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Environmental Impact Assessment of Industrial Development

A State-of-the-Art Review and
a Proposal for UNIDPLAN Activities

Final Report

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Terms of Reference

Environmental impact assessment as a part of industrial planning in developing countries.

The needs for a structured UNIDO approach to environmental aspects on industrial development has long be felt. Corresponding decisions have also been taken by the Industrial Development Board (IDB.4/L.18) and by the internal UNIDO Task Force on the Environment. Important components of a UNIDO approach would be the building-up of a data bank on environmentally sound technologies, guidelines for screening of UNIDO projects with respect to their environmental impact as well as building-up a capacity for advising developing countries on rehabilitation of existing production units. The most essential feature, however, would be to find ways of including the environmental aspect as an integrated part in the industrial planning process in developing countries. UNIDO should assist developing countries in getting access to suitable planning tools in adapting these tools to the requirements of developing countries and in training. This should be done at a micro, sector, and enterprise level.

A useful starting point could be found within the area of environmental impact assessment methods.

The concept of environmental impact assessment was formulated in the middle of the 1960s in the United States as assisting methods have since then become widely in use in the whole industrialized world, both within the public and private realm. Also in developing countries, environmental impact assessment, mainly on new technologies, have come increasingly in use. Within the UN system, related work has been carried out by for instance, ECE, UNEP, UNIDO, and UNCSTD (the ATAS system). Nevertheless, there is a need for methods that can be easily applied to sectoral and subsectoral planning and which can be disseminated by UNIDO.

A first necessary step would be to make an overview of existing literature and the state-of-the-art of available methods. The consultant should present a structured overview and make a concrete proposal for further UNIDO activities within this area. Different timeframes and different levels of ambitions for such activities should be discussed by the consultant, eg.:

1. Identification of easily adaptable and usable methods within the public domain that could be included almost immediately in the UNDIPLAN tool kit;

2. The development of standard methods at macro and sector level to be included in the planning tool kit and also to be introduced in developing countries as specific technical assistance projects;

3. A clearing house system sponsored by UNIDO but in the longer run managed by a Third World institution aiming at providing a concrete and quick information about available planning methods.

Estimated work time is one month. The first draft, in English, of the report, containing between 30 and a maximum 50 pages, should be delivered to UNIDO before the end of December 1988. Upon receipt of UNIDO's comment by mid-January a final draft should be submitted by the end of January 1989.

Contents

1 SUMMARY AND RECOMMENDATIONS

Environmental Impact Assessment (EIA) requires the qualitative and quantitative prediction and analysis 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 projects assessment, and the minimization and mitigation of environmental costs as part of the design.

For industrial development in general, and specific industrial projects in particular, impacts on the environment include:

- land-use and pollution during the construction of 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. Also, impact analysis should be a comparative, not an absolute assessment: the opportunity costs (in terms of the possible projects no chosen in favor of a given one) have to be considered.

Environmental impacts are depending on two major components:

- the choice and scale of the industrial activity and its production technologies, pollution control and and mitigation measures, and the operating conditions and management of a plant;
- the location of the industrial activity, ie., the specific environment that will be impacted upon and may in turn affect the production process.

While the technological aspects can be treated at a generic, site independent level and thus with generic data that can be compiled *a priori*, the site specific part requires a specific case by case study and local data collection effort as part of an environmental assessment.

Numerous sources of information on industrial technologies, pollutants, waste management, environmental standards and criteria, impact assessment methods and software tools, exist in the scientific literature, the publications, manuals, and guidelines of numerous institutions and government agencies, or in public and commercial data bases and information services. These various sources of information provide necessary and critical inputs to the various impact assessment methods, and therefore deserve special attention.

Methods for the assessment of environmental impacts range from simple check lists and qualitative impact matrices to much more complex computer based approaches using, eg., simulation modeling and optimization, geographical information systems, or expert systems techniques. A very important aspect, however, are the legal, procedural and institutional components, 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 (McHard, 1968; Dooley and Newkirk, 1976)
- USGS Matrix (Leopold et al., 1971)
- Network Analysis (Sorensen, 1971)
- Cross Impact Simulation (Kane 1972)
- EES Environmental Evaluation System (Dee et al., 1972)
- HEP Habitat Evaluation Procedures (US Fish and Wildlife Service, 1976)
- Decision Analysis (Keeney and Raiffa, 1976)
- WRAM Water Resources Assessment (Solomon et al., 1977)
- EQA Environmental Quality Assessment (Duke et al., 1977)
- METLUND Landscape Planning Model (Fabos et al., 1978)
- Goals Achievement Matrix (Hill, 1978)
- WES Wetland Evaluation System (Galloway, 1978)
- AEAM Adaptive Environmental Assessment (Holling, 1978)
- EQEP Environmental Quality Evaluation Procedure (Duke et al., 1979)
- CBA Cost-Benefit Analysis and related methods, numerous authors

- Interactive Systems Analysis, Multi-criteria Optimization (Fedra et al., 1987a,b)

In terms of causality considered, methods are based on check lists 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 moneization 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.

While a large number of impact assessment methods have been developed, and more or less successfully applied world wide, none of them are specifically geared toward industrial development projects with their specific technological and economic dimensions. Most of the available techniques are ecologically and resource oriented, designed to evaluate a given project or a set of alternatives. They are not, as a rule, designed to provide substantive input to the planning and design phase of a development project, which should be the ultimate goal of environmental impact assessment techniques.

Within the framework of **UNIDO** and **UNIDPLAN**, it seems appropriate to concentrate on the industrial component of the impact assessment, ie., the sources of pollution, alternative technologies, pollution control and mitigation measures, and good planning, design and management practices with due consideration of environmental problems.

Here generic tools for screening level as well as a specific and detailed assessment can be prepared for the various industrial sectors and their range of production technologies. Such tools, at the various levels from the national economy, various industrial sectors, to the enterprise, can range from simple manual or handbook type guidelines to computer based expert systems and tutorial interactive assessment programs with the integration of the necessary technological data bases. Interactive computer based tools, implemented on modern and easily affordable computer technology, can be made user friendly and easy to use even without any computer experience, and can therefore also be of considerable didactic value for teaching and training programs. Also, interactive software can include, in the form of data bases, eg., on technology characteristics and emission coefficients, environmental standards and thresholds, dose-response curves, and toxicity data, much of the specific background information required to conduct a comprehensive analysis.

The site-specific environmental component can be covered, especially at the screening and pre-feasibility level, by conducting the analysis for a range of generic environments, characterised along dimensions of sensitivities and vulnerabilities for the various impact categories. Once a specific site has been selected for a concrete project, the generic environment description has to be refined and adapted to the specific local conditions.

To collect, adapt, design, and disseminate such methods and tools, in a format that is easy to use, easy to update, and easy to distribute, using preferably electronic media,

UNIDPLAN could develop a **clearing house function**, offering

- **information systems services**, with special emphasis on
- **software tools**, and training in the use of these tools, based on
- **guidelines for impact assessment** developed by UNIDPLAN,

possibly in collaboration with one or several existing or new national focal points for UNIDPLAN, that could be developed into *centers of excellence* for the collection of information and the preparation of the material and software; this activity should gradually involve institutions in developing countries, and ultimately be run by a network of regional and national centers. Functions would include:

- to systematically collect information and sources of information with regard to environmental impact assessment of industrial projects and keep this information basis current;
- to analyse, aggregate, synthesize, and disseminate this information, and provide information systems and training functions in the area;
- to develop general and sectoral to technology specific guidelines for environmental impact assessment with special emphasis on UNIDOs own projects;
- to collect, test, adapt, and prepare for dissemination software for environmental impact assessment, with the ultimate goal to develop and establish an integrated set of standardized and fully tested software tools and procedures for impact assessment of industrial projects;
- to assist individual projects in conducting assessments by providing guidelines, information, software, and expertise.

Information Systems and Data Bases:

It is recommended that UNIDO/UNIDPLAN compiles and prepares data files and data bases on information and sources of information relevant to the environmental impact assessment of industrial projects, such as sectoral and process specific technology profiles including environmentally relevant information such as emission coefficients, waste and byproduct generation, etc.

Information collected should include:

- environmental impact assessment guidelines, procedures, and manuals from various countries and organizations;
- environmental standards, national and international;
- a roster of experts and institutions in the field;

- a collection of illustrative applications and case studies for industrial projects;
- technological, economic, and related environmentally relevant information on industrial sectors, individual production technologies, and pollution control technologies such as emission coefficients or efficiencies;
- sources of further information (data bases, information services, literature, institutions);
- a catalogue of software for environmental impact assessment applicable to industrial projects.

These data bases should ultimately be part of an easy-to-use interactive information system, that assists the user in retrieving the required information in a conversational and tutorial manner. Implementation on personal and micro-computers would allow for the dissemination of the information and information updates, together with the necessary data management and retrieval software, in the form of electronic media such as floppy discs or optical ROM discs.

The information system could be used in various ways:

- through a regular newsletter making potential users aware of the range of services provided;
- answering individual direct queries with the help of the in-house data bases, possible referring the requisitioner to other sources of further information;
- by distributing catalogues of software tools, reviews and reports on selected topics such as literature reviews, and printed versions of relevant data bases, eg., on technologies and pollution control measures;
- by distributing appropriate parts of the data bases in electronic form, ie., floppy disks or equivalent together with the necessary query software to appropriate clients such as national ministries or research institutions;

Depending on the desired coverage and level of detail, start-up effort for such an information system is estimated between 2 to 5 professional person-years, while routine operation and updating the information should not require more than about two person-years per year of operation.

Guidelines and Manuals:

It is recommended that available guidelines and manuals on environmental impact assessment are critically reviewed for their applicability to industrial planning and UNIDPLAN in particular, and a UNIDO specific set of general as well as sectoral guidelines with special emphasis on the technological, institutional, and socio-economic situation in developing countries is adapted and prepared on the basis of examples already existing.

Based on existing guidelines and manuals eg., from the World Bank, the Asian Development Bank, various national institutions for development aid, or UNEP, a UNIDO specific set of guidelines with the exclusive focus on industrial projects could be developed. These guidelines would at the one hand refer to the contents of the information system, and on the other hand recommend or stipulate the use of software tools, where appropriate, as discussed below.

Estimated effort for the compilation of an impact assessment manual and guidelines, again depending on desired coverage and level of detail, ranges from a minimum half a person-year to one person-year and above, depending on the level of detail and the amount of background and tutorial material to be included.

Software Tools:

It is recommended that UNIDO, within the UNIDPLAN framework, undertakes or sponsors the compilation and adaptation of selected general and sector specific software tools, for the environmental impact assessment of industrial projects, and maintains them at headquarter and selected *centers of excellence*, including appropriate institutions in developing countries, for the dissemination in assistance of individual projects.

A software tool kit would have to include interactive information systems components on industrial technologies and technology alternatives, pollution control and mitigation measures, and environmental standards and quality criteria, as well as simulation and optimization models to assist in technology selection, site selection, and finally to predict environmental consequences in air, water, soil, biota, and human populations, of the planned industrial activity and the effectiveness of pollution control and mitigation strategies. Software tools should be adapted or developed for various levels of aggregation, ranging from the national to regional and sectoral, and ultimately the enterprise and site level.

In addition to the necessary documentation and tutorial application examples, UNIDPLAN should also prepare and offer training cources in the use of these software tools, to be organised and conducted at headquarters as well as as at appropriate regional centers.

In addition to a broader selection and choice of models and software tools that should be made available through the clearing house, a specific set of a few tools, that form a consistent and integrated package with a consistent easy-to-use interactive user interface, and standardised interfaces to data bases, should be built for in-house use and for distribution to individual projects as well as national and regional UNIDPLAN centers. The models would form a complementary tool kit in support of the guidelines and manuals, and also be linked to the information system by being able to directly interface with the respective data bases of this system.

A feasible minimum system of models would have to include:

- a national/sectoral macro-economic development model with special emphasis on environmental criteria; this could be based either on appropriately augmented I/O modeling techniques, or on dynamic simulation methods, eg., *Systems Dynamics*; a versatile tools, using partly qualitative and symbolic simulation, is MACSIM, a generic multi-descriptor cross-impact simulator;
- a model for industrial structure design and optimization, ie., the selection of production and related pollution control technologies, subject to various economic, technological, and environmental objectives and/or constraints; a generaly useful approach is the linear optimization of technological input/output models, eg., PDAS;
- environmental fate or impact models for air, surface and groundwater, and soil and biota, including exposure estimation for human populations; a generic multi-media package is TOX-SCREEN; a more refined atmospheric model for industrial installations is ISC; a whole family of related surface water quality models from the USEPA, eg., QUAL2, EXAMS, WASP, or SARAH; a more general 2D finite-elements groundwater quality model is FEFLOW;
- a multi-criteria decision support tool for the comparison and evaluation of alternatives with incommensurate criteria, eg., DISCRET.

All model acronyms used are listed and explained in the respective model survey sections.

In addition to such a minimum core syste, additional basic models would include:

- site selection (generic in terms of general environmental characteristics and constraints, eg., on a national level, or with a given detailed geography) eg., WET or REPLACE;
- noise pollution, estimating noise levels and exposures around a production site; numerous approaches exist, could be built from simple engineering formulas;
- probabilistic risk analysis for hazardous installations, eg., in the chemical industry;
- waste management models, that follow waste or product life-cycles to the final treatment or disposal, eg., WET.

