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Computer-Based Models in Integrated Environmental Assessment

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Executive Summary

Integrated Environmental Assessment (IEA) is increasingly recognised as an important technique for managing the environmental impacts of human actions. IEA may be defined as the interdisciplinary process of identification, analysis and appraisal of all the relevant natural and human processes which affect the quality of the environment and environmental resources. The objective of IEA is to facilitate the framing and implementation of optimal policies and strategies, accounting for both environmental effects and other priorities (e.g. cost constraints). Two points worth emphasising about IEA are that it is:

- practical — the purpose is to facilitate making a decision;
- comprehensive — all relevant aspects which might affect the decision should be incorporated.

To put it less formally, Integrated Environmental Assessments provide information to help decision makers to draw conclusions about the state of environmental resources and relate the findings to appropriate management issues. IEA can help managers and decision makers to:

- solve environmental planning and management problems;
- improve their understanding of environmental conditions;
- design protective or remedial strategies.

The concept of Integrated Environmental Assessment as a discipline is relatively new, and some of the ideas involved are quite novel. This report is intended to help those new to the field. The first half of the report describes in more detail what IEA is and what it can do, in comparison with other assessment techniques, and gives examples of uses of IEA in practical applications. The second part of the report describes how computer models and tools can support assessment work. Because there are many aspects to IEA, a wide range of computer tools are potentially useful, such as simulation models, information management tools and decision support systems. In addition, a number of programs have been written with IEA specifically in mind. The report describes these types of tool, and gives details of a selection of publicly-available programs.

Contents

1. Introduction

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The second part of the report describes how computer models and tools can support assessment work. Because there are many aspects to IEA, a wide range of computer tools are potentially useful, such as simulation models, information management tools and decision support systems. In addition, a number of programs have been written with IEA specifically in mind. Section 5 describes all these types of tool and explains their role in assisting with IEA. To develop this further, a selection of publicly-available computer programs are presented. The criteria used for deciding which programs should be included — the main criterion being that they are suited to or useful in *Integrated* Environmental Assessment — are given in Section 7. The programs are listed in categories in Section 8. Detailed descriptions of the individual programs appear in Appendix A.

Where certain classes of models have not been included in this report for some reason, but are nevertheless considered of possible interest to some readers, Appendix B provides sources of further information, including other places where lists of models may be found.

2. Integrated Environmental Assessment (IEA)

2.1 Introduction

Integrated Environmental Assessment (IEA) is a recent term for a relatively old activity. Frequently, when trying to solve an environmental problem, the concepts of IEA arise naturally. These concepts have been reinvented and applied to assessments in an ad-hoc manner over the years. It is only relatively recently, however, that people have recognised that these ideas can be abstracted and formalised, and a rigorous discipline of IEA created. Although the name has quickly become well-established, there is still widespread uncertainty about what the discipline actually is, what its benefits and drawbacks are, what special skills are required, how and where is can be applied, and how it interacts with other activities. A small but growing band of workers has attempted to answer these questions, to develop IEA as a discipline, and to determine and propagate best practice in IEA. Some of the organisations working to develop IEA are listed in Section 2.8; useful overview papers have been written by Parson and Fisher-Vanden (1995), Parson (1995), Hordijk (1995), and Dowlatabadi (1995).

IEA is an approach which can be used in a very wide range of topics, application areas and problems. This can make it difficult to describe or explain. Sometimes the descriptions in this report are given in rather abstract terms, in order to retain a sense of this generic nature. For example, we talk about assessing a "system": it is implied that this system may need to be assessed in terms of geographical, ecological, physico-chemical, socioeconomic and other characteristics. In other places in this report, where abstract language may be confusing, we talk about IEA in terms of one of the canonical environmental problems — for example, emission of toxic chemical pollutants, or anthropogenic climate change. For examples of actual applications of IEA, see Section 2.7, which will help make some of the concepts described clearer.

To understand what "Integrated Environmental Assessment" is, we build up the meaning of the term by looking at the three words in turn.

2.2 What is Environmental Assessment?

"Assessment" means a scientific study of some problem of practical importance, with the purpose of enabling (or at least helping) someone make a decision about what actions should be taken to achieve the best effects. Generally, there will be alternative courses of action with different consequences, good and bad, to different stakeholders. The objective is to find an optimum compromise between interest groups.

That is, an assessment is not pure research, but intended to be used by decision-makers or policy-makers. Usually it will involve collecting and analysing existing knowledge, although some new research may be required to fill in gaps. Questions of probability and degree of confidence are of great importance and should be addressed explicitly. The conclusions of the assessment must be at the same time justifiable to scientists, useful to decision-makers, and understandable to all interested parties, possibly including the general public. (With regard to understandability, it is possible that the results will have to be presented in different ways to different audiences.)

"Environmental" obviously means that the assessment is about some aspect of the environment or natural or ecological resources. This includes such things as human health, health of ecosystems, biodiversity, landscapes, sites of scientific, archaeological, historic, cultural or aesthetic value, and so on. More specifically, an environmental assessment is, by implication, concerned with some problem or difficulty in the interaction between people and the environment. (This word is often omitted from the literature on "integrated assessment", many of the principles of which could be applied to assessments with no particular environmental aspects.)

Thus, Environmental Assessment (EA) is the process of collecting information about the current and future state of environmental quality and resources, analysing it, and deciding on actions to optimise the future environmental state and avoid, diminish or remedy environmental harm. The ultimate purpose of Environmental Assessment is to optimise the quality of the environment.

EAs are performed by the following procedure (DOE 1995):

- Examine the current environmental character of the area under study (the "baseline").
- Identify natural and artificial processes which may already be changing the character of the study area.
- Consider the possible interactions between anticipated environmental pressures and both existing and future site conditions.
- Predict the possible effects, both beneficial and adverse, of the pressures on the environment.
- Introduce measures to avoid, minimise or mitigate adverse effects and enhance positive effects.

The most important application of EA is determining the impacts of new industrial developments; sometimes the term Environmental Impact Assessment is used in this context. In the European Union, EAs are a legal requirement as part of the planning approval procedure (EC 1985).

2.3 what is Integrated Environmental Assessment (IEA)?

The idea of an *Integrated* Environmental Assessment (IEA) is that it is in some way more general and wide-ranging than a traditional EA, based on a broader view of the system than is usual in a study based on a single discipline, or an impact assessment of a single development. The environmental problem is large, complex and multifarious, and the aim is to tackle the whole problem (or a wide aspect of it). There are two main types of "integration".

First, perhaps the most common way is vertical or end-to-end integration. This incorporates the whole of the causal chain of socioeconomic driving forces, pressures on the environment, the resulting state of the environment, the impacts and the required managerial responses. End-to-end integration is discussed more fully in the Section 2.4, which describes the DPSIR framework for understanding the causal chain and managing an end-to-end IEA.

The other main way to "integrate" an assessment is horizontally, broadening the study across disciplines within a single link of the causal chain. For example, there are many types of environmental pressures: they may be broken down in terms of types of activities, economic sectors, types of emission, location and time (Parson and Fisher-Vanden 1995). Similarly, impacts include impacts on human health, ecosystems, biodiversity, amenity value, financial value and resource availability. In addition, a geographical study area will typically include several different media, such as air, groundwater, lakes, rivers, estuaries and seas; studying these makes different demands and requires different skills, and so they are often tackled separately. A horizontally integrated assessment will include many or all of the pressures, many or all of the impacts and many or all of the geographical media.

Other aspects of integration for IEA have been identified by Rothman and Robinson (1997). These are, in brief:

- Consideration of feedbacks and dynamics (see Section 2.5.3).
- Allowing for human adaptation to environmental change and policies to address this change.
- Recognising multiple base-lines — i.e. recognising that the system under study will depend on other systems which may change for independent reasons.
- Integration of quantitative and qualitative dimensions (see Section 3.1).
- Integrating policy and scientific objectives in an assessment.
- Involvement and participation of the various stakeholders in the assessment process.

Clearly, integration falls on a continuous spectrum. There is no dichotomy between integrated and non-integrated assessments — it is a relative term. All assessments require some degree of integration across disciplines, and it is usual to consider more than one link in the causal chain. On the other hand, it is often not necessary to consider the whole end-to-end chain. Similarly, horizontally integrated assessments are often able to discount some areas without in-depth study. Some IEAs are “more integrated” than others. This point is elaborated in Section 2.5.2.

Moreover, an IEA will normally employ both end-to-end and horizontal integration to some extent. On a higher level of integration the “grand integrated assessment” would look at the whole field of activity, for example considering the whole question of energy consumption and its impacts. This would be an enormous effort, an order of magnitude greater than the current international climate change project. Finally, the ultimate in integration would be to answer the question “How can we optimise the total impact of our lives on the environment?”

