather scenario (wind speed and direction, stability class, ambient air temperature, vertical mixing height, stability class); parameters such a mixing height can in turn be estimated from easily available data such as location and date, cloud cover, and wind speed;
- The interactive user interface allows modification of several of the above default or input values:
    1. the amount of fuel burned for each source, source location (which can be interactively set on the map by dragging and positioning a source symbol), and technical characteristics such as fuel properties, stack data, potential pollution control equipment and its efficiency, etc;
    2. wind speed and direction, air temperature, or, in the case of the long term model, the period to be simulated;
    3. weather characteristics by selecting one of 12 distinct weather patterns that translate into different stability classes used by the model; alternatively, the values implied by these icons can be set directly, within the ranges defined for each pattern.

The model interface lists the point and area sources and displays a background map of the area studied with the location of the sources indicated. Model results are shown as a color-coded overlay on this map, a histogram (using the same color code) of the frequency distribution of concentration values, and the maximum concentration value computed. The user can zoom into the map display for better local resolution, redefine isoline boundaries, select an isoline display rather than the color-coded translucent overlay, and display the concentration field as a 3D wire-mesh body over the rotated and tilted map background (Figures 5 and 6). The spatial concentration distributions represent either a specific event, usually a typical or worst case situation, or a longer period, such as an entire year or the winter season, depending on the regulatory framework under which the model is used.

Surface Water Quality Models:

Several water quality models, for example EPA's SARAH (Ambrose and Vandergrift, 1986), a back calculating toxic waste reduction model or a simple dynamic river water quality model for toxic substances, extracted from the generic screening level USEPA model system TOXSCREEN (Hetrick and McDowell-Boyer, 1978; Hetrick and McDowell-Boyer, 1984), or a dynamic analytical model for toxic spills, developed and implemented in collaboration with the Delft Hydraulics Institute, have been built for a number of impact assessment projects.

The near-field surface water model SARAH calculates the maximum allowable hazardous waste effluent concentrations based on predicted exposure to humans or aquatic life from contaminated surface water. The surface water contamination pathways analyzed in SARAH include: groundwater leachate from a land disposal facility; storm runoff from a land disposal facility; discharge through a waste treatment facility. The human exposure pathways considered include: ingestion of treated drinking water and consumption of contaminated fish. Acceptable leachate or industrial waste contaminant concentrations are computed by a back calculation procedure from chemical safety criteria in surface water, drinking water, or fish. The analytical solutions for contaminant behavior in the catchment and stream near the facility allow rapid, multiple calculations required for good sensitivity and risk analysis.

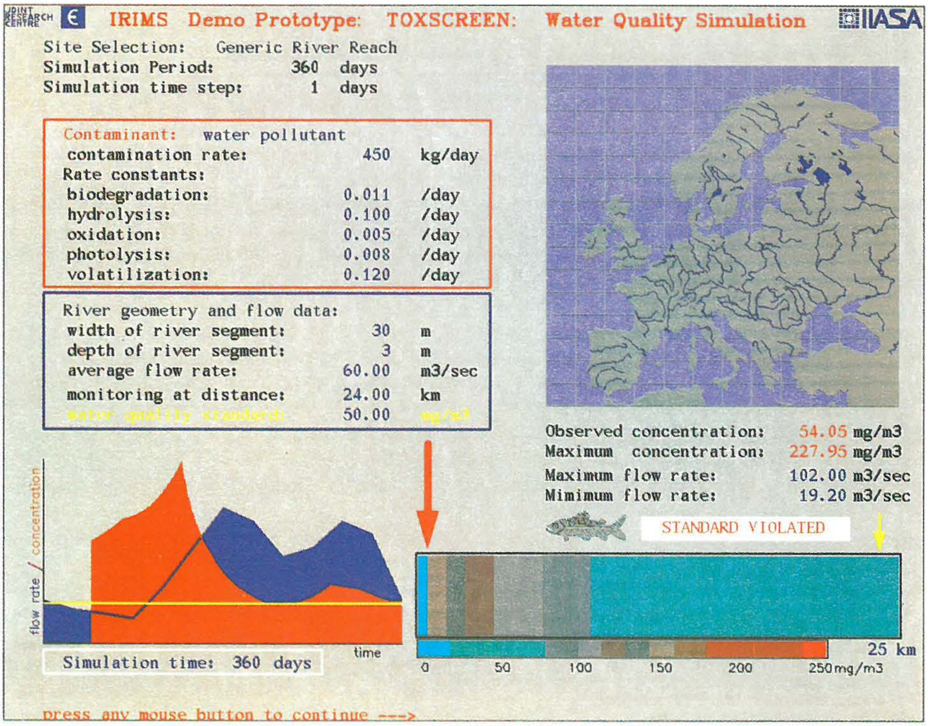
GSARAH is an interactive, menu-driven implementation with a graphical user interface. The program initiates and guides the user dialog through prompt messages, and the user selects the desired option from a set of menus by means of a graphical input device such as a mouse. From an impact assessment point of view, the model predefines an environmental standard, and then checks for compliance by determining the maximum allowable emission level *vis a vis* the respective project characteristics.