The estimated effort to build up such a software system as part of the clearing house activities is estimated to require a staffing level of at least three persons over two to three years at the minimum. An interdisciplinary team with emphasis on computer sciences (for the adaptation of software to/from different machines and the development of easy-to-use input/output and user interfaces) and environmental sciences (for the substantive selection, adaptation, and testing of models), with administrative support for the organisation of the collection and dissemination of the information, would be required. It is important to note that this task not only requires the appropriate sources of information and contacts, but also needs a substantial technical infrastructure (ie., several computer types and peripherals, software tools, electronic communication, etc.) and considerable experience in porting and adapting software. Including on-the-job training of national counterparts from designated regional and national centers during systems development can speed up the eventual transfer of responsibilities for the core system and further adaptations and developments.

2 INTRODUCTION

Human activities, and in particular large scale industrial, energy, construction, or agricultural projects considerably affect the natural environment. These impacts occur during the construction phase, the operational life time of a project, and in many cases, such 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, usually lead to a degradation of the natural environment.

Environmental considerations are increasingly becoming important components of planning. Many countries, pioneered by the 1969 *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 developing countries, see, eg., Munn, 1979, Clark et al., 1984.

Environmental Impact Assessment (EIA) approaches are often organized around checklists of data collection and analysis components (eg., De Santo, 1978, Munn, 1979; Bisset, 1987; Biswas and Geping, 1987).

Basic components of the assessment 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 is the most difficult part. Approaches range from purely qualitative checklist-based matrix approaches (Leopold et al., 1971), expert panels and workshop techniques (Holling, 1978), system diagrams and networks, to various computer-based modeling techniques (Kane et al., 1973; Thompson et al., 1973; Gallopin 1977; Patten, 1971; Walters, 1974; Bigelow et al., 1977; Fedra, 1985b), 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 rather more-or-less formalized qualitative assessment procedures. Also, most methods are more or less general, and have been developed in a context other than impact assessment of industrial projects. Few of the methods discussed below are associated with concrete tools: they are approaches rather then tools, and where tools have been developed, they have been adapted to very specific applications, few if any of them for industrial projects.

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 somewhat more 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.

3 ENVIRONMENTAL IMPACT ASSESSMENT METHODS

While most practical impact assessment studies use several methods or combinations of methods, a classification of methods and approaches will help in a summary presentation and discussion of the various techniques. A classical overview is given in Munn (1975), and a recent overview with special reference to developing countries can be found in Biswas and Geping (1987). Two recent symposia, namely *Industrial Risk Management and Clean Technologies*, Vienna, November 1988, and *Environmental Impact Analysis for Developing Countries*, New Delhi, November/December 1988, provide information on industrial technologies and the environmental aspects in developing countries, respectively.

The following summary of methods is largely based on Biswas and Geping (1987).

3.1 *ad hoc* Methods

Ad hoc methods provide little if any formal guidance for the impact assessment. While varying broadly with the team of experts, they usually identify a broad area of impact rather than defining specific parameters which should be investigated or attempting a quantitative assessment. A major advantage, however, is in their ease of use and the possibility to tailor them to the specific circumstances of a given assessment problem without the constraints of a rigid formalism. In consequence, however, they depend very much on the background, expertise and experience of the people undertaking them. While fast and possible to conduct with minimal effort, they do not include any assurance of completeness or comprehensiveness; they may lack consistency in the analysis due to lack of guidance and a specific formalism; and they require the identification and assembly of an appropriate group of expert for each new assessment.

3.2 Checklists

Checklists consist of a list of environmental parameters to be investigated for potential impacts. They therefore ensure complete coverage of environment aspects to be investigated. Checklists may or may not include guidelines about how impact relevant parameters are to be measured, interpreted, and compared. A typical check list might contain entries such as:

1. Earth: mineral resources; construction material; soils; land form; force fields and background radiation; unique physical feature;

2. Water: surface (rivers, lakes and reservoirs, estuaries); coastal seas and ocean, underground; quality; temperature; recharge; snow, ice, and permafrost;
3. Atmosphere: quality (gases, particles); climate (micro, macro); temperature;
4. Flora: trees; shrubs; grass; crops; microflora; aquatic plants; endangered species; barriers; corridors;
5. Fauna: birds; land animals including reptiles; fish and shellfish; benthic organisms; insects; microfauna; endangered species; barriers; corridors;
6. Land use: wilderness and open space; wetlands; forestry; grazing; agriculture; residential; commercial; industrial; mining and quarrying;
7. Recreation: hunting; fishing; boating; swimming; camping and hiking; picknicking; resorts;
8. etc., etc. .....

Obviously, checklists do carry a geographical as well as cultural bias, or, if universal in intent, carry a large number of mutually exclusive categories. They are usually also implicitly oriented towards certain categories of projects, related to the history of their development. Also, their elements may be interrelated (for example, the categories of water bodies and their relevant properties in the example above) such that the linear presentation in the listing has to be interpreted as a hierarchical or even multi-dimensional system in many cases.

Various sub-categories of checklist based approaches can be identified:

- Simple Checklists, consisting of a simple list of environmental parameters.
- Descriptive Checklists. Includes guidelines on the measurement of parameters (eg., ESSA, 1982; DeSanto, 1978; Schaenman, 1976).
- Scaling checklists. Includes information basic to the (subjective) scaling of parameter values. Important concepts include the *Threshold of concern*, the duration of an impact, and whether it is reversible or irreversible (eg., Sassaman, 1981).
- Questionnaire Checklists. Contains a series of linked questions, that guides the user through the process (USAID 1982). The possible answers are provided as multiple-choice, making the process easy to use even for less experienced persons.
- Environmental Evaluation System (EES). Checklist based including scaling and weighting (Dee et al., 1979; Lohani and Kan, 1982).
- Multi-attribute Utility Theory. Similar to the weighting method used in the EES procedure developed by Batelle Columbus Laboratories in the US, it is basically a decision support (weighting) method that can also be used in conjunction with other approaches to derive the impacts (Keeney and Raiffa, 1976; Keeney and Robilliard, 1977; Kirkwood, 1982; Collins and Gilisson, 1980).

3.3 Matrices

Impact matrices combine a checklist of environmental conditions likely to be affected with a list of project activities, the two lists arranged in the form of a matrix. The possible cause-effect relationships between activities and environmental features are then identified and evaluated cell by cell. Matrices can be very detailed and large, the classical Leopold matrix contains 100 by 88 cells, and is thus more or less cumbersome to handle (Leopold et al., 1971). As a consequence, numerous extensions and modifications have been developed for almost each practical application (eg., Clark et al., 1981; Lohani and Thanh, 1980; Welch and Lewis, 1979; Phillip and DeFillipi, 1976; Fischer and Davies, 1973). In a more strategic approach, project planning matrices are used to structure and guide the assessment procedures in the goal oriented ZOPP method (GTZ 1987).

3.4 Overlays

Overlay methods use a set of physical or electronic maps of environmental characteristics and possible project impact upon them, that are overlaid to produce a composite and spatial characterisation of project consequences (McHarg 1968; Dooley and Newkirk, 1976). Modern Geographical Information Systems such as GRASS, developed by the US Army Core of Engineers for Environmental Impact Assessment, use graphic workstations to implement overlay techniques using digital cartographic material and the more versatile logical interactions between spatial features.

3.5 Networks and Diagrams

Networks are designed to explicitly consider higher order, ie., secondary and even tertiary consequences in addition to the primary cause-effect relations addressed by the methods above. Ithey consist of linked impacts including chained multiple effects and feedbacks (Sorensen, 1971; Gilliland and Risser, 1977; Lavine et al., 1978). IMPACT is a computerized version of network techniques, developed by the US Forest Service (Thor et al., 1978).

3.6 Cost-Benefit Analysis (CBA)

Cost benefit analysis, in a narrow sense, is an attempt to monetize all effects for direct comparison in monetary terms. While providing a clear answer and basis for comparison of alternatives, the monetization of many environmental problems is sometimes extremely difficult and thus can affect the usefulness of the method considerably.

Numerous approaches to help monetize environmental criteria have been developed, some of the more frequently used include the *cost of repair*, ie., the estimated cost to restore an environmental system to its original state, or the *willingness to pay*, based on direct or indirect (eg., travel cost) approaches to assess the value, for example, of park land or wilderness. Approaches and problems, as well as the underlying economic theories, are discussed, eg., in Cottrell (1977), Kapp (1979), or Burrows (1980). An excellent and critical treatment of cost-benefit analysis, and evaluation in environmental planning in general, can be found in McAllister (1980).

Examples of cost-benefit approaches to environmental impact assessment include:

- the UNEP Test Model of extended cost-benefit analysis (UNEP and UNAPDI, 1980), mainly oriented towards the natural resource base of a project. The basic format of the approach includes:

- essential project description setting the physical and economic parameters for the analysis;
- itemizing resources used in the project, those indirectly affected, and residues created;
- resources exhausted, depleted, or deteriorated;
- resources enhanced;
- required additional project components;
- formulation of the integrated cost-benefit presentation, summary od conclusions.

- the cost-benefit analysis of natural system assessment, developed by the East-West Centre in Hawai;
- and the extended cost-benefit analysis graph, developed by the Vietnam Environment Research Programme.

Attempts to overcome some of the weaknesses of CBA have lead to numerous extensions and modifications, such the the *Planning Balance Sheet* (PBS) or the *Goals Achievement Matrix* (GAM). The Planning Balance Sheet (Lichfield et al., 1975) stresses the importance of recording all impacts, whether monetizable or not, and analyzing the distribution of impacts among different community groups. Thus it adds the analysis as to whom cost and benefits accrue to the basic concept of CBA. The Goald Achievement Matrix (Hill, 1968; Hill and Werczberger, 1978) defines and organizes impacts according to a set of explicit goals that the (public) action is attempting to meet and identifies consequences to different interest groups. It is designed to also accommodate unmonetizable impacts, and uses a set of non-monetary value weights for computing a summary evaluation, thus similar to CBA.

3.7 Modeling

Systems analysis and modeling are among the few techniques that allow to consider multidimensional problems that involve multiple (and usually conflicting) objectives, multiple criteria, multiple purposes and users, and interest groups.

Basically, modeling attempts to build a replica of a real-world situation, to allow experimenting with the replica to gain insight into the expected behaviour of the real system. Implemented on electronic computers, models are extremely powerful though complex tools of analysis.

Modeling has been used extensively in developed countries, but its use for impact assessment in developing countries has been rather limited because of perceived constraints of resources, and in particular, of expertise and data.

The two main problems, lack of expertise and lack of data, are good reasons to look into the use of computers, and in particular into new technologies such as expert systems, interactive modeling, and dynamic computer graphics. The basic idea of an expert system is to incorporate into a software system expertise, ie., data, knowledge and heuristics, that are relevant to a given problem area. Application and problem-oriented rather than methodology-oriented systems are most often *hybrid* or *embedded* systems, where elements of AI technology are combined with more classical techniques of information processing and approaches of operations research and systems analysis. Here traditional numerical data processing is supplemented by symbolic elements, rules, and heuristics in the various forms of knowledge representation.

There are numerous applications where the addition of a quite small amount of "knowledge" in the above sense, eg., to an existing simulation model, may considerably extend its power and usefulness and at the same time make it much easier to use. Expert systems are not necessarily purely knowledge driven, relying on huge knowledge bases of thousands of rules. Applications containing only small knowledge bases, of at best a few dozen to a hundred rules, can dramatically extend the scope of standard computer applications in terms of application domains, as well as in terms of an enlarged non-technical user community.

Clearly, a model that "knows" about the limits of its applicability, what kind of input data it needs, how to estimate its parameters from easily available information, how to format its inputs, how to run it, and how to interpret its output will require not only less computer expertise from its user, it will also make less demands on its domain expertise. Environmental impact assessment usually deals with rather complex problems that touch upon many disciplines, and rarely will an individual or a small group of individuals have all the necessary expertise at their disposal. The expert systems component of an EIA system can help to fill this gap and at the same time take over the role of a tutor. For recent surveys of the role and potential of expert systems technology in environmental planning and assessment, see Ortolano, 1987; Gray and Stokoe, 1988; Beck, 1988.

The same line of argument holds for the missing data. A forecast of likely consequences and impacts has to be based on some kind of model. Whether that is a mental model, a set of "rules of thumb" or heuristics an expert might use, or a formal mathematical model, the necessary information must be inserted in the (mental or mathematical) procedure somehow. If no specific data are available, one looks for similar problems for which information or experience exists and extrapolates and draws upon analogies. This role is usually filled by the expert's knowledge, or by handbooks and similar sources of information (Golden et al., 1979; Canter and Hill, 1979). Such information, however, can also be incorporated in a model or its interface, or be made available through dedicated data bases connected to the models for the automatic downloading of parameters required. In a similar approach, basic parameters such as chemical properties relevant to environmental fate and transport calculations, for example, can be provided to the respective models through auxiliary models or estimation techniques (Lyman et al., 1982; Lyman et al., 1984).

4 A SURVEY OF AVAILABLE SOFTWARE TOOLS

The following section draws together a number of models and software tools in the area of environmental impact assessment and industrial pollution modeling. The listings are based on the authors personal exposure to many of these models, as well as literature and data base surveys. However, the field of environmental software is under rapid development. A number of relevant international journals cover the field, for example, the journals *Environmental Software* (Computational Mechanics Publications) or *Ecological Modelling* (Elsevier), Obviously, any survey of the area is necessarily incomplete, rapidly obsolete, and can only serve as a starting point and for orientation.