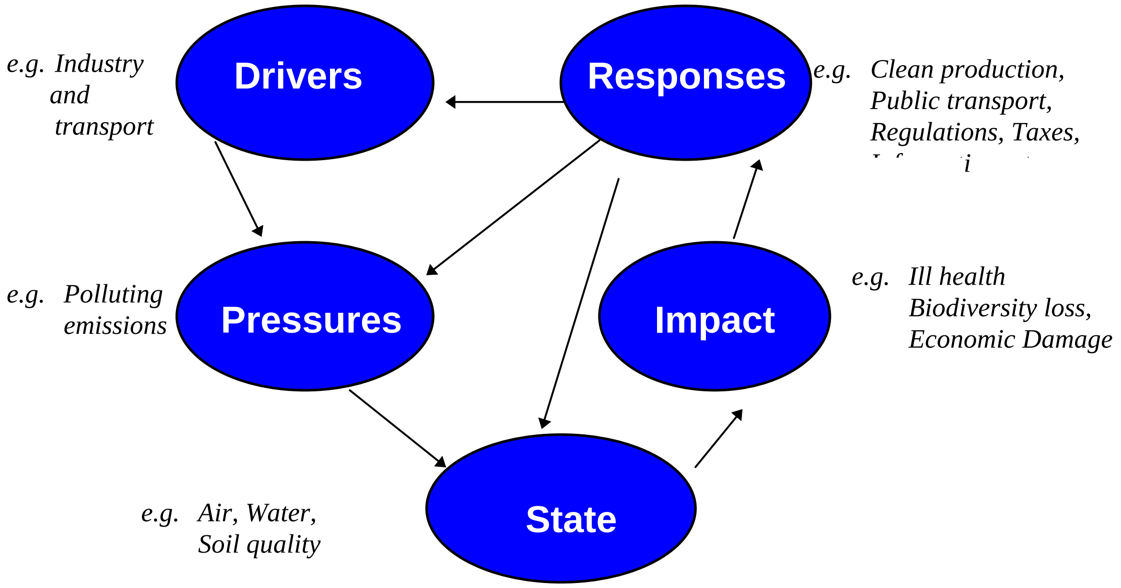
2.4 End-to-end IEA and DPSIR

The idea of end-to-end or vertically integrated assessment has been briefly described in Section 2.3, but requires further explanation both because it is important and useful, and because exactly the same ideas can be used in a wide variety of assessments.

A good way to understand end-to-end integration is to use the DPSIR framework (Figure 1). DPSIR summarises the end-to-end cycle. It provides a framework or conceptual model that gives the assessor a high-level view of the problem. This means that it structures the assessor’s thinking, helping to ensure that she has a good understanding of the dynamics of the system. It can help to ensure that the assessment is properly comprehensive, addressing the whole end-to-end problem.

In addition, the DPSIR model could be used for high-level organisation of the assessment process, perhaps with one team of assessors concentrating on one of the five steps each. (The CIAP project described in Section 2.7.1 used a similar organisational structure with six groups.)

Figure 1. The DPSIR Framework (Source: EEA)



DPSIR treats the environmental management process as a feedback loop controlling a cycle consisting of five stages: Driving forces, Pressures, State, Impact and Response.

- **Drivers** are the underlying causes which lead to environmental pressures. Examples are the human demands for agriculture, energy, industry, transport and housing.
- These driving forces lead to **pressures** on the environment, for example the exploitation of resources (land, water, minerals, fuels, etc.) and the emission of pollution.
- The pressures in turn affect the **state** of the environment. This refers to the quality of the various environmental media (air, soil, water, etc.) and their consequent ability to support the demands placed on them (for example, supporting human and non-human life, supplying resources, etc.).
- Changes in the state may have an **impact** on human health, ecosystems, biodiversity, amenity value, financial value, etc. Impact may be expressed in terms of the level of environmental harm.
- The task of managers or decision makers is to assess the driving forces, pressures, state and their ultimate impact. From the impact they must determine appropriate **responses**, in order to direct the final impact in the desired direction (a reduction in environmental harm). These responses will influence the **drivers, pressures** and **states**, thus completing a feedback loop. Examples of responses might be:
    - introducing “green taxes” to reduce public demand (response acting on a driver);
    - requiring industry to reduce pollution emissions (response acting on a pressure);
    - implementing programmes to clean contaminated land (response acting on a state).

The decision-maker is trying to produce a certain desired impact (typically, a reduction in environmental harm to a given level). She does this by applying responses that directly or indirectly influence the driving forces, pressures and state. The impact can only be changed indirectly, at the end of a chain of events. She must, therefore, use a model to predict what effect her changes to the driving forces and pressures will have on the impact, further along the cycle. The model may be a personal rule of thumb based on her own judgement and experience, or an independent and reproducible tool, usually a computer program. (The use of computer programs should always be tempered by the analyst's judgement and experience, of course.) The kinds of computer model that are available to assist her in this are described in Section 5.

2.5 The relationship between EA and IEA

2.5.1 The task of integration

It has been said that an "unintegrated" EA is merely one end of a spectrum, and most EAs are in practice integrated to some extent. However, there is a qualitative difference between assessments which do not attempt any significant integration, and those that do. Any significant degree of integration introduces a new dimension into an assessment. This is due to IEA's multi-disciplinary nature and its consequent requirement to synthesise different types of knowledge and information.

This can be a non-trivial task. For example, if computer models from different fields are being used, they must often be modified so that they can run together properly. More generally, linking knowledge across fields requires thinking differently *within* the fields, as Parson and Fisher-Vanden point out (1995). Indeed, they go so far as to say that the bulk of the intellectual contribution of integrated assessment will be made at the junctions between disciplines, through processes of linking, sharing and reconciling knowledge. Parson (1995) even suggests that the skills of integration may become a specialism in their own right.

2.5.2 Degree of integration

The purpose of IEA is to solve a problem, within constraints on time and money. These constraints will determine the degree of sophistication required. High levels of sophistication may well be unnecessary to solve the problem while consuming resources. In this context, high sophistication means either investigation in great depth (with large amounts of new, almost "pure" research), or investigation in great breadth — i.e. integration.

A full end-to-end assessment is necessary if a cost-benefit analysis is the objective, for example to determine the optimum level of intervention (balancing the costs of abating or preventing an environmental problem with the costs of leaving or ignoring it). However, it is often the case that limits have already been imposed (maybe from a higher-level assessment, or *ex cathedra*) and it is simply required to find the most cost-effective way of meeting the limits; in this case a large part of the DPSIR cycle can be omitted.

On the other hand, if resources permit, the more extensive the assessment, the bigger the picture that will be obtained, and the better the chances of seeing solutions that do not merely move the problem somewhere else but tackle the root causes.

As an example of the different levels of sophistication and integration that are possible in environmental assessments, Levitan *et al* (1995) reviewed methods of assessing the environmental impacts of pesticides and pest-control systems. Methods of assessment range from anecdotal accounts, databases of basic toxicity data, single-parameter hazard assessments, composite impact ranking systems, to holistic (i.e. highly-integrated) impact assessment methods. The authors conclude that it is not possible to produce an ideal single assessment method because of different specific objectives, methods and decision-making contexts of particular assessment systems. In other words, the type and scale of assessment will depend on the problem in hand.

2.5.3 System feedbacks

A particular merit in using IEA to model the whole of a system is that it is better at handling cycles, feedbacks and responses. Clearly, if you only look at part of a system, you will miss many such effects. The potential significance of feedbacks and cycles in environmental processes may be illustrated by two simple (and simplified) examples from global warming:

- Increased atmospheric CO_2 concentrations tend to increase plant growth, fixing carbon and reducing atmospheric CO_2 concentrations (negative feedback).
- Increased temperatures tend to decrease snow and ice cover, which decreases the amount of solar radiation reflected back into space, which increases temperatures further (positive feedback).

The key question for climate change research is whether the many positive and negative feedbacks like this add up to a total that is positive or negative. If positive, runaway climate change is to be expected; if negative, the climatic system is inherently stable and self-correcting.

Delayed feedbacks — and most feedbacks in environmental systems will be delayed — often lead to unexpected and unpredictable behaviours, instability and even chaos (Pippard 1985). It is unlikely that an IEA study will have the resources to study such exotic effects, but integrated modelling may at least provide a degree of reassurance as to whether such nasty surprises are likely.

2.6 modelling in IEA

Integrated environmental assessment is not the same as integrated assessment modelling. It is possible to perform an IEA without using any computer models. This is not often the case, however. Frequently, a large amount of the work in an IEA goes on the development of a computer model. Parson (1995) offers a cynical reason for this, namely that a computer model is a highly visible product and attractive to funding agencies. However, models are in fact valuable and important. First of all, the initial aim of the process of assessment is to gain *understanding* of the way the system functions; models are an excellent method of both encapsulating (summarising) and disseminating this understanding. Once available, they enable quantitative experimentation into the effects of various proposed responses, for example scenario analysis. They may also allow quantification of the uncertainty of the assessment.

Models may be developed specially for a particular assessment, or an off-the-shelf model may be suitable. It may be necessary or desirable to use a number of different models for different parts of the assessment; one reason for doing this would be as a deliberate effort to avoid a large model imposing a rigid framework on the work. However, if multiple models are used, it is clearly important that they work well together, either through program-to-program interfaces or through good interaction with the human users.

There are many possible roles for models in IEA. In any assessment, how models are best used will depend on the objectives of that assessment. This is discussed in Section 5.

2.7 Examples of IEA

This section discusses a number of examples of IEA in practice. The first three examples are large-scale assessments of global or international problems (the ozone layer, the greenhouse effect and acid rain). The other examples are more typical of IEA in that they are on a smaller scale, both geographically and in terms of the effort put into them.

2.7.1 The Climatic Impact Assessment Program

The first major Integrated Environmental Assessment is generally considered to have been the Climatic Impact Assessment Program (CIAP), which investigated potential atmospheric impacts of the proposed US supersonic transport aircraft (SST) in the early 1970s (Parson and Fisher-Vanden 1995). The principal impacts were potential depletion of the stratospheric ozone layer, with consequent increases in ultraviolet radiation reaching the ground and causing damage to humans and other life. The mission statement said that "in order to determine regulatory constraints on flight in the stratosphere such that no adverse environmental effects result, CIAP will assess… the impact on man, plants and animals of climatic changes which may occur."

This study was integrated in the sense that it examined everything from stratospheric chemistry, jet engine emissions and potential design modifications to reduce them, all along the causal chain to biological impacts and economic and social impacts. The causal chain was structured in six sequential modules, with interfaces between them carefully defined so that each module had the information it required from the other modules (although time constraints meant that in practice, this did not always work well). The teams within each module were also multi-disciplinary. The study was driven by the need to find out what regulation was needed, although a lot of basic research was needed to fill in gaps in knowledge and understanding.

2.7.2 Climate change

If CIAP was the first IEA to be described as such, the term is now very closely linked with climate change research. Much of the literature on IEA is written in this context. As a result, it is easy to think that IEA is only for climate change work. It is better to regard climate change research as a flagship application of IEA and a workshop for new techniques and ideas.