Due to its relative simplicity and thus fast execution, the model also supports sensitivity or risk analysis: the user can select one or more of the model parameters or inputs, and define a range of uncertainty around the base value. Within these ranges, the model will then be run several hundred times in a Monte Carlo approach, to calculate the allowable concentrations for the specified target range. The resulting diagrams plotting parameter values versus maximum concentration are displayed, providing a visual interpretation for model sensitivity to parameter uncertainty or input variability.

As an alternative to the backward calculating scheme of SARAH, the river model component of TOXSCREEN, a system of dynamic simulation models, was adapted as part of an environmental risk assessment system (Fedra, 1988b). Here a given emission scenario is defined, and its environmental consequences are simulated over time, again to be compared with a predefined environmental standard.

The river model component of TOXSCREEN simulates pollutant dispersion in an arbitrary river segment. The model implementation features a graphical user interface, extensive interactive input modification based on predefined default values as well as animated graphical display of model results (Figure 6). The model is connected to a hazardous substances data base, so that the parameters for specific substances can be loaded from this data base after identifying a substance by one of the data base access mechanisms.

To simulate dispersion in a river or part of a river, the river is divided into a number of geometrically equivalent reaches all of which have the same flow rate. An equation similar to the one used in EXAMS (Smith, Mabey, Bohonos et al., 1977; Burns, Cline and Lassiter, 1981) is used to estimate the pollutant mass in each timestep in each reach. A number of first-order rate constants (eg., biodegradation, hydrolysis, volatilization) are used to simulate decay phenomena (Figure 7).



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IRIMS Demo Prototype: TOXSCREEN: Water Quality Simulation
Site Selection:     Generic River Reach
Simulation Period:          360  days
Simulation time step:         1  days

Contaminant:   water pollutant
 contamination rate:                  450    kg/day
Rate constants:
 biodegradation:                    0.011    /day
 hydrolysis:                        0.100    /day
 oxidation:                         0.005    /day
 photolysis:                        0.008    /day
 volatilization:                    0.120    /day

River geometry and flow data:
 width of river segment:               30    m
 depth of river segment:                3    m
 average flow rate:                 60.00    m3/sec
 monitoring at distance:            24.00    km
 water quality standard:            50.00    mg/m3

Observed concentration:     54.05 mg/m3
Maximum  concentration:    227.95 mg/m3
Maximum flow rate:         102.00 m3/sec
Mimimum flow rate:          19.20 m3/sec