In the problem-oriented context of this report, the most important criterion for the evaluation of software appears to be its usefulness. This, however, is also very much dependent on the user, his level of sophistication, institutional structure, technical infrastructure etc. Therefore, only some minimum criteria could be used that are minimally required to make computer software useful: it must be easily available, sufficiently documented, tested, and must not require more exotic computing equipment. These are necessary, but certainly not sufficient criteria for widespread and successful use. In addition, interaction with the model has to be straightforward and simple, and the model and its underlying assumptions must fit not only the problem but also the institutional structure of the client or user.

The listing of models and software tools compiled here is organized in the following groupings:

- Industrial Production
- Industrial Safety
- Waste Management
- Transportation
- Environmental Pathways and Impacts
  - Multi-media Systems
  - Atmospheric Systems
  - Aquatic Systems
  - Terrestrial/Agricultural Systems
- Human Exposure
- Auxiliary Software

Models that are of specific interest due to their proven track record of successful applications and are thus primary candidates for integration into the proposed clearing-house system are discussed in more detail. Due to the multi-media and multi-faceted nature of many of the models listed, some duplicate entries in the tabular summaries below were unavoidable.

4.1 Industrial Production

In this group, selected models that describe the sources of industrial pollutants and hazardous substances in the production process at various levels from the individual production technology to industrial sectors and national economies, are compiled.

Industrial Production, Structure, and Siting Models		
CARBO	Industrial Structure Optimization	Grauer et al ()
CHEMCAD	Process Simulation and Optimization	Behrends (1988)
COST/TOX	Production Structure Design Minimizing Gross Toxicity Model & Expert System, Waste Minimization	Fathi-Afshar & Yang (1984)
I-005	Prediction of Pollution as a function of economic development (Norway)	Foersund & Stroem (1972)
I-012	Prediction of production specific industrial & toxic wastes	Van Wickeren (1973)
MACSIM	Symbolic cross-impact simulator for national/sectoral industrial development	Winkelbauer (1988)
OPTIMIZER	process and design optimization	Grauer (1979)
PDA	Production/Distribution Area Model Chemical Industry, Pesticides	Dobrowolski et al. (1984), Fedra et al. (1987)
PDAS	Spatial Industrial Structure Design, Environmental Objectives & Constraints	Zebrowski et al. (1988)
REPLACE	Site selection for industrial activities under environmental constraints	Reitsma (1988)
SIM	Chemical Production and Process Waste and Risk Simulation	Winkelbauer (1987)
WET	RCRA Risk-Cost Analysis Model	ICF (1984)

Five digit Model Codes are used according to UMPLIS (UBA, 1978).

Only very few models that combine economical, technological, and environmental components could be identified. While there is a large number of economic or technological models, in this area, and in particular of macro-economic planning models and operation control or job-scheduling models, the inclusion of industrial pollution and environmental concerns is not usually attempted. For models at a national to regional level, with a macro-economic emphasis, the description of waste generated by industrial production is usually connected to more global economic development modeling, and estimated in bulk from statistical data rather from technology specific waste coefficients.

One of the more generally useful approaches involves linear optimization of a simple input-output representation of interlinked industrial technologies, including economic as well as material and waste criteria, is represented by the models CARBO, PDA, and PDAS above. The approach has been used for several industrial sectors such as petrochemicals, heavy chemicals, pestizides, or coal based chemistry, fuels and feedstocks, or energy intensive technologies including cement as well as iron and steel (PDA references). The PDA optimization model, for example, describes a specific sector of the chemical industry such as pesticide production, under technological and environmental constraints in terms of an interconnected network of complementary and alternative production technologies. A detailed description is given in *Fedra et al., (1987b).*

The central component is an optimization model that describes the behavior of a chemical industry, given certain assumptions about prices for products, raw materials, and labor, upper and lower limits for certain production lines or waste products, under the basic assumption that the industry will operate to maximize its net economic results while meeting the external constraints. The results of changes in these external conditions (reflecting the market as well as a set of regulatory options) will be a redistribution of production technologies and production capacities, resulting in a different product mix with different effects on the environment. From an environmental point of view, the major control mechanisms are the absolute limits that can be set for any particular waste streams as well as a *waste tax*, ie., a waste-specific economic penalty. The system also can be configured to globally minimize or constrain the waste treatment cost, as well as resource consumption (water and energy).

In other words, the model will show what a rational industry might do, given a certain set of regulations under specific market conditions. It may be worthwhile noting that the market itself is not included in the model; prices are fixed and set externally, ie., by the user, and an adjustment of production volumes does not (within the model) affect prices. However, by formulating constraints on technologies that use or produce hazardous substances and wastes, either through setting absolute limits on technologies in terms of capacities, constraints on the allowable amount of waste substances, or indirectly through the introduction of a waste tax, the feasibility and economic consequence of clean technologies and environmentally sound operation can be explored.

The representation of economics, and the technology alternatives, in the model is certainly very simplistic, in part constrained by the linear model used. The major advantage of the model, however, is its fast and reliable book-keeping of albeit simplified material flows and basic cost components, keeping track of wastes and possibly material risk, that facilitates an efficient and interactive screening of regulatory options and technological alternatives.

Auxiliary data bases, a conversational control over display options, coupled environmental impact analysis that translate waste streams generated directly into environmental quality indicators such as water quality, and finally a post-processor for the comparative evaluation of several optimization experiments integrate into a very powerful, but easy-to-use, software tool.

The above approach can now be extended to include spatial aspects: different locations in a region or country have different sensitivities to environmental pollution, and to risk. As an example, consider the population density around a production plant, its location in relation to important water bodies used for various water supply purposes, etc. In addition, there are of course other important spatial considerations such as transportation costs, risks, and capacity constraints between the individual locations and the sources or markets for raw materials and products. The availability of the necessary technical infrastructure is also a spatial characteristic.

Implemented as part of a case study of regional industrial development in China (Fedra et al., 1987c), the models considers ten major production sites and two external markets, and more then 140 alternative technologies. The model simultaneously considers criteria such as net and gross production value, expert of key commodities (coal and electricity), production cost, domestic and foreign investment, resource consumption, and wastes generated. All the materials in the system have a price that can be interactively modified by the user. Local constraints include the availability of certain technologies at a given site, capacity constraints, resources such as coal, water and electricity, and the available labor force.

For a given scenario in terms of technologies available, desired product mix and production levels, targets or constraints on the global objectives, and the local site specific constraints, the model will produce the optimal selection, allocation, and capacity of technologies, if a feasible solution exists at all. Obviously, by manipulating environmental criteria, the selection of technologies will change, however, usually with economic side effects. A detailed description of the model and its implementation is given in Zebrowski et al., 1988.

Most information that relates to industrial production and production processes to pollutants and environmental impacts was found as tabular material, descriptions of waste streams or waste and emission coefficients (e.g., USEPA, 1976b, 1980). One example is the waste stream data base of the WET model (ICF 1984), that compiles 154 industrial waste streams, defined by production technologies or industrial sector, and provides 30 data elements on each of them. These data elements include information such as waste stream identification including the standard industrial code (SIC) number for the facilities which generate the waste stream, waste stream specific information including physical/chemical data such as the heating value, ash content, etc., and constituent specific data for the constituents of concern.

Another example of tabular information is provided by a study on organic chemicals manufacturing hazards (Goldfarb et al., 1984), describing a series of manufacturing processes, e.g., the polymerization process for polyvinyl chloride, or the chlorination of phenols. The information includes a short description of the industry, a process description, process chemistry and process hazards, and process waste discharges. SIM (Winkelbauer 1987) is a dynamic simulation version of these descriptions, implemented as a symbolic simulation system in LISP.

4.2 Industrial Safety

Industrial safety, or the risk of industrial accidents that can lead to severe environmental impacts, human health consequences, and substantial economic damage, should be considered as an integrated part of industrial planning and environmental impact assessment. Models and approaches estimating mostly the probability of accidents involving industrial pollutants and in particular, hazardous substances, and the circumstances and consequences of their release to the environment, are compiled in this section. They are largely designed for the chemical process industry and energy production sector, mostly originating from the nuclear energy field.

Industrial Safety Analysis Models		
ALLCUTS	Fault tree evaluation	Van Slyke & Griffing (1975)
ARMM	Fault tree evaluation: direct evaluation	(1965)
BACKFIRE	Common cause failure analysis	Kate & Fussell (1977)
BAM	Fault tree evaluation direct evaluation	(1975)
CAFTS	Computer Aided Fault Tree Synthesis	Pouces (1983)
COMCAN	Common cause failure analysis	Burdick et al.(1976)
DYLAM-1	Event Sequence and Consequence Spectrum	Amendola and Reina (1984)

ELRAFT	Fault tree evaluation	Semanderes (1971)
FRANTIC	Fault tree analysis quantitative analysis	Vesely & Goldberg (1977)
GO Fault Finder	Fault tree evaluation direct evaluation	Gateley et al. (1977)
KITT1	Fault tree evaluation quantitative analysis	Vesely (1969)
KITT2	Fault tree evaluation quantitative analysis	Vesely & Narum (1970)
MICSUP	Fault tree evaluation	Pande et al.(1975)
MOCARS	Fault tree evaluation quantitative analysis	Matthews (1977)
NOTED	Fault tree evaluation direct evaluation	Woodcock (1971)
PATREC-MC	Fault tree evaluation direct evaluation	Koen et al. (1977)
PREP	Fault tree evaluation: Qualitative Analysis	Vesley (1970)
SAFETI	Risk Analysis of Process Plant	Technica (1984)
SAFIRE	Systems Analysis for Integrated Relief Evaluation	Fauske et al. (1983)
SETS	Fault tree evaluation: common cause failure analysis	Worrell (1977)
TREEL	Fault tree evaluation	Pande et al.(1975)
WAMCUT	Fault tree evaluation direct evaluation	Erdmann et al. (1978)

A typical example from this group is the SAFETI package (Technica, 1984), a computer-based system for risk analysis of process plants. The software package was developed under contract to the *Ministerie van Volkshuisvesting, Ruitmeljike Ordening en Milieubeheer*, in association with the *Dienst Centraal Milieubeheer Rijnmond*, by Technica Inc., Consulting Scientists and Engineers, London.

SAFETI starts by generating a plant description; next, failure cases are generated and clustered; finally, the failure cases are processed by consequence analysis programs producing: radiation radii for early ignition of flammable gas; dense cloud dispersion profiles and associated flammable mass for late ignition; and toxic effect probabilities as "appropriate" consequence parameters can be combined to produce risk contours and F-N curves. The original SAFETI package itself is accessible from a master menu that also provides access to the graphical interfaces, and runs under its own interactive, line-oriented menu system.

In a study for the Dutch Ministry for Housing, Physical Planning, and the Environment (VROM), IIASA's ACA project has developed an interactive and graphics-oriented framework and post-processor for the risk assessment package SAFETI to facilitate the quick generation, display, evaluation and comparison of policy alternatives and individual scenarios (Figure 6). The graphical interface to SAFETI's data bases and consequence modeling results allows for the display of the raw data such as plant locations, weather data, or population distribution as thematic overlays on a map. Once risk analysis, using SAFETI's original interface, has been performed for a specific process plant, the results are available for graphical display and interpretation. In addition to the F-N curves, risk contours can be displayed as transparent overlays on a map of the Netherlands. This map allows arbitrary zooming to provide the appropriate level of detail and resolution for a given problem.

As the above listing suggests, there are numerous approaches and alternative models, which, however, usually have considerable technical data requirements, such as a detailed technical description of the plant and machinery layout and the sequences and interdependencies of operations. They are, however, mainly designed for a comprehensive safety analysis and not as an auxiliary component or input of a more general environmental impact analysis. As a very simple alternative, one can assume that all or a (probabilistic) fraction of all hazardous material inventories of a given installation could be released to the environment, again with a certain probability. In the case of fire and explosion, impact zones can be estimated for worst case assumptions based on simple engineering rules, eg., TNO (1979), Lees (1980 a,b).

4.3 Waste Management: Treatment and Disposal

A number of models describing and particularly optimizing waste management and disposal strategies have been identified. Their main orientation is economic and process optimization. However, many of the environmental model described below are also partly relevant here: air pollution models relevant to incineration, surface and groundwater models relevant to treatment plant outflows, land disposal, or deed well injection, also describe important environmental aspects of waste treatment and disposal techniques.

In terms of environmental impact procedures, it is important to include considerations of the waste treatment and disposal cycle downstream of any industrial production, and include the assessment of these secondary impacts in the primary, technology oriented analysis.

However, the definition of waste is rather arbitrary: obviously, many emissions to the atmosphere are wastes just as are liquid or solid waste streams. However, conventionally, waste management concerns itself with the latter categories rather than atmospheric emissions.

Waste Management: Treatment and Disposal		
HWMM	Harwell Waste Management Model	Wilson (1984)
I-001	Waste Management Planning	Brasse (1974)
I-002	Waste Management Planning (Waldshut)	Henseleit (1975)
I-004	Waste Disposal Optimization	Schulz (1976)
I-013	Optimization of Waste Collection	Lichtenberg (1976)
SARAH	Surface Water Assessment for Hazardous Waste Reduction	Ambrose et al., (1986)
WET	RCRA Risk-Cost Analysis Model	ICF (1984)

Five digit Model Codes according to UMPLIS (UBA 1978).

Most of the models identified are classical OR type models, applied to waste collection and associated transportation problems. A specific environmental impact model, which, however, describes maximum allowable leachate or effluent concentrations relevant in the management of eg., land disposal facilities, is SARAH. Here the environmental standard is used as an input, back calculating the performance requirements for the waste management facility.