Climate change modelling demands integrated assessment because it is necessary to make predictions about the future in several different areas:

- the future socioeconomic state (including population growth, level of industrialisation among different populations, social and economic demand for and availability of polluting lifestyles, development of abatement technologies);
- the rate at which greenhouse gases are emitted and fixed (these are functions of the socioeconomic state of the world);
- the effects of the resulting levels of greenhouses gases on the climate;
- the effects of climate changes on humans (for example agriculture, water supply, land loss from rises in sea-levels, extreme weather events, spread of diseases, damage to ecosystems);
- ways to change any or all of the above (global actions and local actions).

(These correspond to the five points of the DPSIR cycle.)

All these factors will change in the future and so have to be predicted by some sort of assessment models. Because they are inter-related, the assessment must be integrated to account for these links; even within each of the main areas, an integrated view is necessary.

The very large scale of the climate change problem means that there are a number of unusual features to work in this field:

- The global scale of the underlying causes demands international negotiations before individuals are prepared to accept mitigating actions. There is no single individual or organisation capable of introducing mitigating actions (with or without public support).
- The problem is very long term. Climate change is being caused, and remedial actions are required, now, but the effects will not be felt until some time in the future. Questions of inter-generational equity are important. This is alternatively expressed as:
  - Mitigating actions are a cost now whereas benefits will only be felt in the future (Dowlatabadi and Morgan 1993, Dowlatabadi 1995).

  or as:
  - Polluting lifestyles are a benefit now whereas the costs of climate change will be paid in the future.
- A feature of the uncertainty about changes to the climate is the possible existence of unprecedented, low-probability, high-consequence events (such as abrupt changes to the pattern of ocean current patterns). It is very hard, by their nature, to anticipate such events, or to predict the whole range of their consequences if they occur.

In the same way, many, if not all, environmental problems have their own unusual or idiosyncratic features. They may require special attention in an assessment and assessors should always look out for surprising or non-standard aspects to a problem.

Computer models in climate change IEAs fall into two categories. Global Circulation Models (GCMs) are the main underlying research tools that attempt to predict the consequences of increases in atmospheric carbon dioxide and other greenhouse gases. They are essentially unidisciplinary and focus on one specific part of the problem, namely the response of the environment to the pressures of greenhouse gases.

In addition, a number of Integrated Assessment Models (IAMs) have been developed (Dowlatabadi 1995, Parson and Fisher-Vanden 1995). These attempt to simulate the whole IEA problem using simplified sub-models (much, much simpler than the GCMs). Some are essentially just simulation models, with the ability to vary ranges of policy options; others are designed to calculate optimal abatement strategies.

2.7.3 Acid rain

The most high-profile success for IEA in making policy is the control of acid precipitation in Europe. The second sulphur protocol within the framework of the UN ECE (United Nations Economic Commission for Europe) Convention on Long-Range Transboundary Air Pollution was signed in Oslo in June 1994 by ministers of 33 countries. The international negotiations first agreed on the level of reduction required. This was that there should be a 60% reduction in the excess of the deposition in 1990 over the critical loads (the critical load is the amount of deposition that receptor environments can support without harm). The reduction strategy should minimise the cost. A key point is that reductions in emissions would not be uniform across countries (the first protocol was a flat rate 30% cut) but should be based on effects and be economically efficient. These methods of determining reductions were considered to be the most equitable.

RAINS, a computer model specially developed for the negotiations, was used to calculate cost-minimising national emissions to reach this goal. About half the delegations then made the RAINS-derived cuts their final offer, while several others took the emissions level but delayed the date by five to ten years (Alcamo *et al.* 1990, Parson and Fisher-Vanden 1995, Hordijk 1995).

Similar attempts in the US by the National Acid Precipitation Assessment Program (NAPAP 1991) were much less successful (Rubin *et al.* 1992). Some reasons were given by the oversight board: "The assessment function should have been the central focus of the NAPAP endeavor from the first, but it was not", and "NAPAP scientific efforts were guided to an excessive degree by the potential to resolve interesting scientific questions… Interim assessments and periodic reports of findings were late or lacking, leading to a partial disconnection between the research and analysis products of NAPAP and the decision-making process. This was especially evident in 1989 and 1990 when publication of the findings followed policy decisions, not preceded them" (quoted in Hordijk 1995). The Bush administration announced steps to reduce SO_2 emissions before the NAPAP results were published.

2.7.4 External costs of energy: ExternE

External costs are those which are not included in the market price. They include costs associated with loss of human life or damage to health, loss of amenity or leisure value (e.g. a scenic landscape), loss of biological resources, and so on. Such costs have traditionally not been included in economic assessments of, for example, energy production and consumption, partly because it has not been clear how to do so (see Section 3.3).

In 1991, the European Commission set up a major project called ExternE to develop a consistent methodology to evaluate the external costs associated with a range of different fuel cycles. The main objectives are to apply the methodology to a wide range of different fossil, nuclear and renewable fuel cycles for power generation and energy conservation options, and a series of National Implementation Programmes to implement the methodology for reference sites throughout Europe. The methodology is also being extended to address the evaluation of externalities associated with the use of energy in the transport and domestic sectors and a number of non-environmental externalities such as those associated with security of supply.

To date (the project entered its third phase in 1996), the project has developed an effective methodology, assessed several different fuel cycles (coal, nuclear, oil, gas, lignite, hydroelectric and wind), made assessments of marginal costs and identified the key externality issues for future policy (EC 1996).

The methodology developed is typical of IEA. Impacts from the whole fuel cycle are identified and evaluated. First, the stages of the fuel cycle are identified. Depending on the fuel, the fuel cycle includes things like construction of plant, mining or extracting fuel, transport of fuel, power generation, waste disposal and electricity transmission. Next, a comprehensive list of burdens and impacts is then described for each stage. Priority areas for assessment are identified, based partly on the results of earlier studies and partly on expert judgement.

Impacts are assessed and valued using the most appropriate models and data available. The project has convened international groups of experts to identify the functions to be used for impact assessment in the areas of human health, building materials, crops, forests, freshwater fisheries and biodiversity.

Three important principles are stated as guiding principles for the project:

- *Transparency:* to show how the work was done, and what was assessed and what was not.
- *Consistency:* to allow valid comparisons to be made between different fuel cycles and different types of impact within a fuel cycle.
- *Comprehensiveness:* all impacts of a fuel cycle should be considered, even though many may not be investigated in detail

2.7.5 Grand Canyon visibility

Much of the value of the national parks and wilderness areas of the Colorado Plateau, US, comes from its visual panorama. This depends on maintaining high visual air quality in the region, which is threatened by haze resulting from projected growth over the next 50 years. The US Congress created the Grand Canyon Visibility Transport Commission in 1991 to advise on strategies for protecting the visual air quality. The Commission performed an IEA which lead to the publication of recommendations in 1996 (GCVTC 1996).

The assessment had six stages:

- Development of an emissions inventory for the study region.
- Development of a technical basis for assessing visibility impacts from changes in emissions.
- Development of criteria to evaluate options. These were:
  - effectiveness in achieving visibility goals,
  - economic effects,
  - social effects,
  - environmental effects in addition to visibility,
  - equity, and
  - administrative ease and effectiveness.
- Development of emission management options.
- Development of scenarios based on varying levels of emission management options. These included:
  - a baseline or lower bound, which projected effects of applying existing laws and regulatory programs;
  - an upper bound which included maximum application of controls on emissions irrespective of costs;
  - and several different intermediate goals.
- Development of a computer-based Integrated Assessment System (IAS) to evaluate and compare costs and visibility impacts of different scenarios. This contained estimates of future population and economic growth and information on how emissions will change as the economy changes.

The optimum management responses (which lead to the recommendations) were obtained by scenario analysis. A number of scenarios were developed, reflecting different combinations of options and goals for improving visibility. Each scenario was fed into the IAS model, which calculated the changes in visibility and the direct costs which may result from the scenario (these being two of the assessment criteria).

In DPSIR terms, the scenarios cover the range of expected drivers; the resulting pressures are built in to the IAS model, which then calculates the state (emissions) and impact (visibility, costs). Appropriate responses are then determined by the Commission.

2.7.6 Indoor air pollution

Small (1992) describes models for integrated assessment of indoor air pollution, namely radon and VOCs (volatile organic compounds) from a contaminated water supply; other forms of indoor air pollution would include pollution from household cooking and heating, tobacco smoke, and VOCs from household chemicals. Consideration of individual perception and response is important for environmental pollution problems such as these, where exposure depends on disaggregate decision making by individuals. Therefore, to properly characterise these problems, environmental models must consider both the physics and chemistry that determine the fate and transport of pollutants, and also the human decision making process that determines pollutant generation and subsequent exposure of individuals.

Human activities are the cause of many indoor air pollution problems, time-activity patterns determine the locations of individuals for potential exposure, and opportunities for individuals to modify the indoor environment are often available. Small's models integrate pollutant behaviour simulation and "mental models" of human decision-making behaviour, the latter incorporating risk perception and preference models. This enables risk assessment and risk management of the problem.

2.7.7 Water protection zones

The River Dee, which flows through north-west England and north Wales, supplies approximately 5% of the United Kingdom's drinking water. The UK National Rivers Authority proposed that the river's catchment area, which is heavily industrialised and has a history of chemical spills, be declared a Water Protection Zone, giving the NRA (now the Environment Agency of England and Wales) regulatory control over industrial activities within the catchment. An assessment identified significant hazards to the river, with the goal of striking a sensible balance between the benefits of industrial development and the protection of drinking-water supplies.

This assessment required an integrated study of the whole of the river catchment area in terms of hazardous installations and potential impacts of accidental releases of pollution. A risk-based analysis determined appropriate levels of regulatory intervention. It entailed developing a cost-effective assessment method focused on risk prioritisation, inclusion of cost-benefit considerations and public consultation.