STANDARD VIOLATED

Simulation time:  360 days

press any mouse button to continue --->
```

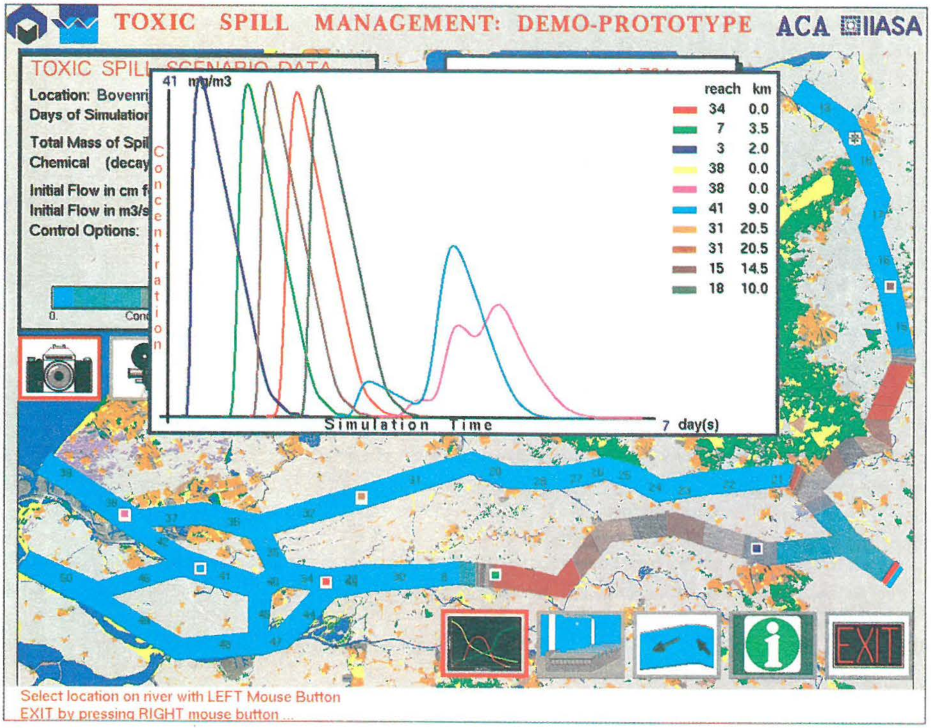
Figure 7: Dynamic river water quality simulation

A site-specific implementation for the river Rhine, XSPILL is a dynamic analytical model that simulates the propagation of an accidental spill of a chemical, represented by its initial mass and a first-order decay rate. Numerous control options allow the interactive definition of a spill scenario, and a number of model control options provide a rich repertoire of display and analysis styles (Figure 8).

Groundwater Quality Modeling:

Graphical display and visualization as one of the major components of ACA's approach is extremely important in areas such as groundwater contamination, where the problem cannot be observed directly. And since groundwater simulation models are among the more complex environmental simulation tools, an easy-to-use interface is an important characteristic, if not a prerequisite, of an efficient tool.

The prototype groundwater contamination model system FEMCAD (Fedra and Diersch, 1989) was designed for the assessment of waste management technologies and facilities such as landfills and dump sites. One of the main application areas of the system within



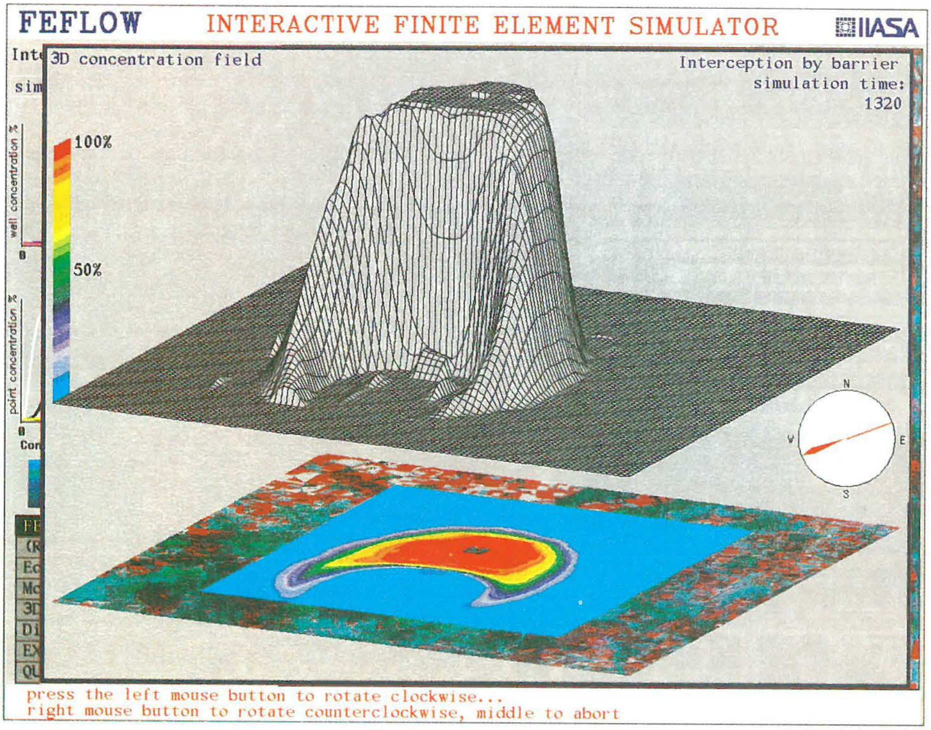
Select location on river with LEFT Mouse Button
EXIT by pressing RIGHT mouse button ...

Figure 8: Simulating a spill of toxic material for a complex hydrographic regime

the framework of impact assessment is in the analysis of mitigation options. The software system consists of the following basic components:

- the user interface, based on interactive color graphics and a completely menu-driven dialog system with its component knowledge bases;
- the problem selection and data base management system;
- the interactive problem definition and editor module;
- and the 2D finite-element simulation model.

In principle, the movement of contaminants in subsurface water represent an unsteady 3D mass transport problem. Taking into account the extensive numerical calculations required to solve such problems, and the accuracy of data available for model quantification (transmissivities, retardation coefficients, etc.), in most practical cases a simplification to a 2D problem becomes necessary and is reasonable. This may be either horizontal-plane


FEFLOW INTERACTIVE FINITE ELEMENT SIMULATOR IIASA

3D concentration field

Interception by barrier
simulation time:
1320

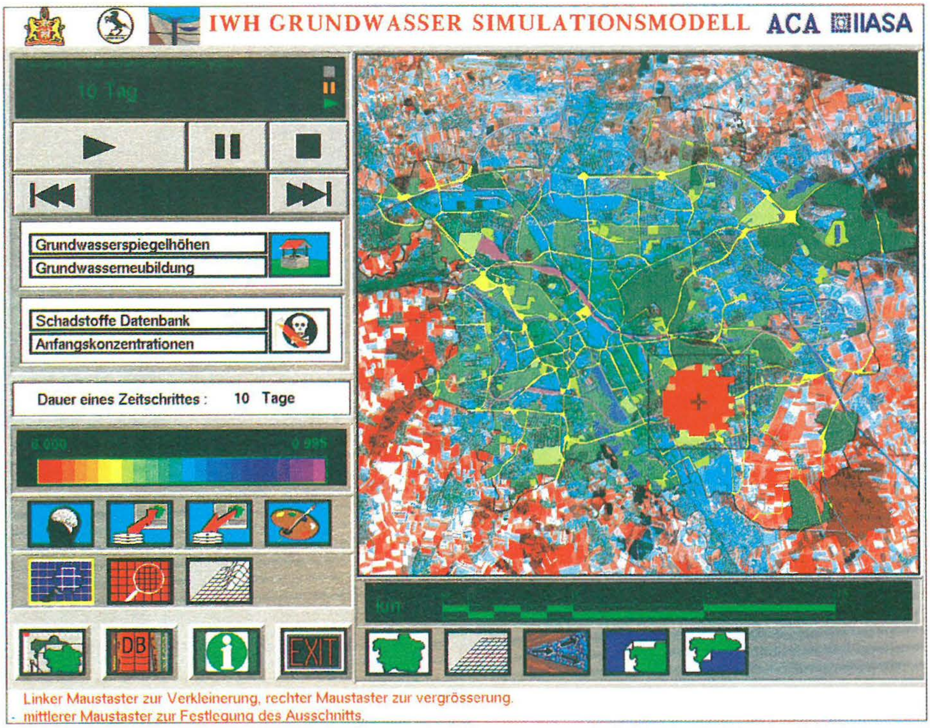
press the left mouse button to rotate clockwise...
right mouse button to rotate counterclockwise, middle to abort

Figure 9: Simulating the effectiveness of a hydraulic barrier with FEMCAD

problems (eg., areal distribution of a spill or leakage, pumpage of bank filtered water for water supply), or vertical-plane problems (eg., deep-well injection).

The user interface is always menu driven ie., the user is prompted to select options from menus of possible options the system offers. Wherever possible, the options are specified in a symbolic format. Model output is displayed dynamically as a color coded concentration field over the background map; display parameters and styles can be chosen interactively, and include association of isolines or color coded concentration ranges with water quality standards or 3D displays of concentration data over rotated background maps (Figure 9). Here the relevant criteria, ie., the pollutant concentration in the groundwater, can be directly interpreted within a regulatory framework by the use of the color coded representation: individual colors can be assigned to classes of, eg., acute toxicity, chronic toxicity, various qater quality standards, etc. (Figure 10).