Again, much technical information is available in narrative or tabular form, that could rather easily be translated into computer code. New and emergent technologies, which have to be considered as possible future alternatives are described in Edwards et al., 1983). Data on waste streams and applicable treatment technologies are compiled, for example, in the UNEP/IRPTC waste management file (UNEP/IRPTC, 1984), or INFUCHS (developed and maintained at the Umweltbundesamt, UBA, FRG), or the waste stream–treatment and disposal technology linkages of the RCRA (WET) Model (ICF 1984).

Several recent books cover treatment and disposal technologies for hazardous wastes in considerable technical detail (e.g., Edwards et al., 1983; Francis and Auerbach, 1983; Lehman, 1983; Kiang and Metry, 1982; Brown et al., 1983; Peirce and Vesilind, 1981). Groundwater quality models that can describe deep well injection as one possible waste disposal technology are listed below.

The basic structure and approach of the WET model, combining technological, economic, and environmental assessment criteria, possibly extended by the more disaggregated technology specific waste and emission data compiled, eg., in the Dutch Governments Handbook of Emission Factors, Part 2: Industrial Sources (Reinders, 1984), and combined with the IRPTC waste management files to determine the feasible subset of recommended treatment technologies, seems to be a promising approach. For a given production technology, waste generated, applicable treatment methods and their costs, as well as remaining environmental impacts for generic environments could be estimated.

4.4 Transportation

The transportation models determine costs and risks, including the risk of environmental pollution, for transporting certain amounts of a given substance from one location to another. This estimation is done for various transportation alternatives (e.g., air, rail, road, ship), and possible alternative routes. Formulated as optimization problems, they will determine minimum distance, cost, exposure, risk, etc., route/mode of transport alternatives. According to studies of the USEPA (ICF 1984a,b) 90% of hazardous waste in the US is currently transported by truck. Rail and ship transport are of considerable importance for the transportation of *hazardous goods*. Also, transportation itself, and in particular road transport, creates pollution, primarily due to vehicle exhausts.

Transportation Impact Assessment		
A-007	Dispersion of Vehicular Emissions	Egan & Lavery (1973)
CALINE-2	Simple air pollution near highways	Jones et al. (1976)
CALINE-3	Air pollution near highways	Benson (1979)
HASTM	Transportation risk-cost analysis	Kleindorfer & Vetschera (1985)
HBMS	Harvard-Brookings Model System	Kresge & Roberts (1971)
HIWAY	line sources (roads), hourly model	USEPA (1975)
INTERTRAN	Impact from Transporting Radioactive Material	Ericsson & Elert (1983)
MOBILE1	vehicle source terms for HIWAY	Guthman (197[illegible])
MOBILE2	vehicle source terms for HIWAY	USEPA (19[illegible]

PDAS	Spatial Industrial Structure Optimization with Transportation Model	Zebrowsky et al. (1988)
RADTRAN-II	Transportation of Radioactive Material	Taylor et al. (1980)
SRGP	Short-Range Generalized Policy Analysis	Ruiter & Ben-Akiva (1977) Roberts et al. (1977)
US Coast Guard	Conditional Probability Model	NSC (1976)
USC	Risk analysis for the transportation of hazardous materials	Jones & Barrow (1973)
UTMS-1	Urban Transport Model System	UTMA 1976
UTPS	Urban Transportation Planning System network analysis software	Ben-Akiva et al. (1977)

Models in the transportation sector are of three types: classical transportation models, that primarily estimate demand, mode/route selection, energy consumption, travel times, etc., risk/cost analysis models, mostly developed for risk assessment for the transport of radioactive or other hazardous materials, and finally and air pollution models that estimate atmospheric emission and dispersion due to vehicle exhaust.

In the latter category, air pollution impacts are estimated based on vehicle frequencies, speeds, climatic variables, etc., to generate the source term, and then calculated with standard line-source dispersion models.

UTMS-1, one of the first major general transportation models, deals with four major dimensions of choice (Manheim, 1979):

- frequency
- destination
- mode
- route

A *trip generator* predicts the number of consumers choosing to make trips. Second, *distribution* predicts the number of trips to each destination. Third, *mode split* predicts the number of trips to each destination by each available mode. Finally, *network assignment* predicts the choice of paths.

While this framework is only partly applicable in the context of environmental impact assessment, the basic elements of mode and route selection can be used and easily augmented by a vehicle specific emission pattern, noise level, or risk of accidental spill.

Examples of models for the estimation of risks and costs of the transportation of hazardous materials include INTERTRAN (IAEA. 1983), which was developed for assessing the impact from transportation of radioactive material. Several models for hazardous substances transportation are summarized and discussed in Posner (1984), including approaches developed by:

1. Simmons et al. (1973), which examines the risk associated with spills of volatile, toxic chemicals, primarily chlorine;

2. U.S.Coast Guard (National Science Council, 1976), a simple model based on conditional probabilities, but requiring data rarely available in practice;

3. Garrick et al., (1969), based on fault-tree analysis and a spatial decomposition of the route in a system of nodes and arcs;

4. Jones and Barrow (1973), developed as part of an integrated risk assessment system, the model combines estimates of likelihood of several types of incidents involving hazardous materials and a number of severity classes with the potential cost of an incident. Data for this approach were taken from HMIRS (Hazardous Materials Incident Reporting System, Ispra).

5. Kloeber et al., (1979), used for the assessment of air versus other modes of transportation of explosives and flammable cryogenic liquids;

6. Battelle-Pacific Northwest Laboratories (Rhoades, 1978; Andrews et al., 1983), which again uses the product of the probability of occurrence of release and the consequence of that release to describe risk; this simple model has been used to examine a wide range of hazardous materials generally transported by rail and truck.

A simple and generally applicable model which already uses a multi-criteria approach and can thus easily be augmented to include normal environmental impacts (exhaust) in addition to the risk components, HASTM (Kleindorfer and Vetschera, 1985) was developed under contract to the CEC/JRC. The model is based on a map of a given region (e.g. a map of the region of the industrial site and its main markets for raw materials and products) which specifies supply and demand points together with various routes connecting these points, on regulatory policies such as risk minimization and on economical policies such as cost minimization. The function of this model is to enable the user to solve the problem of choosing the "best" route and mode for the transportation of hazardous substances from a certain supply point to a certain demand point.

As a policy-oriented tool the structure of the model has to closely follow the structure of decision variables open to regulators. In general we can distinguish two different levels at which regulations might operate: *micro level*, dealing with individual transport activities or connections, an *aggregated level* aiming at global regulations that can be applied to all shipments specified.

For analysis at the micro level the model will generate and evaluate possible transportation alternatives for a given transport objective. A transport objective is described by the amount and type of hazardous substance to be transported and the points between which the goods are to be transported.

A transport alternative in the model is represented by a geographical route along which the transport is to occur and the choice of a transport mode, both associated with risk-cost criteria. The possibility of mode changes along the route is also considered in the model.

A detailed cost and risk analysis for all the alternatives generated is then performed and the results of this evaluation are presented to the decision maker for his final choice among the alternatives using the Interactive Data Post Processor (Zhao et al., 1985).

From the perspective of software engineering the implementation of the model consists of three main modules. The first module generates candidate paths which in turn generates different route/mode combinations. To limit the amount of alternatives to reasonable ranges, the search area is restricted.

The second module executes a risk-cost evaluation of the paths generated in the first phase. The outcome of the second phase is a list of criteria of all the alternatives for further evaluation.

The third module selects the "best" transportation alternative with respect to the criteria specified by the decision maker. The number of alternatives is usually too large to be handled by the decision maker without a supporting tool. A display-oriented data post processor for multi-objective is a useful tool that can be employed to perform these tasks in a user-friendly and efficient way.

4.5 Environmental Pathways and Impacts

At the source or emission point, which may be industrial production, use of a product (e.g., dispersive use of agrochemicals), treatment and disposal, and transportation (loading/unloading, en route losses, or accidents) the nature of a pollutant is specified. These specifications minimally describe the physical property, e.g., liquid, gaseous, dust, solid, etc. and the point of release (chimney, canal, dump site, etc.). The substances are then moved and dispersed through one or more of the environmental transport pathways. These are:

- atmospheric
- aquatic: surface/groundwater, rivers, lakes/reservoirs, estuaries, coastal marine systems
- terrestrial: soil system and biological food-chain

Environmental effects, obviously, depend on the nature and amount of the substance as well as as on the environment affected. Different substances can have very different effects eg., on terrestrial or aquatic systems. While in many cases a rather detailed description of the physical environment is a necessary part of the model, several of the models can also be run for generic environments, which are defined along several dimensions such as

- atmospheric assimilative capacity: describes the atmospheric turnover or dilution capacity of a region; valleys with frequent inversion situations and low average wind speed would have a much lower capacity as a location on the plains, exposed to regular strong winds;
- surface water assimilative capacity: describes turnover or retention times of aquatic systems; fast flowing streams have higher assimilative capacity than lakes or reservoirs with long retention times;
- groundwater systems: the distance of the groundwater table from the surface, and the porosity and adsorption potential of the unsaturated zone above the groundwater, and the groundwater retention time;
- landuse characteristics: indicated the relative proportions of waste land, wilderness (parks, recreation areas), forest, agricultural, and urban/industrial land use;
- population density: self explanatory.

Any given specific site could then be classified along the above dimensions, and average values be used for the impact analysis.

4.5.1 Multi-Media Systems

Multi-media models describe the transportation of toxic substances in more than one environmental medium, and across media boundaries. Several models are compiled in the table below.

Multi-media Environmental Models			
ALWAS	Air Land Water Analysis System Multi-Media Model for Toxic Substances	A W T	Tucker et al. (1984)
ECCES	Environmental Consequences from Energy Systems	A T	Petersen (1984)
ENPART	Environmental Partitioning Model	A W T	Pilote (1982)
Fugacity	thermodynamically based environmental transport	AWT	Mackay & Paterson (1982)
GEMS	Graphical exposure modeling system	A W T	EPA
PCGEMS	Personal Computer version of GEMS	A W T	EPA
TOX-SCREEN	Multi-Media Screening Level Program for Assessing the Potential Fate of Chemicals released to the Environment	A W T	Hetrick & McDowell-Boyer (1984)
UTM-TOX	Unified Transport Model for Toxics	A W T	Oak Ridge/EPA (198?)

A - atmosphere, W - water (aquatic), T - soil & terrestrial systems

A multi-media framework is provided by TOX-SCREEN (Hetrick and McDowell-Boyer, 1979, 1984). TOX-SCREEN, developed at Oak Ridge National Laboratory, is designed to assess the potential environmental fate of toxic chemicals released to air, water, or soil. It evaluates the potential of chemicals to accumulate in environmental media and is intended for use as a screening device. The model makes a number of simplifying assumptions and operates on a monthly time step. Assumptions include a generic positioning of surface water bodies relative to atmospheric pollutant sources and contaminated land areas. The data used are typical of large geographic regions rather than site specific. This multimedia screening tool will therefore be augmented by a second layer of more detailed and site-specific models for the individual environmental media (e.g., Fedra et al., 1986).

In TOX-SCREEN, the physical/chemical processes which transport chemicals across air-water, air-soil, and soil-water interfaces are simulated explicitly. Deposition velocities, transfer rate coefficients, and mass loading parameters are used. Monthly pollutant concentrations in air, surface waters, and soil reflect both direct input to any or all of the media from a specified source or sources, and subsequent interaction via processes such as volatilization, atmospheric deposition, and surface runoff. Methods for estimating bioaccumulation in the food chain are also included.

PCGEMS is the personal computer version of EPA's Graphic Exposure Modeling Systems, residing on the Office of Toxic Substances (OTS) VAX 11/780 at Research Triangle Park in North Carolina. PCGEMS offers greater access and ease then the original mainframe GEMS, being ported to the IBM PC XT or AT. Since the future is towards greater use of personal computers, PCGEMS will expand in capabilities as the hardware improves. In its PC version, PCGEMS currently encorporates the following major components:

- **ENPART:** ENvironmental PARTitioning model, based on the fugacity approach. It is a first level screening tool for pre-manufacturing notices and existing chemicals. It uses simple physical chemical data to estimate equilibrium concentration ratios of a chemical between different environmental media.

- **PCLOGP:** chemical property estimation (octanol/water coeff.) PCLOGP estimates the partition coefficient, i.e., the equilibrium concentration of a solute in a non-polar solvent (water) divided by the concentration of the same species in a polar solvent (octanol). All the input required is the Simplifies Molecular Line Entry System (SMILES) notation for the chemical. For an introduction to the SMILES notation system, see the PCGEMS User's Guide p 3-3 and 3-4.

- **PCCHEM:** automatic chemical property estimation. Based on input of the SMILES notation and the log Kow values (known or estimated with PCLOGP), PCCHEM estimates: melting point; water solubility; boiling point; vapor pressure; Henry's Law constant; bioconcentration factor; organic carbon adsorption. Many of these parameters are required by subsequent environmental impact models.

- **PCHYDRO:** chemical property estimation (hydrolysis). This module is still under development. The current version is limited to a few of the carboxylic acid esters.

- **PCFAP:** fate of atmospheric pollutant. Models such as ENPART, ISC, or TOX-SCREEN can use, as part of their input, the rate of degradation and loss of a chemical in air. The FAP model estimates the rate of atmospheric oxidation from structural information (SMILES notation) alone.

4.5.2 Atmospheric Systems

Atmospheric transport models describe one of the most important mechanisms of environmental distribution of hazardous substances. Transport, dry and wet deposition, and resuspension are the main physical processes considered. Some models also include descriptions of (photo)chemical reactions and first-order decay.