2.8 Groups working on IEA

A number of groups and organisations are making special efforts to promote the use of IEA, to develop new IEA techniques and to develop best practice. These include:

- Center for Integrated Study of Human Dimensions of Global Change. A group of more than 30 scientists world-wide who study how people affect the environment. Goals are to merge social and scientific knowledge so that we can best understand the patterns of human activity and environmental change, and to develop new methods for framing and analysing environmental problems based on the needs of government and industry decision-makers. URL: http://hdgc.epp.cmu.edu/text.main.html

- Consortium for International Earth Science Information Network (CIESIN). A non-profit non-governmental organisation that distributes environmental information. Host of the Socioeconomic Data and Applications Center (SEDAC), including the Model Visualization and Analysis service (MVA). Provides background information on the use of integrated assessment to examine global climate change, descriptions of integrated assessment models, and access to model-generated output. Features the Thematic Guide to Integrated Assessment Modeling (Parson and Fisher-Vanden 1995). URL: http://www.ciesin.org/

- European Environment Agency. Encourages the use of IEA as part of its remit to orchestrate, cross-check and put to strategic use information of relevance to the protection and improvement of Europe's environment. URL: http://www.eea.eu.int/

- European Forum for Integrated Environmental Assessment. A network of European scientists conducting multi-disciplinary, policy-relevant research on complex environmental issues. It is hoped to extend the existing network, particularly towards government, industry, non-governmental organisations, etc. URL: http://www.vu.nl/english/o_o/instituten/IVM/projects/research/efiea/index.html

- Stockholm Environment Institute. An independent, international research institute specialising in sustainable development and environment issues. URL: http://www.york.ac.uk/inst/sei/

- ULYSSES (Urban Lifestyles, Sustainability and Integrated Environmental Assessment) is a European research project on public participation in Integrated Assessment. It aims to advance IEA methodology by integrating computer models with a monitored process of social learning. The advances in IEA methodology will support public participation in environmental policy making. By combining public participation with the application of computer models designed for decision support, ULYSSES aims to integrate lay knowledge with expert knowledge. The goal is to arrive at integrated assessments that are both well informed and acceptable to the public at large in a democratic context. The results of ULYSSES will be made available to the interested public, and to decision makers and scientist. URL: http://zit1.zit.tu-darmstadt.de/ulysses/

2.9 Related types of assessment

This section discusses briefly some related types of environmental assessment. These are Environmental Risk Assessment (ERA), described in Section 2.9.1, and Life Cycle Assessment (LCA), described in Section 2.9.2.

2.9.1 Environmental Risk Assessment (ERA)

A type of environmental assessment that may form part of an integrated assessment is Environmental Risk Assessment (ERA). ERA focuses on discrete, occasional and usually accidental events, rather than routine, continuous conditions. ERAs are usually performed on the operation of industrial plant which pose environmental hazards. "Risk" is made up of the combination of two distinct elements:

- what is the probability (or frequency) that an event (usually an accident) will occur?
- what are the consequences if it does occur?

Assessment of the consequence side is, in principle, similar to any other environmental assessment, although since it deals in general with events that have never happened, there is a much greater requirement for predictive computer models.

The new element is the question of how often the event occurs, and this requires the assessor to examine the industrial process in question to determine and quantify possible accident scenarios and their root causes. Moreover, since different accident scenarios have both different probabilities and different consequences, it is necessary to couch the assessment in probabilistic terms. Whereas most models are deterministic (calculating the consequences of a single, specified accident of probability one), models developed with ERA in mind normally run additionally in probabilistic mode (calculating the consequences of an ensemble of possible accidents, with different probabilities). Probabilistic runs are used to calculate, for example, how often accidents will occur at an industrial plant which lead to a certain environmental pollutant concentration threshold being exceeded.

As usual, the ultimate objective of ERA is to find out how best to reduce and mitigate the (average or statistically-expected) environmental consequences of (for example) running an industrial plant.

A report has been prepared for the EEA discussing ERA in detail, and including information on ERA software models available (Fairman *et al.*, forthcoming). Appendix A describes the computer model PRAIRIE as a representative of this kind of tool.

2.9.2 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is the assessment of the environmental impact of (usually) a manufactured product across its full life-cycle ("from cradle to grave"). It is comprehensively defined by the Society of Environmental Toxicology and Chemistry (1993) as "a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and material uses and releases to the environment; and to identify and evaluate opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance, recycling, and final disposal."

LCA is usually performed by manufacturers when designing a new product (or redesigning an existing one). A good Life Cycle Assessment tool should identify the whole range of environmental impacts of a product, as described in SETAC definition above.

In application, LCAs are usually broken down into four stages:

- Goal definition and scoping — defining the purpose of the study, its scope, establishing the functional unit and determining data quality.
- Inventory assessment — quantifying the inputs of materials and energy, and the releases to the environment.
- Impact assessment — assessing the environmental impact of the burdens identified in the inventory assessment.
- Improvement assessment — finding and evaluating options for reducing the environmental impact.

The LCA methodology is still very much under development. Even more important, the databases of environmental costs and benefits on which the assessments rely are even more uncertain. To illustrate this, the SimaPro LCA tool features an example assessment comparing paper shopping bags with plastic ones, using three different sets of polyethylene data (all from published sources). The difference in the results is considerable. The choice between using paper bags and plastic bags depends greatly on which data set you believe (PRé Consultants 1995). In the same way, even the popular flagship environmental issue of paper recycling is not supported by recent scientific research (Pearce 1997, Leach 1998). The results of a computer-assisted LCA assessment, as with so many computer models, should therefore be interpreted as guidance, not a definitive answer.

A number of LCA computer tools are commercially available. A couple of representative examples are described in detail in Appendix A, and sources of further information are given in Appendix B. In general, these tools combine extensive, user-customisable databases of the environmental and economic properties of the various life cycle elements with an interface which guides the user through the stages of an LCA and an expert system which interprets the assessment and draws out the relevant information from the database.

A report has been prepared for the EEA discussing LCA in detail, and including information on LCA software models available (Jensen *et al,* forthcoming).

3. Weaknesses of IEA

Previous sections have looked at the capabilities of Integrated Environmental Assessment. This section describes some of the weaknesses in current IEA techniques and capabilities. These will doubtless get better over time, but for now it is important for users of IEA to be aware of them.

3.1 Limits on computer modelling capabilities

Despite the great increase in affordable computer power over the years, unidisciplinary models are still constrained by the available capacity of current computer technology. Often modellers can conceive of more complex models, and would like to implement them for greater accuracy, but they are not yet feasible because of their computational requirements. *A fortiori,* IEA models, which typically combine several unidisciplinary models along with other features such as optimisation, must still rely on highly simplified models. The IEA constituent models, although simple, need to be calibrated in some way so that they accurately capture the most important aspects of what they are simulating. Developing such reduced-form models can be as demanding as developing full-blown models.

In some cases, there are feedback processes in the IEA cycle that are essential to understanding the overall behaviour, but which at present cannot be satisfactorily modelled. In such circumstances, it is important to be able to build in such knowledge as exists, based on expert judgement; this will be inaccurate, but better than ignoring the effect altogether.

Uncertainty analysis is an important function of IEA computer tools (see Section 5.3.4). However, IEA models generally have so many variables and dependencies that there are huge numbers of permutations, making uncertainty analysis very difficult. Efficient algorithms and heuristics are needed to solve such problems (Dowlatabadi 1995).

A major drawback to traditional mathematical computer models is that they are poor at handling qualitative aspects of a system. For example, the success of trying to change people's behaviour to prevent an environmental problem will depend on many factors other than simple quantitative (cash-oriented) economics, such as availability of information, trust, credibility, status, ethics and so on. It is possible that scientific understanding of the effects of these factors could be implemented in a computer model, probably through an expert system, rather than traditional Fortran codes. This is a long way from becoming standard modelling practice. In the meantime, it is necessary for IEA workers to allow for qualitative effects "by hand".

3.2 Limits on understanding

Often, lack of understanding of the systems being assessed is the biggest weakness in an assessment. One example of this with wide relevance to IEA is in understanding decision-making process (Parson and Fisher-Vanden 1995). The study of economics provides a method of taking into account the actions of other participants under certain conditions — that there are many small actors acting through a market system. However, in international (and often in domestic) negotiations, it is the actions of a small number of powerful actors that are decisive. At present, there is little understanding of how to simulate these conditions. The assumption of a pure market economy may also be invalid for many environment-related problems (see Section 3.3).

3.3 Comparison of impacts

Assessing impacts is often one of the most difficult parts of an IEA. It is often necessary to make trade-offs and compromises between different impacts. The problem is that many impacts cannot be directly compared, because they cannot be measured in the same way or on the same scale (they are said to be incommensurate). An assessment may find impacts that include any or all of financial costs, loss of amenity or leisure value (e.g. a scenic landscape), loss of ecosystems, extinction of species, damage to human health, loss of human life, and others. How can we compare these?

The usual approach is to assign a notional financial value to non-market quantities, but how this is to be done has never been satisfactorily solved. One common work-around is simply to assign an arbitrary value, say $1 million for a human death. More sophisticated methods currently being used include "willingness-to-pay" (how much money are people willing to pay to preserve a resource) and "willingness-to-accept-compensation" (how much money would people demand to accept loss of a resource). Willingness-to-pay especially is becoming popular and in some circumstances it seems to be legitimate.

However, willingness-to-pay can be problematical, because it can value the lives of rich people more highly than poor people. The most notorious example of this is in the Second Assessment Report of the Intergovernmental Panel on Climate Change Working Group III (IPCC 1995). The main report costed climate change impacts using willingness-to-pay and effectively valued the life of an American or European at 10 times higher than a citizen from a low-income country; it was opposed by its own Summary for Policy-makers (written by different authors) following heavy criticism (Meyer and Cooper 1995).