Selection of numerical data to be changed ie., the pumping rates of wells in the system, or any of the geo-hydraulic paramcters used, is possible by identifying the respective value on the display screen and editing it with a number of "smart" tools that ensure data consistency and plausibility: Changes are only allowed in a certain, context dependent



Dauer eines Zeitschrittes : 10 Tage

Linker Maustaster zur Verkleinerung, rechter Maustaster zur vergrösserung.
mittlerer Maustaster zur Festlegung des Ausschnitts.

Figure 10: Simulating groundwater contamination over a SPOT image with selected vector overlays

range defined by a set of rules. For an interactive system, it is extremely important to assist the user to stay with his assumptions not only within plausible ranges (from the problem perspective), but also within the ranges over which the methods to be used are valid.

For the interactive system, three different types of input data sets or problem descriptions are considered: existing specific sites, generic problem descriptions, and user-generated problem descriptions.

For existing specific sites, the user can choose from a hierarchically organized description of regions and sites, currently implemented for the US, or from the corresponding maps. The user can choose generic problem descriptions, either from a list of available locations and generic descriptions or from pictograms representing problems available in a schematic form. The completely specified site-specific or generic problem description is then loaded from a data base with input files for each specific site or generic problem. They are ready-to-run examples that the user can run with the appropriate menu-option choice; alternatively he can use them as the starting point for an alternative problem description, using the Problem Definition and Editor module described below. There is also the possibility of storing newly-defined problems.

For site-specific problems, reference to a background map, either in the form of a raster map (LANDSAT or SPOT), or a vector-based map (in a binary version of the USGS DLG (digital line graph) format), is stored together with the problem description. This graphical background information may be loaded to provide a geographical reference for the problem in question (Figure 10).

The Problem Editor module allows the user to edit a problem description, or define a new problem from scratch. What can be edited depends on the type of problem: for a site-specific problem, only a few non-structural components of the problem definition can be edited. Examples would be simulation control parameters such as the time step, pumping rates, decay and adsorption coefficients, initial conditions, etc.

In the generic cases a large number or super-set of options may be built into the problem descriptions. For example, most cases include a large number of wells at different locations, the majority of which, however, are inactive, ie., not pumped but used only as observation wells. By activating/deactivating them through prescribing appropriate pumping rates, alternative well locations can be implemented without necessarily having to modify the geometry of the problem.

If structural changes are made, a new version of the generic problem is created, and stored parallel to the original one. Thus, new user-defined problems are either based on modifications and reconfiguration of existing descriptions, starting from any of the generic or specific problem descriptions, or they are completely generated from scratch.

To support the experimental nature of the system, each of the control variables determining a problem situation can be modified independently. For example, once a certain problem is defined, the user can run it for several different amounts of substances, or different substances. Pumping rates may be changed, a hydraulic barrier may be introduced, or the dump site can be sealed off. The interactive problem editor with its graphical problem definition tools provides a convenient and efficient means of problem specification with immediate visual feedback. For the assessment process, this means that a larger number of alternatives can be examined and compared with marginal additional effort.