Atmospheric Systems		
A-001	Plume Model	Ooms (1973)
A-005	Simple Urban Air Pollution Model	Gifford (1972)
A-007	Dispersion of Vehicular Emissions	Egan & Lavery (1973)
ADPIC	3D Pollutant Dispersion/Deposition	Lange (1976)
AQUIP	package of several models, regional point, line and area sources	Reifenstein et al., (1974)
APRAC	Urban Carbon Monoxide Model	NTIS PB213-091
ARADS	Dispersion of airborne radionuclides	Plato et al. (1967)
ARL	Air Resources Laboratory Trajectory Model	Pack et al. (1978)
ASTRAP	Lagrangian with diurnal/seasonal variations	Niemann & Young 1981
ATM	Atmospheric Transport & Diffusion	Culkowski (1976)

ATM80	Atmospheric Transport & Population Exposure	General Software Corp.(1980)
BOXMOD80	steady-state box model (area sources)	Hanna (1980)
CALINE-2	Simple air pollution near highways	Jones et al. (1976)
CALINE-3	Air pollution near highways	Benson (1979)
CAPITA	Monte-Carlo Model	Niemann & Young 1981
CDM	Climatological Dispersion Model, long-term multiple source	USEPA (1973)
CDMQC	CDM Update	USEPA (1977)
DIFOUT	Aerosol Transport & Diffusion	Luna & Church (1969)
ENAMAP-I	EURMAP including chemistry	Niemann & Young (1981)
EURMAP	Lagrangian Model	Johnson et al. (1979)
Heffer	Regional-Continental Transport	Heffer et al. (1975)
HIWAY	line sources (roads), hourly model	USEPA (1975)
ISC-ST	Industrial Source Complex Short-Term	Bowers et al. (1980)
ISC-LT	Industrial Source Complex Long-Term	Bowers et al. (1980)
LANTRAN	landuse pattern and emission coefficients based source terms	Reifenstein (1974)
LIRAQ	Livermore Regional Air Quality Model	McCracken et al. (1975)
MARTIK	Source integration for AQUIP	Reifenstein (1974)
MEP-TRANS	Sophisticated Trajectory Model	Niemann & Young (1981)
MESOS	Transport of airborne radionuclides	ApSimon (1979)
METEO-11	Atmospheric Dispersion	Veverka et al. (1975)
MOBILE1	vehicle source terms for HIWAY	Guthman (1978)
MOBILE2	vehicle source terms for HIWAY	USEPA (1983)
OME-LRT	Long Range Transport, by Venkatram	Niemann & Young (1981)
P&S-A	Pseudo-Spectral Model	Prahm & Christensen (1977)
P&S-B	Moment-Conservation Model	Nordo (1974)
P&S-C	Particle-in-Cell Model	Nordlund (1973)
P&S-D	Regional Particle-in-Cell Model	Lange (1978)
P&S-E	Original Particle-in-Cell Model	Sklarew et al. (1971)
P&S-F	Trajectory Model	Eliassen (1978)
P&S-G	Pressman's transboundary flux Model	WMO (1981)
P&S-H	UK National Radiological Protection Board	Jones (1981)
P&S-I	Atmospheric Environment Services (CAN)	Niemann & Young (1981)
P&S-R	Sector Analysis Model	Fuller (1973)
P&S-U	Statistical Lagrangian Model	Fisher (1978)
P&S-V	Continuous Release Model	Jones (1981)
P&S-W	Simple Statistical Model	Smith (1982)
P&S-X	Constant Eddy Diffusivity Profile	Fisher (1975)
P&S-Y	Variable Eddy Diffusivity Profile	Bolin & Persson (1975)
PTDIS	short-term point source model	Turner & Busse (1973)
PTMAX	hourly concentration maximum, point source	Turner & Busse (1973)
RCDM-2	University of Illinois, by Fay & Rosenzweig	Niemann & Young (1981)

SUBDOSA	External Dose from Atmospheric Release	Strenge et al. (1975)
SURE	Small-scale Lagrangian Model	Hidy et al. (1976)
TOX-SCREEN	Multi-Media Screening Level Program for Assessing the Potential Fate of Chemicals Released to the Environment	Hetrick & McDowell-Boyer (1984)
SYMAP	Isopleth maps for eg., AUQIP	Reifenstein (1974)
UMACID	University of Michigan Model	Niemann & Young (1981)
UNAMAP	package of several models	USEPA (1983)

P&S codes from Pasquill and Smith (1983).

Most atmospheric transport and impact models identified are rather general in nature, i.e., they can describe any conservative substance. An excellent text on the underlying physics and mathematics is presented by Pasquill and Smith (1983), who also compare and discuss 28 simulation models in current use. The authors conclude that for the determination of long-term deposition fields, very simple (statistical) models do very well.

Substance specific models have been developed for radionuclides or fossil fuel combustion (SO_2, NO_x, CO). Here special source and sink terms, like photochemical reactions or radioactive decay have to be considered, requiring substance specific representation of chemical processes. However, most of them could easily be modified to handle almost any substance or a small number of interacting substances.

In the TOX-SCREEN framework, atmospheric dispersion from point sources is described by a modification of the original Gaussian plume equation of Pasquill (1961). Modifications include plume depletion due to wet and dry deposition, gravitational settling, and chemical degradation. Sector averaged and maximum concentrations are calculated on a monthly average basis, assuming a constant Pasquill Stability Class D (.i.e., neutral conditions). Also assumed is a constant wind direction over the period of model application.

To describe atmospheric dispersion in a more detailed, dynamic, and possibly site-specific way, the Industrial Source Complex Model (ISC) developed by the U.S. Environmental Protection Agency (EPA) is used as an alternative or extension to the TOX-SCREEN model. It is again based on an extended Gaussian model, describing the concentration/deposition of substances in time and space.

The *ISC Long-Term Model* (ISCLT) is designed to calculate the average seasonal and/or annual ground level concentration or total deposition from multiple continuous point, volume and/or area sources.

The *ISC Short-Term Model* (ISCST) is designed to calculate ground-level concentration or deposition from stack, volume or area sources. The receptors at which the concentration or deposition are calculated are defined on a x-y, right-handed cartesian coordinate system grid. Discrete or arbitrarily placed receptors may be defined. Average concentration or total deposition may be calculated in 1-, 2-, 3-, 4-, 6-, 8-, 12-, and/or 24-hour time periods. An 'n'-day average concentration (or total deposition) or an average concentration (or total deposition) over the total number of hours may also be computed. Concentrations (depositions) may be computed for all sources or for any combination of sources the user desires. Other options include input of terrain heights for receptors, tables of highest and second highest concentrations or depositions at each receptor and tables of the fifty maximum values calculated.

Other extensions of the Gaussian Model include:

- the influence of urban or rural area on the weather;
- plume rise (Briggs 1971, 1975);
- variable topography of the area, influencing the variation of wind and temperature;
- the influence of buildings close to the source (Huber and Snyder, 1976; Huber 1977), affecting the coefficient of dispersion;
- the exponential decomposition of chemicals;
- a simple deposition model (Dumbauld et al., 1976; Cramer et al., 1972).

For long-range transport on medium- to long-term time scales, the Gaussian models referred to above are not well suited. At larger distances, depending on the atmospheric stability conditions, results become more and more uncertain. Also, the variability of wind directions over the run time of a simulation will result in complex trajectories. Therefore, for long-range transport, a Lagrangian model (e.g., Eliassen 1978) will be used instead of the Gaussian models.

4.5.3 Aquatic Systems

The importance of aquatic systems as the recipients of hazardous waste is obvious from the proportions reported in the 1983 CMA Hazardous Waste Survey (CMA, 1983): In the US, 99% of the hazardous waste generated (by industrial sources of the Standard International Code 2800 group, Chemicals and Allied Products) was wastewater. These wastewaters are dilute streams defined as hazardous by the RCRA mixture rule. As a consequence, the most important (in terms of mass) pathway of environmental distribution of hazardous substances is through aquatic systems. While most water quality models have concentrated on DO-BOD dynamics, or eutrophication, some models directly applicable to toxic substances (e.g., heavy metals, pesticides) and radionuclides have also been identified.

Aquatic Systems		
A816/A837	Inorganic Chemical Concentrations	USGS, Steele (1973)
ABMAC	Stormwater Pollution Analysis	Litwin et al. (1981)
ACTMO	Agricultural Chemical Transport Model	USDA/ARS
AQUAMOD	Aquatic Radionuclides Transport	Booth (1975)
AQUIFEM	A Finite Element Model for Aquifer Evaluation	Pinder & Gray
AQUIFEM-1	Finite element aquifer flow	Townley & Wilson (1980)
Baca77	Nonconservative Mass Transport	Rockwell Hanford Operations(1977)
COLHEAT	Estuarine Transport	Daniels et al. (1970)

DDEM	Dynamic Delaware Estuary Model	Ambrose (1980)
DEM	Dynamic Estuary Model	EPA (1974)
DO-Model	Streeter Phelps DO-BOD model (FORTRAN)	Wang et al. (1979)
DO-Model	Streeter Phelps DO-BOD model (BASIC)	Hughto & Schreiber (1983)
DOSAG-1	Water Quality in Streams and Canals	Texas Dept. of Water Resources (1970)
DPRWCR	Random Walk Transport Modeling Surfacewater	Ahlstrom & Foote (1976)
DPRWGW	Random Walk Transport Modeling Groundwater	Ahlstrom & Foote (1976)
DYNTOX	analytical models for instream toxicity	Limno-Tech (1985)
EXAMS	Exposure Analysis Modeling System	Burns et al. (1982)
FEFLOW	Finite Element Simulator (Contaminant Migration)	Diersch(1978)
FEMCAD	Interactive Groundwater Quality model, color graphics and ICAD system	Fedra & Diersch(1989)
FETRA	Sediment & Radionuclide Transport	Onishi et al. (1976)
FRONT	Moving Intrusion in Thin Aquifer	Vandenberg (1975)
GSWIM-II	Groundwater Simulation Program	Texas Dept. of Water Resources (1978)
HSPF	Water Quality/Toxic Substances	EPA (19??)
HSSWDS	Hydrologic Simulation of Solid Waste Disposal Site	Perrier et al. (1980)
Lantz76	Deep Well Injection of Waste	INTERCOMP (1976)
LEVEL III	Urban Water Quality Management	Medina (1979)
PEST	Pesticide Accumulation Model for Aquatic Ecosystem	Leung (1978)
QUAL-II	Stream Quality Model	Texas Dept. of Water Resources (1977)
QUAL2E	Enhanced Stream Water Quality Model	Brown & Barnwell (1987)
QUNET-I	Multibasin Water Quality Simulation	Texas Dept. of Water Resources (1972)
RECEIV-II	Receiving Water Model	EPA (1975)
RESOP-II	Reservoir Operation and Quality Routing	Texas Dept. of Water Resources (1978)
Robertson	Radioactive & Chemical Waste Transport	Robertson (1974)
SARAH	Surface Water Assessment Model for Abiotic Hazardous Wastes	Ambrose & Vandergrift (1986)
Schum82	Radionuclide Migration through Coastal Marine Ecosystems	Schum & Varnell 1982
SERATRA	Sediment-Contaminant Transport Model	Onishi (1977)
STORM	Storage, Treatment, Overflow Runoff	HEC (1976)
SWIFT	Sandia Waste-Isolation Flow and Transport Model	Greeves
SWMM	Storm Water Management Model	USEPA (1971)
TODAM	Water Quality/Toxic Substances	USEPA (1979)

TOXIC	Water Quality/Toxic Substances	USEPA (1981)
TOXIWASP	Toxic Substances Transport and Fate	Ambrose et al. (1983)
TOX-SCREEN	Multi-Media Screening Level Program for Assessing the Potential Fate of Chemicals released to the Environment	Hetrick & McDowell-Boyer (1984)
UTM-TOX	Unified Transport Model for Toxics	Oak Ridge (1983)
WASP	Water Quality Simulation Program	DiToro et al. (1983)
WASP4	Hydrodynamic and Water Quality Model	Ambrose et al. (1987)
WASTOX	Water Quality/Toxic Substances	EPA/HydroQual (1984)
WATEQ2	chemical model, trace and major elements	Ball et al. (1979)
Willis-1	Groundwater Quality Management	Willis (1975)
Willis-2	Groundwater Management/Waste Injection	Willis (1976)
WSMM	Storm Water Management Model	EPA (1975)
WQRRS	Water Quality River-Reservoir Systems	HEC (1978)

What was said above for atmospheric transport models also holds in the water field: most models are general purpose mass transport simulators for conservative substances. Only a few provide for first order decay of constituents. More complex reactions are only included for the biological components and nutrients. Impacts are either bioaccumulation along the food chain, or some "toxicity" related decrease in bioproductivity.

In the TOX-SCREEN framework, chemicals introduced into surface water bodies, either directly or indirectly due to runoff from soil, or deposition from air, are dispersed in water and sediment according to the respective flow regime and the characteristics of the chemical. Using simplified assumptions to simulate dispersive processes underlying the dilution mechanism, TOX-SCREEN estimates concentrations in rivers, lakes, estuaries, and coastal marine systems.

Rivers: To simulate dispersion in rivers, a river is split into a number of geometrically equivalent reaches which all have the same flow rate. An equation similar to the one in EXAMS (Smith et al., 1977; Burns et al., 1981) is used to estimate the monthly pollutant mass in each reach. Instantaneous mixing in each reach upon introduction of a pollutant is assumed. Pollutant concentrations are calculated for dissolved neutral, dissolved ionic, and adsorbed forms, according to chemical equilibria. Adsorption onto sediment is also described.