There is a more general danger with representing environmental resources in terms of cash values, however derived. This is that the nature and significance of the underlying resource can be forgotten. For instance, one economist (Beckerman 1995, quoted in de Selincourt 1995) has written that "Alarm over the predicted effects of global warming is vastly exaggerated. For the USA at least, global warming could hardly have a significant effect on national income. For the sector most likely to be affected is agriculture, which constitutes only about 3 per cent of GNP." This position fails to recognise that agriculture has importance transcending its cash value.

As a practical example of the incommensurability problem which does not involve monetary values, Greenfelt *et al.* (1994) argue that the next European Long-Range Transboundary Air Pollution protocol should cover a number of pollutants, integrating the problems of acid precipitation, eutrophication and tropospheric ozone. The difficulty is, given X amount of acid deposition, Y amount of eutrophication, and Z amount of ozone, how can one compare them and decide which is the greatest problem?

However, as described in Section 2.7.4, The European Commission's ExternE project is a major effort to establish a coherent and consistent framework for costing the diverse impacts of energy use. This is expected to prove an important step forward in the assessment of environmental impacts.

3.4 Usefulness to policy-makers

IEAs may be used to improve scientific understanding, but the ultimate aim must be to assist decision-makers by providing them with information on what options are open to them, and the consequences of each option. The ideal would be to recommend specific measures such as reduction of emissions to a particular level, with methods for achieving this (technological methods of cleaning up pollution, demand reduction through taxation, provision of alternatives), and details of costs and benefits (including any incidental effects).

Naturally, the provision of such advice to the requisite level of detail gets harder as the scale of the problem increases. As an extreme example, global climate change assessments that treat the EU as a single region neither help European officials to allocate targets to member states, nor help national officials to understand the expected impacts in their countries (Parson 1995). However, the example of acid rain in Europe (discussed in Section 2.7.3) shows that even for large-scale problems, it is possible to conduct integrated assessments that produce concrete solutions, given commitment by both decision makers and scientists.

The biggest difficulty in IEA may not be integrating the assessment, but integrating the audience. Individual policy or decision-makers only have limited areas of responsibility. Often an assessment will imply that a number of decisions need to be made across different areas of responsibility. Alternatively, proposed remedial actions may benefit some people but have an adverse impact on others, so that negotiation is necessary to ensure that actions for the greatest good can be taken.

The art of making IEA useful to decision-makers is one that requires effort on both sides, but will come with experience. Some suggestions are given in Section 4.

4. Conducting an IEA

This section gives some guidance on how to ensure an assessment is successful. A successful assessment will:

- Be scientifically sound (as far as reasonably practical, given unavoidable constraints on time, money and knowledge).
- Be publicly defensible.
- Offer concrete advice on courses of action and their consequences.

Probably the single most important factor in obtaining a satisfactory conclusion is good project management, the techniques of which are applicable to IEA projects as much as any other. Several of the suggestions below reflect this.

4.1 Planning an IEA

When it is recognised that an assessment is needed, the crucial first step is to decide what exactly the assessment is for. What decisions will it feed into? What questions must it answer? These provide the ground-rules for the assessment.

Having decided this, it is necessary to decide:

- Who is competent to do the assessment?
- How long will it take?
- How much will it cost?

In turn, these raise further questions:

- What level of accuracy and confidence is required?
- What level of sophistication (including degree of integration — see Section 2.5.2) is required?
- What information and knowledge is required?
- What is the availability of existing knowledge? How much "pure" research will be required to obtain necessary background information?
- What suitable off-the-shelf tools for modelling and/or analysis are available (see Section 5)?

Nearly always, there will be constraints on either the amount of money available, or the time available before a decision must be made. These may necessitate compromises on the quality of assessment that can be produced.

4.2 Audience and purpose

These are essential and need to be clearly defined at the beginning of the work so that the assessment is focused accordingly. The assessors should consider the amount of authority the audience has: a single individual's responsibility may be limited in scope, or the audience may be a coalition of decision or policy-makers with a wide range of responsibilities. The assessment may also be directed at the general public. The assessment should allow for the fact that other priorities or vested interests may conflict with the results of the assessment; ideally such interests should be integrated into the assessment.

4.3 decision-makers and scientists

An important factor in the production of a successful assessment is the development of a good relationship between decision-makers and scientists, with mutual understanding and trust. Some factors in this are:

- Scientists should concentrate on the problem at hand and remember the practical objectives, restraining their instincts to solve interesting but irrelevant problems. Timescales and reporting requirements must be followed.
- Scientists should explain to their audiences what they are doing and how they draw their conclusions, preferably in a dialogue.
- Decision-makers should use the results presented by scientists fairly and honestly. They should not be distorted or wilfully misunderstood if they disagree with prior assumptions or hidden agendas. Nor should policy-makers commission research in the expectation of getting the "right" answer.
- Decision-makers must be aware that uncertainty is inevitable is any assessment. Uncertainty should not be abused by using it as an excuse for inaction. Decisions should be based on best estimates and the precautionary principle.
- Wherever possible, all key reports should be published and made available for scientific peer review (and the public). The scientific credibility of the modellers was a major factor in the success of the UN ECE acid rain negotiations (Hordijk 1991).

5. Use of computer-based models in IEA

There are three main areas where computers can help in environmental management:

- simulation modelling (pollutant transport through air, surface water or groundwater, ecosystem modelling)
- information management (GIS, DBMS, experimental data, results from simulations, regulatory requirements, data visualisation)
- decision support (regulatory compliance, cost/impact optimisation, suggesting response actions)

These are discussed in more detail in Sections 5.1–5.3 below. Section 5.4 describes integrated tools, which can manage all of these tasks within a single framework, and are therefore especially useful when performing IEA.

5.1 Simulation modelling

Environmental simulation tools fall into a number of main categories:

- Pollutant transport
  - Air (e.g. ADMS)
  - Surface water
    - Lakes (e.g. OTTER)
    - Rivers (e.g. OTTER, PRAIRIE, QUAL2E)
    - Marine
  - Groundwater (e.g. OTTER)
- Ecology
  - Response of physical environment to disturbance
    - Soil loss
  - Ecosystem modelling (e.g. GEM)
- Other
  - Noise (e.g. INM)

The purpose of these models is to predict the consequences (in DPSIR terms, the state and sometimes the impact) of some source of environmental harm (pressure). They attempt to answer the question "What happens if pollutant X is released into environment Y? How much is transported where, and what health effects does it have?" This is answered by developing mathematical models (often based on differential equations) and implementing them as computer programs (historically usually written in Fortran, nowadays increasingly in C/C++).

Almost any environmental assessment will involve this sort of question, so these are very important tools. For many of the above categories, a great many models exist — there are literally hundreds of air and groundwater transport models. Many of them are intended as research tools and either are not available for general distribution or have very rudimentary user interfaces (including data input and output and error checking). Others have been developed with non-expert users in mind, sometimes as a commercial venture.

Models may also be categorised into the specialised, focusing on a particular situation (for example, the release of a heavy gas, or the release of a gas from a pressure vessel), and the general-purpose, intended for wide application, often including a large number of sub-models for handling all sorts of circumstances.

Most of these models treat only a single medium (by environmental media we mean air, surface water, groundwater, etc.). Some models, however, simulate a number of different media seamlessly. They include processes which transfer pollutants between media, such as atmospheric deposition, sedimentation, volatilisation and erosion (Zannetti 1995). These are of particular value in integrated assessments. One example is OTTER, with which one can simulate the transport of a pollutant deposited onto the surface of the ground through the catchment area (by both surface runoff and subsurface groundwater flow) and into receiving rivers and lakes; arbitrary networks of catchments, lakes and rivers may be modelled. Other examples include MMSOILS and MULTIMED.

Environmental Risk Assessment tools are a particular subset of simulation models which have the special feature of a probabilistic mode of running. PRAIRIE is an example of such tools, for the assessment of spills of chemical substances into rivers.

This report does not attempt to list all the available simulation models. The ones mentioned here are examples only, intended as an indication of the type of products available. Appendix B includes sources of further information which will enable you to select one of these models if these are what is most appropriate for your assessment.

5.2 Information management

Computers are of course excellent tools for information management. Some application areas of environmental relevance are discussed here. In DPSIR terms, these tools should be regarded as providing the underlying information required for the process of assessment, rather than serving any particular stage in the assessment.

5.2.1 Visualisation

Data visualisation tools enable users to see and understand raw data — notably model results — more easily. Visualisation functions include graphical plots (e.g. graphs, histograms, pie charts and contour plots), statistical analysis, time series analysis, and overlaying geographical data onto maps.

There are stand-alone visualisation tools for use with data imported from external sources. Spreadsheet programs such as Microsoft Excel provide basic data visualisation functions which are reasonably simple to use and adequate for many purposes. There are also much more complex programs, such as PV-Wave, designed for sophisticated analysis of large datasets. More commonly, however, readers will prefer it if tools that generate data provide their own visualisation functions suited to the data (this may simply be displaying a graph of trends against time).

5.2.2 Databases

Depending on their degree of sophistication, environmental models rely on databases to provide their input information and calibration. Examples of the sort of data that might be found in an environmental database include:

- properties of substances (physical, chemical, toxicological, etc.)
- economic costs (remedial actions such as alternative technologies, costs associated with environmental burdens such as reduced crop yields due to pollution, etc.)

- geographical information
- regulations (quantitative and qualitative)
- models (either the actual executable model code or information on models)

Simulation codes may simply use this sort of data for model calibration; they store the essential information they need (mainly substance properties and sometimes economic information) and access it as required without the user being aware of it. On the other hand, in some tools the database is the heart of the system, and a full-blown database management system (DBMS) is implemented. Often, especially where more qualitative data is being handled, an expert system is often used to manage what information is needed and how it is used, and in this case the system may be described as a Decision Support System — see Section 5.3.1.