An Integrated Approach to Impact Assessment

As the above examples illustrate, computer-based methods can be powerful tools to support environmental impact assessment. However, it is important to realize what their actual role and limitations are.

Certainly the expert systems approach is not a replacement for the human expert; it still requires a knowledgeable and responsible person to perform the assessment. However, the system will take care of the more mundane tasks of data handling, freeing the analyst to concentrate on the real problems that require human creativity, which is somewhat difficult to build into computers.

The expert system organizes the assessment process; it provides structure, ensures completeness, and may even ascertain plausibility. It provides support in the assessment procedure, using circumstantial evidence and rules provided by experts to determine the impact level or the magnitude of potential problems. It is the easy-to-use "smart" interface, the fast and efficient operation, and the apparent intelligence of the program that make it attractive. Based on the organized collection of experience from numerous experts, international literature, but also on various guidelines, regulations, and environmental law, a systems knowledge base may indeed provide intelligent advice to any individual user.

The same holds for the simulation models: by integrating data bases, Geographical Information Systems components, and embedded AI technology, they are easy and efficient to use. They allow the analyst to test numerous assumptions, run multiple scenarios under varying assumptions, and to explore the problem. The models certainly will not be able to predict the future state of the environment with a high degree of precision; but they can reveal patterns and trends, and hopefully they will make the analyst think.

The precision of results in any modeling approach, and in particular when predicting expected environmental impacts of projects that are, at this stage, only on the drawing board and thus do not allow for any measurements in the field, has obvious limitations. However, forecasting results must include the uncertainty of the estimate as part of the information provided as an important aspect for their further use, ie., decision making.

The interactive approach, the integration of the models with the necessary data bases, and the visualization of results in formats that are intuitively understandable make them attractive tools. Impact assessment, even with well-defined guidelines, criteria, and standards, is a very judgemental and intuitive process, an art as much as a science. Support tools need to recognize that, provide answers in the appropriate formats, but also use only information that will actually be available to the analyst.

By relying on symbolic representation and a menu-driven user dialog that uses the machine not only to perform the necessary information processing tasks but at the same time to guide and assist the user in his analysis and assessment, the approach becomes sufficiently general to be useful in a wide range of institutional circumstances and application areas. More or less successful implementation in a number of countries with quite different institutional, and regulatory, frameworks indicates that the overall approach of "smart" interactive software, derived from generic tools and approaches but customized for the specific use and user is a promising one that seems worthwhile pursuing.

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