For a more detailed treatment, alternative codes include WQRRS, developed by the U.S.Army Corps of Engineers (HEC 1978), or QUAL-II, developed by the Texas Department of Water Resources. With a much shorter time step, they can simulate individual spills on a higher spatial resolution and considering numerous biotic and abiotic variables together with a limited set of chemicals.

Lakes: Lakes are treated in a manner similar to that used for rivers. Again, the mass balance approach of EXAMS is used. For more detailed treatment and a shorter time step, numerous alternative models do exist. EXAMS is specifically designed for toxic chemicals (Smith et al., 1977; Burns et al., 1982). EXAMS describes the behavior of synthetic organic chemicals in aquatic environments. From the chemistry of a compound, and the relevant physical/chemical and transport characteristics of the system, EXAMS computes:

- the ultimate steady state environmental concentration resulting from a specified pattern of loading;

- the distribution of the chemical in the system and the fraction of the loadings consumed by each transport and transformation process;
- the time required for effective purification of the system via export and transformation processes once inputs cease.

The model combines loadings, transport, and transformations into a set of differential equations based on mass conservation. This accounts for all chemical mass entering and leaving the system due to

1. external loadings,
2. transport processes that export the compound from the system,
3. transformation processes that convert the parent compound to daughter products.

Concentrations are described as the balance between increases originating from external and internally recycled loadings, and decreases resulting from transport and transformations. Environmental data consist of a concise description of the aquatic system, represented by a set of n compartments or zones with specified geometry and connectedness. EXAMS also accepts standard water quality and limnological parameters.

A lake model of high complexity, MS.CLEANER (Park et al., 1979) has been extended into the pesticide accumulation model for aquatic ecosystems, PEST (Park et al., 1977). Estimates of the required rate constants and partition coefficients are largely based on the octanol:water partition coefficient of a substance. Special emphasis is given to the accumulation of toxics in fish; examples given are DDT and Methoxychlor (Leung 1978).

Estuaries: In TOX-SCREEN, a one-dimensional steady-state model that assumes constant cross-sectional area, a constant tidally and sectionally averaged longitudinal dispersion coefficient, and a constant fresh water velocity is used for simulating dispersion of pollutants in estuaries.

Coastal Marine Systems: A steady-state Gaussian type linear diffusion model is used for discharges to coastal waters (Brooks 1960). Assumptions of the model include offshore discharge via an outfall terminating in a multipoint diffuser, movement of the resulting pollutant field at the same rate as the prevailing current, negligible vertical and longitudinal mixing and steady flow.

Groundwater: Groundwater is an extremely important medium due to its high value as a high-quality potable water resource. Causes and consequences of qualitative changes in groundwater regimes can be separated by decades or centuries. Once contaminated, groundwater resources may be permanently impaired. Groundwater contamination, particularly from hazardous wastes, has been recognized as a very serious national problem in many countries (Wood et al., 1984).

A survey of management-oriented groundwater models is given in Bamachmat et al., 1980. Only few field-tested models, however, that could be incorporated into a tool kit for environmental impact assessment are available. FEEFLOW is a sophisticated two-dimensional finite element model for the simulation of contaminant transport in porous media (Diersch, 1980; Diersch and Kaden, 1984). It has been used successfully in several case studies.

A special case of a model linking terrestrial and aquatic systems is a hydrological simulation model for solid waste disposal sites (HSSWDS), Perrier et al., (1980), describing leachate behavior.

As a special case, somewhere in between disposal technology evaluation and dispersion in aquatic systems, the following table lists models for the description of turbidity plumes resulting from the dispersion of sludge or sediments.

Water disposal of sludges and sediments				
Model	*Discharge Source*	*Applicability*	*Dim.*	*Reference*
KOH-CHANG	Barged dump moving jet	Ocean	3-D	Koh & Chang (1973)
EDGE-DYSART	fixed jet	Deep Ocean	3-D	Edge & Dysart (1972)
KRISHNAPPAN	Barged dump	Deep Ocean	3-D	Krishnappan (1975)
Tetra Tech	Barged dump fixed/moving jet	Ocean/Estuary	3-D	Johnson & Holliday (1978)
MIT	vertical line	Estuaries, coastal waters, wide rivers	3-D	Christodoulou (1974)
WALDEN	point/line source	rivers, estuaries	3-D	Wechsler & Cogley (1977)
SHUBEL	vertical line	rivers, estuaries	2-D	Shubel et al. (1978)

Source: Johnson, 1980.

4.5.4 Terrestrial and Agricultural Systems

In this category, food production and foodchains are clearly of special importance from the point of view of human consumption. Most agricultural models concentrate on pesticides or, in some cases, on radionuclides. They can, however, easily be adapted to any air borne pollutant from an industrial source.

Terrestrial & Food Production Systems		
ACTMO	Agricultural Chemical Transport Model	Frere et al. (1975)
AIRDOS	Radionuclides in terrestrial food	Moore (1975)
BIOTRAN	Environmental Transport of Radionuclides in Forests	Gallegos et al. (1978)
CASSANDRA	Effects of Air Pollutants on Forests	Harwell & Weinstein (1983)
CERES	Trace Contaminant Effects on Forests	Dixon et al. (1983)
CREAMS	Chemicals, Runoff and Erosion from Agricultural Management Systems	Knisel (1980)
ECCES	Calculating Environmental Consequences from Energy Systems	Petersen (1984)
FOOD	Contaminated Food Products	Baker et al. (1976)
GRONK	Environmental Radiation Doses	Soldat et al.(1974)
GROW1	Impact of gaseous pollutants from geothermal technologies on crop growth	Kercher (1977)
HERMES	Environmental Pathways of Radionuclides	Fletcher & Dotson (1971)
PATHWAY	Radionuclide Transport in Crop Systems	Kirchner et al. (1983)

PTR/ARM	Pesticides on Agricultural Land	Donigan & Crawford (1976)
SESOIL	SEasonal SOIL Compartment Model	Bonazountas & Wagner (1981)
SILVA	Air Pollution Effects on Forest Growth	Kercher (1980)
TELOC	Effects of Lead on Corn	Wheeler & Sale (1980)
TERMOD	Contaminated Terrestrial Environment	Booth et al.(1971)
UTM	Soil-Plant-Water Effects on Uptake and Movement of Contaminants	Luxmoore et al. (1974)

Chemicals applied to surface or subsurface soils, or deposited on the ground from the atmosphere, are dispersed in soil as a result of processes associated with the hydrological cycles and with physical and chemical phenomena. This dispersion may lead to contamination of adjacent surface waters and air, depending on chemical, soil, and climatic conditions. Uptake by plants is referred to below in the discussion of the human exposure model TERMOD.

In TOX-SCREEN, the soil system is represented by the one-dimensional model SESOIL (Bonazountas and Wagner, 1981). The model describes the unsaturated soil zone in a simple mass balance approach for a multi-layered soil compartment of arbitrary size. The simulation is structured around three cycles:

- *Hydrological Cycle*, which includes rainfall, infiltration, soil moisture, surface runoff, exfiltration, evapotranspiration, groundwater runoff, capillary rise;
- *Sediment Cycle*, which includes sediment resuspension due to wind, and sediment washload due to rain storms (not operational in the version described by Bonazountas and Wagner (1981).
- *Pollutant Cycle*, which includes advection, diffusion, volatilization, adsorption and desorption, chemical degradation and decay, biological transformation and uptake (see TERMOD-II below), hydrolysis, photolysis, oxidation, cation exchange, and complexation chemistry.

Numerous models have been developed for agrochemicals (Wagner ...), and for the description of detailed physico-chemical behavior of substances in the soil system, e.g., volatilization.

4.6 Human Exposure

The majority of models describing human exposure was built for radionuclides. Inhalation of aerosols, and the translation of external to internal radiation doses are among the more common applications.

For the most important class of hazardous substances, i.e., toxic substances, human health risks are estimated from *exposure* and *toxicity*. They are evaluated for the individual as well as for the affected population. The toxicity of a substance or substance class determines the type of adverse effects that exposure or intake of the substance can cause (e.g., cancer, birth defects, kidney damage) and the relationship between exposure and/or intake and the magnitude of the effect. Exposure depends on the concentration in the environment and the environmental media affected (i.e., water, air, food) and the related probabilities of exposure and/or intake.

A possible model to describe these effects in detail could be based on TERMOD-II (Zach, 1978). Originally developed for radionuclides, the model calculates the time-dependent input of a substance through terrestrial pathways to man following an acute or accidental release. The model calculates daily input rates and the total intake over specified periods. The model includes three types of food, which can be contaminated by deposition. Food crops and grass can be contaminated by direct foliar deposition and via root uptake. Beef, and consequently milk, can be contaminated by uptake of contaminated grass.

An extended version will have to include direct human uptake and exposure through inhalation and skin contact as well as uptake via drinking water. The original radiation concept will be extended into a description of toxicity, considering oral and dermal toxicity (measured as LD_50) for acute toxicity. Long-term effects have to consider toxicological effects such as mutagenicity, carcinogenicity, teratogenicity, embryotoxicity, neurotoxicity, hepatotoxicity, renal toxicity, and pulmonary toxicity. Extended data on such effects are available for selected substances in quantitative form, for example, the Environmental Chemicals Data and Information Network (ECDIN) developed and maintained at JRC, Ispra, or in qualitative form (e.g., Epstein et al., 1982).

Human Exposure and Bioaccumulation		
AERIN	Acute Aerosol Inhalation Exposure	Voilleque (1968)
AIRDOS	Population/Individual Doses of Radionuclides	Moore (1975)
CEDRIC	Dose-Intake Relationship for Radionuclides	Clarke (1972)
DACRIN	Organ Dose from Acute or Chronic Radionuclide Inhalation	Houston et al.(1974)
EXAMS	EXposure Analysis Modeling Systems	Burns et al. (1981)
GETS	Gill-uptake of toxics by fish	EPA
FGETS	Food and Gill-uptake by fish	EPA
HERMES	Regional Radiological Effects	Fletcher & Dotson (1971)
INDOS	Internal Radiation Dose to Man	Killough & Rohwer (1974
TERMOD	Radionuclide Intake by Man	Booth et al (1971)
TERMOD-II	Radionuclide/Food Consumption	Zach (1978)
VADOSCA	Population Exposure from Radionuclides	Bramati et al. (1973)

4.7 Auxiliary Software

In addition to the simulation models listed above, there are several auxiliary software products required for an integrated tool kit designed for comprehensive environmental impact assessment of industrial activities.

Auxiliary software includes

- basic dynamic simulation systems,
- user interface design and graphics,
- data base management,

- data analysis,
- synthetic time series generation,
- optimization,
- presentation graphics
- report generation

Most of the above functions, however, are covered by basic systems utilities as distributed with most operating systems as well as basic mathematical subroutines (eg., as are used for model integration) and are omitted from this survey.

As a set of approaches rather than specific software tools, a number of simulation techniques frequently used in impact assessment modeling, are introduced below. These techniques have primarily been developed as a computer based version and extension of impact matrix techniques, or network analysis methods. They include:

- GSIM: simulates qualitative (positive or negative) cross-impacts between variables (Gallopine 1977);
- KSIM: qualitative normalised cross-impacts, includes state as well as derivative dependencies in a normalized state space, and transforms impacts in a basically logistic model of interdependencies (Kane (1972);
- XIMP: an interactive cross-impact simulation package based on KSIM, offering additional features such as parameter identification, optimization, sensitivity analysis, and stability analysis (Moll and Woodside, 1976);
- QSIM2: continuous simulation method based on interaction matrices, using multiple additive impacts and simple difference equations (Wakeland 1972);
- MISS-E: includes event modeling capabilities (Kwasnicka and Kwasnicki, 1982);
- Systems Dynamics: a classical modeling technique based on interactions and feedback structures, it also provide a system of notation and diagrams to assist model development (Forrester, 1968, 1972; Meadows et al., 1974; Goodman, 1974). Computer implementations use support packages such as DYNAMO, DYSMAP, or DYMOSIM.
- Symbolic Simulation: a versatile combination of the above, using symbolic and object-oriented programming languages such as LISP or Prolog as a basis for implementation (Fedra et al., 1987; Winkelbauer, 1988).

A recent overview of these simulation methods for environmental impact assessment is given in Mohapatra and Vizayakumar (1988).

4.8 A Summary of the Evaluation

A very rough, random and preliminary screening has resulted in more than 200 models. The major sources of information used as a starting point in our survey, i.e., other surveys and listings of models and software, are summarized in the table below.

Software and Model Surveys	
Computer Codes for the Assessment of Radionuclides Released to the Environment	Hoffman et al. (1977)
Names of published computer models in the environmental biological sciences	Kickert (1984)
Computer Codes for Analyzing Nuclear Accidents	Winton (1974)
Directory of Computer Programs for Assessment of Radioactive Waste Disposal in Geological Formations	Broyd et al. (1984)
Compilation of Water Resources Computer Program Abstracts	Kohlhass (1982)
Groundwater Management: the use of numerical models	Bachmat et al. (1980)
UMPLIS: Verzeichnis rechnergestützter Umweltmodelle	Umweltbundesamt (1978)

However, only a few of these models can be regarded as potentially and generally useful. However, it is only fair to mention that most of them were never built to be generally useful. Many serve a very special, well-defined purpose. Others have been constructed at a prototype level, to demonstrate a principle rather than to develop a generally useful tool for widespread application. Also, by and large these models are developed by scientists, not by software professionals. They tend to be idiosyncratic, and most of them are not sufficiently documented for non-expert users. But again, they were never designed for non-expert users. Most have probably not been designed a priori for use outside of the developing group of researchers or the institution.

as an illustrative example, in their evaluation of groundwater models, Bachmat et al. (1980) give some very telling numbers on model use potential: From a total of 39 mass transport models surveyed, only 11 are documented, 16 are easily available, 23 have been applied, and 3 are rated usable. Similar proportions are given for all other model groupings, and in particular in the groundwater management grouping, with 3 usable models out of a recorded total of 29.