It is usually possible for users to update the databases where appropriate, for example to allow for user-specific circumstances, for new information, or for changes to regulations.

A rather special sort of database is the so-called Model Base Management System (MBMS). A MBMS is a system for helping a user to decide which of the various environmental computer models available is most suitable for a particular job. These use database techniques coupled with expert systems and hypertext to give the user information about the models stored. Several of the information sources listed in Appendix B may be described as modelbases, although they do not take advantage of the more sophisticated capabilities of database management systems.

5.2.3 Geographical Information Systems (GIS)

Geographical Information Systems (GIS) are specialised database management systems for handling geographical data — i.e. data whose key characteristic is “place”. These manage data on land use, roads, buildings, habitations, and so on. Data includes both their positions and their various related properties (for example, information about a road may include its traffic capacity, traffic flows and traffic speeds). In addition to simply storing such data, GIS can manipulate and analyse the data — for example, calculating the area of forest within 50 m of a road — and include visualisation tools.

GIS systems are clearly of great value to environmental managers. They exist as stand-alone data management systems. They may also be built in as integral components of a larger system which can perform additional manipulation of the data contained. For example, a simulation model may use a GIS to obtain site-specific input parameters, and then use the GIS’s visualisation facilities to make the output meaningful.

5.3 Decision support

While all modelling can be considered part of decision support — and the term Decision Support System is used of a range of technologies — there are some computer functions which offer more direct assistance in making decisions. These are discussed here.

5.3.1 Expert systems

Foremost among these are expert systems — these are often the basis of what are called Decision Support Systems. These are computer programs which are designed to imitate the advice of a human expert. They are used to draw conclusions from information where there is not a precise, unambiguous answer. An expert system consists of three components:

- a knowledge base;

- an inference engine, which applies built-in rules (often rather rough rules of thumb) to the knowledge base to draw conclusions;
- a user interface, which enables the user to ask questions and understand the answers.

The knowledge base may include any of the sort of data held in a DBMS, but especially includes "softer" information such as what crops grow well in what soils or regulatory or best practice requirements — information that needs some sort of interpretation to be processed usefully. Expert systems also include explain functions, which help to interpret the results to the user, and are ideal when a tool is needed for suggesting remedial strategies or actions.

Expert systems may be applicable to any or all of the DPSIR stages of an assessment. An integrated expert system, covering all the stages, replaces elaborate simulation models in circumstances with simple models or empirical rules (or even rules of thumb). For the I–R–D stages of the cycle, traditional-style simulation models may not be applicable or available, and expert systems may be the most suitable way of modelling problems of this type.

Expert system models are particularly useful for scoping calculations — that is, the early stage in an assessment which determines what areas, if any, pose problems and require further examination. Their relative simplicity and human-like approach means that, with a small amount of care by the developers, expert systems can be very user-friendly and suitable for inexperienced and non-expert assessors. Indeed several have been developed specifically as training tools.

Depending on the extent of the information supplied in the knowledge base, and the generality of the program design, such systems may be aimed at specific areas such as agriculture (e.g. EMA), or they may be intended as general-purpose Environmental Impact Assessment tools (e.g. Calyx, EIAxpert).

5.3.2 Life Cycle Assessment tools

LCA tools work in a similar way to expert systems for EIA. These tools combine extensive, user-customisable databases of the environmental and economic properties of the various life cycle elements with an interface which guides the user through the stages of an LCA and an expert system which interprets the assessment and draws out the relevant information from the database.

5.3.3 Optimisation

When faced with an environmental problem, there are generally a number of possible remedial actions. Each course of action will have different results and will be more or less effective at solving the problem. Each course of action will also entail different costs and drawbacks. In these situations, the following sorts of questions arise:
- How can we achieve a specified reduction in environmental harm while minimising the cost?
- How should we spend our fixed budget to achieve the greatest reduction in environmental harm?

Answering these questions is called optimisation. A simple method for this is trial-and-error scenario testing, which is effective when there are only a small number of possibilities. More sophisticated methods include the simplex method of linear programming and genetic algorithms. Depending on the nature of the problem, optimisation can be straightforward and fast or difficult and time-consuming. Since it is often the output of a computer model that is to be optimised, it is natural to get a computer to perform the optimisation as well. In fact, optimisation is a feature of a larger program rather than a stand-alone tool in its own right.

Clearly this covers the whole DPSIR cycle, and supposes a corresponding integrated tool (see Section 5.4).

5.3.4 Uncertainty analysis

It is also important, when using a computer model to make decisions, to have some idea about the level of uncertainty in the model's outputs, and what the main sources of this uncertainty are. Uncertainty in a model is both parametric (the quantitative data used in the model) and structural (the assumptions and simplifications that constitute the model itself). Parametric uncertainty analysis can be a large task, requiring a large number of model runs followed by a statistical analysis. For a large model with a large number of parameters and a substantial run time, this may only be done once for a typical scenario. On the other hand, model framework systems such as RAISON, which enable relatively simple models to be built from standard parts for particular circumstances, may include a facility for performing parametric uncertainty analyses as required.

Structural uncertainty analysis is even harder, requiring a model comparison exercise, which in turn requires a set of models which are similar enough in their functionality to be comparable. These are usually done as one-off exercises where groups of modellers predict results for a suitable scenario, and the various predictions compared. They involve a great deal of work, co-ordinating model developers, finding a suitable scenario with the requisite data, performing the model runs and assessing and comparing the results. Code comparison exercises are, however, extremely useful for finding the strengths and weaknesses of models.

While in principle the requirement for parametric uncertainty analysis applies at all stages in a DPSIR assessment, it is currently only applied to simulation models (i.e. the P–S–I stages). The same is true of structural uncertainty analysis.

5.4 Integrated modelling tools

5.4.1 Philosophy

The previous sections have shown how computer tools can assist in environmental assessment. There are a number of different types of tool, with different uses and playing a different role in supporting the performance of an assessment. When one is conducting an IEA, however, one needs to consider the whole DPSIR cycle covering a wide range of issues, and many or all of these tools may be needed in a single piece of work. The ideal is clearly to have a single tool, smoothly integrating each of these functions and guiding the user through the assessment step by step.

This ideal has been recognised by a number of people and various efforts have been made to produce such integrated tools for integrated assessments. This has become more feasible in recent years as techniques have matured and as computer processing power has become more affordable, so that interfaces become more user-friendly and increasingly sophisticated models can run on personal computers. Because integrated tools try to do several different tasks, to make them manageable they normally use relatively simple models as components; however, they usually have a modular design which makes it possible to have a number of models of different levels of sophistication, which can be chosen as required, or to add new models.

Having said this, there are always compromises between different approaches to the design of models and tools. Some of the compromise areas are:

- Designed for a particular problem or application area / general-purpose
- Customised / off-the-shelf

- Sophisticated / simple
- Location-specific / location-generic
- Reductionist / conceptual
- Distributed / lumped
- Data requirements onerous / data largely supplied or readily available
- Based on fundamental theoretical equations / based on empirical equations
- Detailed analysis / screening
- Slow to run / fast to run
- Unwieldy to use / user-friendly
- Highly reliable answers / less reliable answers
- Expensive / cheap

Each of these has value if used appropriately. One approach is to use a modular framework into which a wide variety of components can be added to meet different requirements. This enables a middle ground between bespoke customised software and generic off-the-shelf products. Designing, developing, supporting and using such a framework is a non-trivial task and is rather expensive. This path has been taken by two groups, leading to the production of RAISON and the ESS family of products, described in Section 5.4.2 below. An alternative approach with a different set of compromises is the "model development environment" tool, also described in Section 5.4.2.

5.4.2 Applications

Integrated Assessment Modelling is most mature in the field of climate change. Some twenty integrated assessment models have been developed, tackling the problem from different approaches with different emphases. A number of models cover the drivers that lead to greenhouse emissions (economic, demographic, social and technological processes), the effects of emissions on the state of the environment (using much simpler models than the full-blown Global Circulation Models) and the impact of changes of state.

Work in the field of climate change modelling is relatively coherent and well-structured, as well as being rather specialist. For these reasons, it is not covered in detail in this report. Sources of further information, including directions to lists of models, are given in Appendix B.

Another relatively mature field for integrated modelling is acid deposition. The RAINS model was developed by the International Institute for Applied Systems Analysis (IIASA) in Austria to assist in negotiations over acid-producing emissions in Europe (see Section 2.7.3), and subsequently further developed for use in south-east Asia.

RAINS models the whole DPSIR cycle. For example, it calculates:

- energy trends based on socioeconomic and technical assumptions (drivers);
- pollutant emissions for the given energy scenario (pressure);
- consequent acid deposition (state);
- whether the acid deposition exceeds the critical load, that is, whether ecological damage will be caused (impact);
- optimal (cost-minimising) methods of emission control (response).

RAISON is another model initially developed with the acid rain problem in mind, but designed in a modular fashion with the early intention of extending it to a range of other applications. It is now a general-purpose, Integrated Environmental Assessment tool from the National Water Research Institute of Environment Canada. It is a generic toolkit which can be used to assemble data from diverse sources and to link various computer models. It incorporates data management, including GIS, data analysis, visualisation, simulation models, optimisation, and expert systems (to control and advise on the correct operation).

A family of Integrated Environmental Assessment tools has been produced by Environmental Software and Services (ESS), a commercial splinter group of IIASA, including AirWare (for air quality problems), WaterWare (for water quality), CityWare (air and water quality in the context of large cities) and EIAxpert (for assisting with general Environmental Impact Assessments). The functionality is broadly similar to RAISON, although with more emphasis on modelling and less on data management. Again, the ESS tools are designed as modular toolkits (customised systems are available to suit particular problems). Components include standard simulation models, including the US EPA's ISC and PBM models; data management, including GIS; data analysis (e.g. time series analysis of observation data); visualisation; and optimisation.