According to several of the above evaluations, computer code transferability may also pose a major problem for the widespread practical use of most models. Although some of the codes in this survey may use models that represent the most sophisticated approaches currently available, limitations in transferability among computers, input data, validation potential, or operation costs may force the use of a code with somewhat less sophistication but one that still produces results within an acceptable degree of accuracy. Also, most available impact assessment models are environmental fate models. Only very few models have been identified that explicitly include a treatment of the industrial process and technology, and thus allow for the explicit choice between production alternatives, including their economic consequences.

Most models identified are of a scientific rather than a management and decision-oriented nature.

The requirements for their use, in terms of input data and user experience reflect this orientation. Only very few of the models can be rated "user-friendly"; few are interactive, even fewer offer pre- and postprocessors that make it easier to configure, run, and interpret the codes.

In summary, while numerous valuable elements for supporting the environmental impact assessment of industrial projects could be found, most of them are targeted at isolated and specific problems, or a narrow perception of a problem. They are mostly quite difficult to use, in terms of their data requirements, user training, and the often idiosyncratic input/output formats they use. Some of them could certainly serve as valuable building blocks for an advanced decision-support and information system for impact analysis. This, however, would definitely require a major restructuring of the user interface – in a very inclusive sense – of these models as well as some effort to link and integrate a number of them for a more comprehensive set of tools for environmental impact assessment of industrial activities.

4.9 An Interactive Approach

EIA is by definition a complex procedure that draws on numerous disciplines: the behavior of highly interdependent, but usually ill-defined, systems needs to be understood and forecast. This interdisciplinary nature also calls for an array of related tools. At the same time, the subjective and discretionary human element must also be given due weight, in particular where aesthetic or cultural values are concerned that are difficult or impossible to express in monetary terms or measure reliably on any cardinal scale. This necessary subjective element calls for the direct and interactive involvement of users, allowing them to exert discretion and judgement wherever formal methods are insufficient.

Also, many information processing tasks such as recognition and comparison of complex patterns that depend on background information and an understanding of context, are often done more efficiently by man than by a machine. The direct integration of the user in turn requires a man-machine interface that is easy to use and error correcting, and thus minimizes problems of user error and user training.

The background information required for any comprehensive EIA is characterized by a broad range of disciplines and is subject to a variable degree of resolution and uncertainty. The assessment process therefore requires a strong element of human expertise and judgement in addition to the more formal, scientifically-based, analytical techniques based on technological, physico-chemical, ecological, and economic principles. Computer-based methods of applied systems analysis, implemented using modern information processing technology, can now support such a comprehensive, interdisciplinary approach to environmental impact assessment. This approach can provide a powerful interactive tool for managers and planners, regulators and policy makers, because it makes access to a large number of relevant data bases, problem simulation modules, and decision support tools easy and reliable.

At the core of this interactive approach, developed at the *Advanced Computer Applications* (ACA) group of the International Institute for Applied Systems Analysis, is an integrated set of modular software tools, building on existing models and computer-assisted procedures, that is intended for a broad class of users and should provide them with easy access to methods of analysis and information management which have previously been restricted to a small group of experts. To facilitate access to complex data base systems and computer models by the non-expert user, it is necessary to build much of the accumulated knowledge of the subject areas into the user interface. The interface therefore incorporates elements of knowledge-based expert systems which assist the user to retrieve information or select, set up, run and interpret the specialized software relevant to his needs with a minimum of data preparation and manipulation effort.

By providing a coherent user interface, the interactions between different models, their data bases and auxiliary software become more transparent to the user. Extensive use of symbolic representation with high-resolution color graphics and menu-driven operations aids this transparency and make the systems user friendly. Customizing the information and decision support systems for only a small set of specific applications, and then building the necessary background, context, and expertise into this special-purpose system, means trading off flexibility and generality for efficiency. However, as a consequence, a very efficient and largely error-free use of complex computer systems becomes possible even for users that have no expertise in the use of computers.

A number of examples, following the above design and implementation guidelines to various degrees, have been developed at the *Advanced Computer Applications* group at IIASA, and, with various emphases on the interactive design, artificial intelligence components, operations research aspects, or geographical information systems, at CADSWES (University of Colorado), the US Bureau of Reclamation, the USEPA, Environment Canada, as well as by a number of commercial software developers in the United States, Canada, the United Kingdom, or the Federal Republic of Germany. Recent examples are described, eg., in Fedra et al., 1987; Fedra, 1988a,b,c; Vallance and Weigkricht, 1988; Beck, 1988; Gray and Stokoe, 1988.

Although they differ widely in their degree of sophistication, detail, and complexity, all of the above application examples have a common structure:

Built around one or more coupled simulation models, the systems feature:

- an interactive, menu-driven user interface, that guides the user with prompt and explain messages through the application. No command language of special format of interaction is necessary, the computer assists the user in its proper use;
- dynamic color graphics for the model output and a symbolic representation of major problem components, that allow for easy and immediate understanding of basic patterns and relationships. Rather than emphasizing the numerical results, symbolic representations and the visualization of complex patterns and time and space support an intuitive understanding of complex systems behavior;
- the coupling to one or several data bases that provide necessary input information to the models. The user's choice or definition of a specific scenario can be expressed in an aggregated and symbolic, problem oriented manner without concern for the technical details of the computer implementation;
- embedded AI components such as specific knowledge bases allow user specifications in allowable ranges, to be checked and constrained and ensure the consistency of interactively defined scenaria.

In summary, the models are designed for easy and efficient use, even in data-poor situations, and do not require specific technical expertise from their user. The "intelligent" interface and its preand post-processing functions free the user from the time consuming and error-prone tasks of data file preparation, the mechanics of model runs, and finally the interpretation and translation of numerical results into meaningful and problem-adequate terms. This not only allows the user to employ the models more freely in a more experimental and informative way, it also allows the analyst to concentrate on the more important tasks he can do best, ie., the recognition of emerging patterns, the comparative evaluation of complex alternatives, and the entire institutional aspects of any environmental impact assessment rather than its technicalities.

5 SOURCES OF INFORMATION

A very important precondition to any modeling activity, and more generally, any impact assessment exercise, are the data and information that each procedure or model requires.

A vast and rapidly growing scientific literature, numerous handbooks and guidelines, reference manuals, published procedures, data files and data bases, as well as complex information services are available. To get access, however, requires knowledge as to what is available, where, and what procedures are necessary to retrieve information from any of the available sources. Collecting and organizing information *about relevant information* is therefore a very necessary and valuable task.

5. 1 Industries, Processes and Products

As an example, consider the problem of industrial pollutants: the main organizing principles, required for structuring information on pollutants to make it useful for industry specific impact assessments, are

- Industrial Sectors
- Production Processes and Technologies (which are also used as subcategories for the industrial sectors as well as the products)
- Industrial Products
- Industrial Waste Streams and Chemical Substances

Each *Industrial Sector* produces *Products*, possibly with a number of alternative *Production Processes* or *Technologies*, and with each Product/Process combination, a certain amount of pollutants in the form of routine emissions and wastes, is generated. These substances are then either recycled, used for further production or marketed as the products of a production process, or released into the environment. In addition to these routine emissions, accidental emissions have to be considered.

The relationship between the industrial sectors and production processes and the wastes they produce, or, alternatively, substances and their origin in the production process, are discussed in Fedra et al. (1985).

Source-specific emission factors (eg., for atmospheric pollution) have been compiled by EPA in the United States (USEPA 1976b). They cover more than 100 source classes, grouped into the following main categories:

- External Combustion Sources (e.g., Natural gas combustion, Lignite combustion, ...);
- Internal Combustion Engine Sources (e.g., Highway vehicles, stationary sources, ...);
- Solid Waste Disposal (e.g., Refuse incineration, Open burning, ...);
- Evaporation Loss Sources (e.g., Dry cleaning, Gasoline marketing, ...);
- Petroleum Industry (e.g., Petroleum refining, Natural gas processing, ...);
- Chemical Process Industry (e.g., Explosives, Paint and varnish, Synthetic fibres, ...);
- Metallurgical Industry (e.g., Lead smelting, Steel foundries, ...);
- Mineral Products Industry (e.g., Asphalt roofing, Glass manufacturing, ...);
- Wood Processing (e.g., Chemical wood pulping, Pulpboard, ...);
- Food and Agricultural Industry (e.g., Meat smokehouses, Sugar cane processing, ...);
- Miscellaneous Sources (e.g., Forest wildfires, ...).

Similar collections of industry specific emission coefficients have been compiled by the Dutch Ministry for Physical Planning, Housing, and the Environment (VROM). A collection of simple methods for impact and risk estimation, the so-called *yellow book* has been prepared by TNO for the Directorate-General of Labour, Ministry of Social Affairs, in the Netherlands (TNO, 1979).

Other sources of sector specific information are, for example, the *Environmental Aspects* and related series of the Industry and Environment Office of UNEP in Paris. Overviews, technical reviews, manuals, or guidelines are currently available for the following sectors and industries:

1. pulp and paper
2. sugar industry
3. iron and steel production
4. selected non-ferrous metals industries
5. oil refineries and terminals
6. alumina production
7. aluminum smelting
8. nickel production
9. chemical industries (risk management and accident prevention)

So-called sector catalogues have been prepared by the Federal Ministry for Economic Cooperation (BMZ), Federal Republic of Germany, as an instrument for identifying problems. They can be used to ascertain which projects (industries) are ecologically unproblematic and to prepare specific studies. They are designed, at the pre-feasibility and screening level, to assist in the identification, initial assessment, and provisional selection of projects. In conjunction with guidelines for carrying out environmental studies, a catalogue of standards, and national and country specific parts of a catalogue of institutions, they provide assistance for the in-depth identification and assessment of environmental effects when a specific project is being appraised. Sectoral catalogues are available for the following industrial sectors:

1. nitrogenous fertilisers, raw materials, ammonia and urea production
2. nitrogenous fertilisers, starting materials and final products
3. cement and lime, production, storage, further processing
4. fine ceramics and earthenware
5. glass
6. iron and steel; production and further processing
7. non-ferrous metals; production and further processing
8. mechanical engineering; workshops. shipyards
9. wood; sawmills, wood processing, wood products
10. cellulose and paper
11. oils and greases
12. meat; slaughterhouse and meat processing
13. sugar; production and further processing
14. grain mills
15. textile industry

The structure of these catalogues follows the pattern described below:

- *Description of project area* information concerning project size, capacities, interaction with other project areas, general site requirements, locations of environmental effects.
- *Environmental effects and environmental protection measures*
    1. description of environmental impact typical of the project on water, weather and air, soil, the human being, plant and animal worlds, ecosystems.
        - noise, oscillation, electromagnetic waves, effects of transmitters and receivers
        - land requirements, nature reserves, land use, water pollution, waste oil, storage tanks, etc.
    2. prevention, avoidance, and disposal methods
        - low-noise engines, frequency spectrum, interference suppression

  - noise control walls, oil separators, land use planning, selection of aircraft take-off and approach routes

- *Guidelines for the assessment and evaluation of environmental effects*
  - compilation of environmental quality standards and maximum permissible limits, indication of measuring method
  - measuring stations, environmental quality standards, establishments of aircraft flight altitudes, national and international rules, regulations and directives
  - approaching flight route delimitation, construction regulations, safety margins, storage of flammable materials, etc.

- *Interaction with other project areas* description, linkages, land use conflicts
- *Summarised evaluation of environmental impact*
- *Reference Material* Listing

5.2 Industrial waste and waste management

In addition to high-volume but relatively low-risk pollutants such as BOD and COD, SO_2, NO_x, dust dust, hazardous waste is probably the single most important subset of industrial pollutants causing severe environmental impacts. According to a 1980 study of the USEPA, the four industrial sectors indicated below, together with several subsectors, contribute 82% of the hazardous waste generated in the U.S. (Putnam, Hayes, and Bartlett, Inc. (PHB) 1980). Similar results were obtained in a 1983 survey of the EPA's Office of Solid Waste (Westat Research, 1984). For these industrial sectors, the USEPA study (ICF 1984a,b) identifies and provides data for 154 industrial waste streams, each characterized by 30 data elements.

The specific Industrial Production Sectors considered include (List based on ICF,1984):

- **Chemical Industries:** Alkali and chlorine, Inorganic pigments, Synthetic organic fibers, Gum and wood chemicals, Organic chemicals, Agricultural chemicals, Explosives
- **Petroleum and Coal Products:** Petroleum
- **Primary Metals:** Iron and steel, Secondary nonferrous metals, Copper drawing and rolling
- **Fabricated Metals:** Plating and polishing

The Waste Management, or Treatment and Disposal Sector, receives the waste streams from the *Industrial Production Sector* and the *Use/Market Sector* (industrial and domestic waste). Similar to the industrial production sector, the models can describe several alternative technologies, and estimates costs and remaining environmental impacts for alternative waste management schemes. Besides a normal operation mode, "accident" or mismanagement scenarios are possible.