Sometimes, there are no off-the-shelf models suitable for a particular application, but the burden of developing a new program in Fortran or C/C++ is excessive. Model development environments can make it relatively easy to implement custom computer models without having to worry about incorporating routines for equation solving, visualisation etc. Typically, with these tools the user simply has to specify her model using either native mathematical equations, or special graphical symbols or icons which represent directly the behaviour of the system. The tool then solves the equations and displays the results for you.

There may be constraints on the types of model that can be used. Generally, the easier it is to enter a model (e.g. through graphical drag-and-drop interfaces), the more restrictive the type of model. For example, STELLA assumes that your problem can be modelled by stocks and flows of substances but, within this representation, it displays the model in an intuitive graphical fashion. On the other hand, Analytica uses a spreadsheet-style interface which allows a greater range of functions (but is still less flexible than a custom-written Fortran or C/C++ program).

In addition to equation solving and visualisation tools, model development environments may include facilities for uncertainty analysis, statistics and other types of data analysis. Note that because they use general-purpose numerical solution techniques, they may be unable to handle complex models with stiff sets of equations.

LUCAS is an example of a tool developed for integrated assessments of a particular problem area, in this case land use. This makes a point of including the role of socioeconomic driving forces, as well as inherent ecological processes, in determining impacts such as habitat fragmentation and spatial dynamics. LUCAS does not include tools to directly help ascertain an appropriate response, so it is a D–P–S–I model.

6. Criteria for selection of models in this report

A very large number of environmental computer-based models have been developed over the years. Only a small proportion are described and referenced in this document. These are the ones that meet the aims of this document (see Section 1) — to list models which enable non-specialists to solve environmental planning and management problems and improve their understanding of the ecosystem conditions.

Particular criteria for the inclusion of models are as follows:

- Models should be of use in *Integrated* Environmental Assessment. Ideally the model should assess a complete DPSIR cycle and provide a corresponding response.
- Models should be usable by people without specialist technical knowledge (though not necessarily easily).
- Models should be publicly available, either as public domain software, commercial software, or operated in-house by specialist consultants.
- Models should cover areas on a local or regional scale.
- Models should preferably be applicable to generic locations.
- In addition, a number of models have been included as representatives of an important class of models which, however, falls outside the main scope of this report (e.g. air transport models).

These criteria have been applied flexibly. Deviations will be clear from the model descriptions.

The selected models are listed in Appendix A. Descriptions of each model are given, designed to enable readers to find which models meet their requirements. Sources for more information are given, and so is information on availability and obtaining the software.

It has not been possible to review all the available models. In particular, certain models and groups of models have been excluded as follows:

- Simple simulation models (see Section 5.1) have been excluded, apart from a number of representative examples, because they are not specifically suitable for IEA, their inclusion would make theme of integrated assessment in the report harder to follow, and other sources of this information are available (see Appendix B.1).
- Similarly, Environmental Risk Assessment and Life Cycle Assessment are tangential to the main theme of the report; again, examples are detailed and sources of further information given in Appendix B.2 and B.3 respectively.
- Climate change and other global models are excluded partly on the grounds that individual actions by local and regional managers are unlikely to have a noticeable effect given the resolution of such models, and also because this field relatively coherent and well-structured, as well as being rather specialist (meaning that there are good information sources already available; see Appendix B.4).

Disclaimer. *Inclusion or exclusion of any model in this document does not represent any endorsement or other comment on any model by AEA Technology plc. Selection has been on the basis of whether the model meets the specified criteria, according to information supplied by the model developer, model supplier and/or others. Such information (including value terms such as "easy" or "flexible") has been accepted* *and used by AEA Technology plc in good faith. No attempt has been made by AEA Technology plc to run, test, verify or validate models for inclusion in or exclusion from this document.*

7. Examples of computer models for use in IEA

The models listed in Appendix A may be grouped as follows.

- Simulation models (e.g. air, groundwater, etc.). As noted above, there are many of these and only a few representatives have been chosen, for illustrative purposes. These are:
  - ADMS
  - CMS
  - GEM
  - INM
  - QUAL2E
- Multimedia models:
  - HSPF
  - MMSOILS
  - MULTIMED
  - OTTER
- Environmental Impact Assessment (EIA) tools. These are expert systems, backed up with databases of regulatory and other information, for assisting in conducting EIA. They are either general-purpose (Calyx, EIAxpert) or specific (the agricultural tool EMA).
  - Calyx
  - EIAxpert
  - EMA
- Environmental Risk Assessment (ERA) models. A single representative example is included here, for illustrative purposes:
  - PRAIRIE
- Life Cycle Assessment (LCA) models. Two representative examples are included here, for illustrative purposes. These are:
  - PEMS
  - SimaPro
- Integrated Environmental Assessment tools:
  - The ESS family: AirWare, CityWare, WaterWare
  - GEMS
  - LUCAS
  - RAINS
  - RAISON
- Model development environments:
  - Analytica
  - M
  - STELLA
- Information management tools. Two representative examples are included here:
  - PV-Wave (visualisation)
  - ARC-Info (GIS)

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Appendix A: Model descriptions

A.1 ADMS (Atmospheric Dispersion Modelling System)

Purpose: Simulation of pollutant transport through air.

Source: Cambridge Environmental Research Consultants
3 King's Parade, Cambridge, CB2 1SJ, UK
Tel: +44 (0)1223 357773
Fax: +44 (0) 1223 357492
Email: enquiries@cerc.co.uk
URL: http://www.cerc-uk.demon.co.uk/nophrame/models/adms/adms2.htm

Platform: PC, 8Mb RAM, Windows 3.1

Approximate price: N/K

Description:
Simulation of pollutant transport through air (passive plume). ADMS is a PC-based model for atmospheric dispersion of passive, buoyant or slightly dense releases from single or multiple sources. ADMS uses a parameterisation of the boundary layer that defines the boundary structure in terms of measurable physical parameters, instead of Pasquill–Gifford stability categories.

Developed by CERC and the UK Meteorological Office. Sponsors include the regulatory authorities HMIP and HSE. ADMS is used widely by industry, research institutions (both in the UK and abroad), and by the Environment Agency in the UK.

Comprehensive validation includes:
- comparisons with standard field, laboratory and numerical data sets;
- participation in EU workshops on short range dispersion models;
- comparison with archived data in a study sponsored by HMIP.

Model applications include Integrated Pollution Control applications, odour predictions, risk assessments, planning applications and environmental statements. Concentrations can be calculated for different averaging times to directly compare model predictions with different limits and guidelines such as EPAQS, WHO, and EU.

A.2 AirWare

Purpose: Integrated, model-based information and decision support system for air quality assessment and management.

Source: Environmental Software and Services GmbH
PO Box 100 A-2352 Gumpoldskirchen, Austria
Tel: +43 2252 63305
Fax: +43 2252 633059

Email: info@ess.co.at
URL: http://www.ess.co.at

Platform: Unix

Approximate price: systems from US$25 000

Description:
AirWare is an interactive, integrated, model-based information and decision support system for air quality assessment and management, supporting the implementation of European and national environmental legislation. Designed for major cities and industrial areas, the flexible modular software components makes it possible to adapt and apply the system to a broad range of physiographic, meteorological, socioeconomic and environmental conditions.

The system provides access to advanced tools of data analysis and the design and evaluation of air quality control strategies, using a suite of simulation and optimisation models together with integrated data base management, a geographical information system, and expert systems functionality. These components are integrated with an interactive and graphical user interface designed for users with little or no computer experience. An extensive data base provides background information on legislation, pollutants, emission sources and coefficients, models, health effects, and control technologies.

AirWare is designed as a modular system; it can integrate a range of information resources:
- geographic background data including administrative divisions, land use and land cover, population data, transportation networks, water bodies, orography, satellite imagery and aerial photography; these are managed by the embedded GIS;
- observation data, including links to on-line monitoring stations, and statistical analysis of these time series data;
- emission inventories for a range of different source types and pollutants; an embedded rule-based expert system simplifies the task of estimating unmeasured emissions;
- a range of air quality simulation models, including:
  - US EPA Industrial Source Complex (ISC) steady-state Gaussian long- and short-term models;
  - US EPA Photochemical Box Model (PBM) smog and ozone model;
  - traffic emission modelling;
  - an optimisation routine for emission reduction strategies.
- linkage to external models covering areas such as the energy system of traffic, i.e., major sources of air pollution; this includes energy analysis and optimisation, as well as linkages to traffic simulation models;
- decision support tools, ranging from simple impact assessment and post-processing tools to complex optimisation models for the design of optimal investment strategies in pollution control equipment;
- hypertext system, with on-line help and explain functions, and references to regulations, standard definitions and guidelines.

For the design of cost-efficient control strategies, AirWare includes an optimisation module. The model requires cost functions for emission reduction for each source, including zero technology and the possible complete closure of a source as the extreme cases.

The optimisation model uses a long-term model scenario, for which the individual contributions of each source (a spatially distributed source–receptor matrix) have been determined. Alternative objectives include: minimise total emission; maximise cost efficiency of emission reduction; minimise ambient concentrations (this can be limited to certain sub-areas of the domain, e.g., populated areas only); maximise cost efficiency of concentration reduction; and minimise environmental impact or maximise cost-efficiency of impact reduction, subject to a budget constraint.

A.3 Analytica

Purpose: Model development environment.

Source: Lumina Decision Systems, Inc.
59 North Santa Cruz Avenue, Suite Q, Los Gatos, CA 95030, United States
Tel: +1 408 354 1841
Fax: +1 408 354 9562
Email: info@lumina.com
URL: http://www.lumina.com/software/index.html

Platform: Macintosh, System 6 or System 7. PC, Windows 95 or Windows NT.