In its RCRA Risk/Cost Analysis Model (ICF 1984), EPA is considering a selection of treatment technologies:

1. *Vacuum filtration*: dewaters and concentrates the suspended solids contained in a sludge stream;

2. *Centrifugation*: dewaters and concentrates the suspended solids contain from a sludge stream;

3. *Sludge drying beds*: dewaters sludges by drainage through graded sand and gravel layers and by evaporation;

4. *Evaporation/drying*: removes free liquids to concentrate waste streams or dry sludges;

5. *Chemical precipitation*: removes dissolved metals from aqueous solutions;

6. *Oxidation/reduction*: oxidation/reduction coverts constituents to a lower or higher valence state, respectively, that may be less toxic or more amenable to further reactions or other treatment;

7. *Steam stripping*: removes constituents by volatilization, a form of fractional distillation;

8. *Solvent extraction*: separates specific constituents from a liquid solution through solvents such as benzene, toluene, chloroform, methylene, methylene chloride, isopropyl ether, or butylacetate;

9. *Leaching*: extracts and concentrates constituents from a solid material by dissolution into a solvent;

10. *Distillation*: separates components of a mixture using differences in vapor pressure;

11. *Carbon adsorption*: removes organic contaminants from wastewater;

12. *Biological treatment*: destroys biologically degradable organic compounds in wastewater with a mixture of microorganisms;

13. *Chemical stabilization/fixation*: binds constituents into a durable, less leachable cement;

14. *Asphalt solidification*: coats the waste with a heated asphalt binder, and incorporates it into a solid asphalt matrix;

15. *Containerization*: stores accumulated constituents in metal, plastic, or fiber containers for transport, and on-site or off-site disposal.

Each of these technologies has different characteristics with regard to key design and operating features, feasible waste streams, the effectiveness of the technology in altering the hazardous nature of the waste, and finally the amount and probability of any environmental release of hazardous constituents generated by the technology.

The second set of technologies in the waste management sector is *Disposal Technologies*. A list of six major technologies is used in EPA's WET approach (ICF, 1984a,b):

1. *Landfills*: placing waste in a specifically prepared excavation or trench and covering the waste with fill material (Ware and Jackson, 1978; Shen, 1981; USEPA 1982a,b, 1983);

2. *Land treatment*: uses soil or a soil-vegetation system to decompose or immobilize waste (Brown et al., 1983; SCS Engineers, 1978; Bentley, 1981; USEPA, 1982);

3. *Surface impoundment*:

4. *Deep well injection*:

5. *Waste piles*:

6. *Incineration*:

Similar to the treatment technologies, disposal technologies differ in terms of feasible waste streams, the release of constituents to the environment, and the cost and resource consumption for operation. Cost estimates for each technology are given in ICF (1984b). New and emergent technologies such as:

1. molten salt combustion,
2. fluidized bed combustion,
3. ultraviolet/ozone destruction,
4. catalyzed wet oxidation,
5. dehalogenation by ultraviolet light and hydrogen,
6. electron irradiation in aqueous solution,
7. catalytic hydrogenation dechlorination,

are described, for example, by Edwards et al., 1983.

Description of waste treatment and disposal technologies are given, for instance, in the data of the UNEP/IRPTC waste management file (UNEP/IRPTC, 1984), or INFUCHS (developed and maintained at the Umweltbundesamt, UBA, FRG), or the waste stream treatment and disposal technology linkages of the RCRA (WET) Model (ICF 1984).

smallskip Several recent books cover treatment and disposal technologies for hazardous wastes in considerable technical detail (e.g., Edwards et al., 1983; Francis and Auerbach, 1983; Lehman, 1983; Kiang and Metry, 1982; Brown et al., 1983; Peirce and Vesilind, 1981).

5.3 Information Services and Data Bases

As an important group of auxiliary information, data on major sources of information, i.e., abstracting and information services, reference and information centers, and data base services, should be collected. Again, their major purpose is to refer the user to a likely source of information that may not be found in the present system. This holds certainly true for many detailed aspects of information on substances, where, with more than 30,000 chemical substances on the world market and about 1000 substances added to this list every year, any attempt at a complete information system is rather unrealistic.

Information Systems and Data Base Services			
AEROS	Aerometric and Emissions Reporting System	USA	EPA
AQUALINE	Literature on water	UK	Water Research Center
APTIC	Air Pollution Technical Information Center	USA	EPA
CHEMLINE	Chemical Dictionary On-Line	USA	Public Health Service
ECDIN	Environmental Chemicals Data and Information Network	ECE	Joint Research Center (JRC)
EDBD	Environmental Data Base Directory	USA	NOAA
EDS	Environmental Data Service	USA	NOAA
EIAC	Environmental Information Analysis Center	USA	Battelle Memorial Inst.
EIC	Energy Information Center	USA	Battelle Memorial Inst.
EISO	Environmental Information System Office	USA	Oak Ridge NL
EMIC	Environmental Mutagen Information Center	USA	Oak Ridge NL
ENDEX	Environmental Data Index	USA	NOAA
ENVIRON	Environmental Information Retrieval On-Line	USA	EPA
ESIC	Environmental Science Information Center	USA	NOAA
ESIC	Ecological Sciences Information Center	USA	Oak Ridge NL
EUROCOPI	Scientific/Technical Software	CEC	JRC Ispra
GEMS	Global Environment Monitoring System	UN	UNEP
GPSF	General Point Source File	USA	EPA
GRID	Global Resource Information DB	UN	UNEP
HATREMS	Hazardous and Trace Substance Inventory System	USA	EPA
HAZCHEM	Hazardous Chemicals	UK	Harwell
INFOTERRA	sources of information, expertise	UN	UNEP
INFUCHS	Informationsystem für Umwelt-chemikalien, Chemieanlagen, und Störfälle	FRG	Umweltbundesamt
IRPTC	International Register of Potentially Toxic Chemicals	UN	UNEP/IRPTC, Geneva
MERES	Matrix of Environmental Residuals for Energy Systems	USA	Council on Environmental Quality
NEDS	National Emission Data System	USA	EPA
NERC	National Environmental Research Center	USA	EPA
NIEHS	National Institute of Environmental Health Sciences Information Services	USA	Public Health Service
NIH/EPA	Chemical Information System	USA	EPA

NIOSH	National Institute of Occupational Safety and Health Technical Information Services	USA	Public Health Service
NWDS	National Water Data System	USA	Geological Survey
OWDC	Office of Water Data Coordination	USA	Geological Survey
RISCA	Industrial Process Information	FRG	UBA
STORET	Storage and Retrieval of Water Quality Data	USA	EPA
SWIRS	Solid Waste Information System	USA	EPA
TIRC	Toxicology Information Response Center	USA	Oak Ridge NL
TOXLINE	Toxicology Information Program	USA	Public Health Service
TMIC	Toxic Materials Information Center	USA	Oak Ridge NL
UMPLIS	Literature, data, and software references	FRG	Umweltbundesamt, Berlin
UNAMAP	User Network for Applied Modeling of Air Pollution	USA	EPA
WRSIC	Water Resources Scientific Information Center	USA	Dept. of the Interior

Again, it must be stressed that the above listing is only a small subset of the existing information systems. For example, Golden et al. (1980) list and evaluate 260 data files in eight toxic pollutants categories (derived from Bracken et al. 1977).

In addition to the computer based data files, there are numerous printed sources of information such as manuals and handbooks. A first selection of such sources of information is included in the *References and Selected Bibliography* section.

6 A PROPOSAL FOR UNIDPLAN

For industrial development projects, environmental impact assessment as an integrated part of the overall development planning process is becoming an increasingly important component, required under the laws and regulations of an increasing number of countries, including developing countries, or organisations.

Within the framework of UNIDO and UNIDPLAN in particular, it seems appropriate to concentrate on the industrial, technological, and economical components of environmental impact assessment, ie., the sources of pollution, alternative technologies and their costs, monetary as well as in terms of resource consumption, pollution control and mitigation measures, and good planning, design and management practices with due consideration of environmental problems.

Here generic tools for a screening level assessment can be prepared for the various industrial sectors and their range of production and auxiliary technologies. Such tools, at the various levels of conceptualisation and aggregation, from the national economy to the enterprise, can range from simple manual or handbook type guidelines to computer based expert systems and tutorial interactive assessment programs with the integration of the necessary technological data bases.

Interactive computer based tools, using modern computer technology, can be made easy to use, and can therefore not only be used by a broad group of user including those without computer experience, but are also of considerable didactic value for teaching and training programs. Also, they can include in the form of data bases, eg., on technology characteristics and emission coefficients, environmental standards and thresholds, dose-response curves, or toxicity data, much of the specific background information required to conduct a comprehensive analysis.

The site-specific environmental component can be covered, especially at the screening and pre-feasibility level, by conducting the analysis for a range of generic environments, characterised along dimensions of sensitivities and vulnerabilities for the various impact categories. Once a specific site has been selected for a concrete project, the appropriate generic environment has to be refined and adapted.

To collect, adapt, design, and disseminate such methods and tools, in a format that is easy to use, easy to update, and easy to distribute, using preferably electronic media, UNIDPLAN could develop a clearing house function, possibly in collaboration with one or several *centers of excellence* for the collection of information and the preparation of the material, that should gradually and increasingly with time involve appropriate institutions in developing countries.

Functions of the clearing house for environmental impact assessment of industrial development projects would include:

- to systematically collect information and sources of information with regard to environmental impact assessment of industrial projects and keep this information basis current;
- to analyse, aggregate, synthesize, and disseminate this information, and provide information systems function in the area;
- to develop general and sectoral to technology specific guidelines for environmental impact assessment with special emphasis on UNIDOs own procedures and projects;
- to collect, test, adapt, and prepare for dissemination software for environmental impact assessment, with the ultimate goal to develop and establish an integrated set of standardized and fully tested software tools and procedures for impact assessment of industrial projects;
- to assist individual projects in conduction assessments by providing information, software, and expertise.

The proposed information systems, that should be developed and maintained by UNIDPLAN, should contain the following major components or data bases:

- information on industrial production technologies and in particular on environmentally sound, *clean*, or *best available* technologies
- information on industrial pollutants
- information on pollution control and waste management technologies, including recycling and the use of byproducts and wastes

- information on basic environmental data required for impact assessment
- information on standards, guidelines, and procedures
- selected illustrative case studies of impact assessments
- a collection of general, sectoral, and technology specific guidelines and procedures for impact assessment
- information on software tools, related sources of information, institutions and experts
- a collection of selected easy-to-use software tools for dissemination.

Obviously, since much of this information is already available at many institutions and organisation, it is the compilation of secondary information, ie., on sources of information and the procedures to obtain this information, that is of primary relevance. It is not proposed to duplicate all the effort undertaken in this field, but rather synthesize and facilitate access by providing one focal point for enquiries, that can then be either referred to other institutions or satisfied directly from the clearing house.

It is recommended that UNIDO compiles and prepares data files and data bases on information and sources of information relevant to the environmental impact assessment of industrial projects, such as sectoral and process specific technology profiles including environmentally relevant information such as emission coefficients, waste and byproduct generation, environmentally sound alternative technologies, possibilities for recycling and the use of byproducts and wastes, pollution control and mitigation techniques, etc.

These data bases should ultimately be part of an easy-to-use interactive information system, that assists the user in retrieving the required information in a conversational and tutorial manner. Implementation on personal and micro-computers would allow for the dissemination of the information and information updates, together with the necessary data management and retrieval software, in the form of electronic media such as floppy discs or optical ROM discs.

Numerous guidelines for *Environmental Impact Assessment* have been published in the scientific literature, or have been developed by various institutions such as UNEP, WHO, World Bank, Asian Development Bank, USAID, or the Federal Ministry for Economic Cooperation (BMZ), Federal Republic of Germany, as well as numerous individual countries. A number of references are included in the *References and Selected Bibliography* section. However, most methods and approaches and related guidelines are not designed for a wide range of projects, and not for industrial development projects in particular. They are thus only of limited usefulness for the specific purpose of impact assessment of industrial activities, where the predominant source of environmental impacts is well understood and subject to technological and economic mitigation and solutions. The majority of existing methods can therefore at best serve as a starting point for the development and implementation of more directly relevant specific methods and guidelines.

It is recommended that these available guidelines are critically reviewed for their applicability to industrial planning and UNIDPLAN in particular, and a UNIDO specific set of general as well as sectoral guidelines with special emphasis on the technological, institutional, and socio-economic situation in developing countries is adapted and prepared on the basis of examples already existing.

As a specific contribution by UNIDO, a set of software tools for environmental impact assessment of industrial projects should be compiled, adapted, and prepared for dissemination. They should include interactive checklists and matrix approaches, coupled with interactive data bases with expert systems features, dynamic simulation models for environmental consequence modeling, as well as planning oriented simulation and optimization models for technology selection, pollution control and environmental mitigation measures. Important considerations for the selection and preparation of software tools are

- well established scientific background and track record of successful use, extensive practical testing;
- user friendliness and ease of use, including self-teaching features, integration of basic background information, easy-to-understand presentation of results, eg., through graphics, etc.
- possible operation on widely available or low-cost computer equipment.

It is recommended that UNIDO undertakes or sponsors the compilation and adaptation of selected general and sector specific software tools, for the environmental impact assessment of industrial projects, and maintains them at headquarter and selected *centers of excellence*, including appropriate institutions in developing countries, for the dissemination in assistance of individual projects.

In addition to the necessary documentation and tutorial application examples, UNIDPLAN should also prepare and offer training courses in the use of these software tools, to be organised and conducted at headquarters as well as as at appropriate regional centers.

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