Approximate price: US$795

Description:
Analytica is a modelling software tool, based on an earlier version called Demos. The qualitative structure of models can be created and viewed using influence diagrams which distinguish between decisions (variables you can control), chance variables (uncertain quantities you cannot control), and objectives (criteria you want to maximise). Models have a hierarchical, modular structure; modules may be stored in libraries. The Analytica model definition also serves as documentation.

Analytica specifically supports risk analysis and uncertainty modelling. You can:

- Express uncertainty about any variable, selecting a probability distribution using a graphical browser.
- Propagate uncertainties through the model easily and efficiently using Latin hypercube or Monte Carlo sampling.
- Display uncertain results as standard statistics, probability bands, probability density functions, or cumulative probability functions.
- Compare the relative contribution of each uncertain input on your result, using rank-order correlations, or importance analysis.
- Discover non-linearities and interactions by graphing model behaviour as you vary one or more inputs parametrically.
- Visually understand the relations between uncertain variables using scatter plots.

Analytica is being used for two major IEAs. The Tracking and Analysis Framework (TAF) is a model assessing the costs and benefits of the US Clean Air Act 1990, with an emphasis on acid precipitation. The Integrated Climate Assessment Model (ICAM) is designed to order knowledge about climate change, identify key uncertainties, and explore how uncertainties can be addressed in the policy process.

Further reading:
For TAF:
See online at URL http://www.lumina.com/taflist

For ICAM:
H Dowlatabadi, M Ball et al. An Overview of the Integrated Climate Assessment Model version 2 (ICAM-2). Vancouver, Canada, Western Economic Association, 1994.

A.4 ArcView GIS

Purpose: Geographical Information System (GIS).

Source: ESRI
380 New York Street, Redlands, CA 92373-8100, USA
Tel: +1 909 793 2853 Ext. 1 1235
Fax: +1 909 307 3070
Email: intlwebmaster@esri.com
URL: http://www.esri.com/base/products/arcview/arcview.html

Platform: Windows (3.1, NT, and 95), Macintosh, UNIX

Approximate price: N/K

Description:
ArcView GIS is one of the most commercially successful GIS programs for the storage, analysis and visualisation of geographical information. It enables you to create maps and add your own data to them. Data can be in tables, maps or charts. On one map, you can integrate many different types of data including business, demographics, facilities, CAD, and images. Maps can be used alongside traditional analysis tools, such as spreadsheets and business graphics. A number of maps are supplied with ArcView GIS, and additional map data is available from ESRI and third parties. It's also possible to create your own basemap layers. You can modify existing maps to meet your exact needs; or if no maps currently exist, you can create your own. Using the software's visualisation tools, you can access records from existing databases and display them on maps.

ArcView GIS gives you hundreds of new ways to query and analyse your data. You can query your data according to location, content, proximity, and intersection. Add data to maps, then find the geographic factors that drive trends and distributions. Add different data layers, and then find locations at which particular characteristics coincide. Aggregate data geographically by summarising it based on areas. The output from one analysis can be used as the input to the next analysis, enabling you to create advanced geoprocessing applications.

Results can be presented as maps or interactive displays by linking charts, tables, drawings, photographs, and other files.

A.5 Calyx

Purpose: Expert system and database tool for Environmental Impact Assessment.

Source: ESSA Software Ltd
Suite 300, 1765 W 8th Avenue, Vancouver, BC, Canada V6J 5C6
Tel: +1 604 733-2996
Fax: +1 604 733-4657

Email: calyx@essa.com
URL: http://www.essa.com

Platform:
Basic version: PC, 486/66, 16 Mb RAM, Windows 3.11
GIS version: PC, Pentium 90, 32 Mb RAM, Windows 95

Approximate price: N/K

Description:
Calyx is a tool for assisting with Environmental Impact Assessments. It is an expert system which uses impact rules and databases to deduce both direct and indirect environmental impacts of a project. It also recommends appropriate technology and actions to reduce potential impacts. Alternative project scenarios can be considered.

The tool guides the user through the process of determining a project's potential for environmental effects. The user can devise several different project scenarios, compare their environmental effects and recommended mitigating actions, and then reach conclusions about the best solution. Calyx manages the storing and tracking of environmental data entered by the user, finds patterns in the data and charts impact pathways.

The expert system (databases, impact rules, etc.) can be updated by the user.

Available in two versions. Calyx EA is designed to focus on the preliminary scoping steps in an environmental assessment. Calyx GIS couples the Calyx inference engine with GIS capabilities; this version is better suited for project design, evaluation and planning.

A.6 CityWare

Purpose: Information and decision support system for the urban environment.

Source: Environmental Software and Services GmbH
PO Box 100 A-2352 Gumpoldskirchen, Austria
Tel: +43 2252 63305
Fax: +43 2252 633059
Email: info@ess.co.at
URL: http://www.ess.co.at

Platform: Unix

Approximate price: systems from US$25 000

Description:
CityWare is an interactive, integrated, model-based information and decision support system for the urban environment. Designed for major cities, metropolitan areas and urban conglomerates, it combines elements of the AirWare air quality assessment and management system and WaterWare for water quality and water resources management with elements of technological risk analysis and Environmental Impact Assessment, and special tools to support public access to environmental information through the Internet.

A.7 CMS (Comprehensive Modeling System)

Purpose: Air quality modelling.

Source: Consortium for Advanced Modeling of Regional Air Quality (CAMRAQ).
Email: ahansen@msm.epri.com or jake@odysseus.owt.com
URL: http://odysseus.owt.com/Camraq/index.html

Platform: Pentium PC, IBM OS/2 Warp, 48MB RAM (Prototype #1)

Approximate price: No charge (Prototype #1)

Description:
The Comprehensive Modeling System (CMS), currently under development, is an air quality modelling tool that aims to incorporate all the functions of an air quality assessment into one tool. It will combine issues such as:

- Regulation of new and existing sources.
- Ozone control: estimation of the effects of alternative VOC and NO_x emission control strategies on ozone concentrations and ozone attainment demonstration modelling.
- Acid deposition issues: estimation of the sources of acid deposition and identification of potential remedial control strategies.
- Particulate matter: air quality, deposition, and health effect impacts; regional-scale and local particulate matter (PM) concentration impacts at coarser (PM10) and finer (PM2.5) size distributions; visibility impairment.
- Toxics: impacts of toxic compounds (e.g., formaldehyde, benzene, 1-3-butadiene, POMs, dioxin, mercury, cadmium, etc.) on health, both through direct exposure to ambient air and through indirect sources (e.g., bioaccumulation of toxics in fish) and on ecosystems (e.g., deposition of toxics into bodies of water).
- Source Apportionment, i.e., the assessment of the fractional contribution of a source (or a group of sources) to the air pollution concentrations measured in a certain region.
- Emergency planning and response through estimation of the range and level of impact of accidental releases (real or hypothetical) of toxic compounds.
- Exposure of humans to harmful air pollutants through inhalation (e.g., ozone, PM10, toxics) and other pathways.
- Risk assessment of different mitigation measures including cost-benefits analysis of alternative emission control strategies.

The user interface will be designed to be user-friendly and will incorporate the following functions:

- Visualisation
- Geographical information systems (GIS)
- On-line CMS training
- Policy and regulatory aspects
- Data acquisition/reduction
- Support for report preparation

The CMS is currently at the first prototype stage.

The CMS is being developed by the Consortium for Advanced Modeling of Regional Air Quality (CAMRAQ). CAMRAQ is a cooperative membership organisation open to all interested participants. Associate Members pay a nominal membership fee and have full access to CAMRAQ's models and computation facilities. Full Members pay a larger membership fee, which is applied to ongoing development of CAMRAQ's modelling facility.

A.8 EIAxpert

Purpose: Expert system for Environmental Impact Assessment.

Source: Environmental Software and Services GmbH
PO Box 100 A-2352 Gumpoldskirchen, Austria
Tel: +43 2252 63305
Fax: +43 2252 633059
Email: info@ess.co.at
URL: http://www.ess.co.at

Platform: Unix

Approximate price: systems from US$25 000

Description:
EIAxpert is an interactive, rule-based expert system for Environmental Impact Assessment. It is designed for a screening level assessment of development projects at a pre-feasibility stage.

The system can operate with a minimum of data and information about the project, its alternatives, and the environmental setting by drawing on a generic knowledge and rule base as well as a regional geographical information system and a set of data bases.

EIAxpert is a generic, completely data driven assessment tool that can easily be configured for a broad range of application domains and regions.

The generic EIAxpert system includes:

- a data base and interactive editor tools for water resources development projects, that allow users to maintain (and compare) multiple alternatives for each project;
- a two-layer, hierarchical geographical information system, covering the entire river basin as well as the areas immediately affected by individual projects. The GIS uses both vector data and satellite imagery;
- a set of data bases, including meteorology, hydrography, water quality observations and environmental technologies such as waste water treatment;
- a knowledge base with checklists, rules, background information and guidelines and instructions for the analyst;
- the inference engine, which guides the analyst through a projects assessment in a simple menu-driven dialogue;
- a summary report generator, which summarises and evaluates the impact assessment and provides a hardcopy report.

Through the rules of the expert system, external models can be invoked as part of the inference procedure. Models can be used to calculate impacts of reduced flow, waste water discharges, land use changes, etc., or to estimate project parameters such as irrigation water demand, or changes to the groundwater table.

A.9 EMA (Environmental Management for Agriculture)

Purpose: Decision support system for agricultural Environmental Impact Assessment.

Source: University of Hertfordshire
Department of Environmental Sciences, Hatfield Campus, Hatfield, Hertfordshire AL10 9AB, United Kingdom
Tel: +44 (0)1707 284582 or 285259
Fax: +44 (0)1707 285258
Email: k.a.lewis@herts.ac.uk or j.tzilivakis@herts.ac.uk

Platform: PC, Windows 3.1 or higher

Approximate price: N/A

Description:
A tool for agricultural Environmental Impact Assessment, and for supporting good environmental practice in farming. Includes decision support via:

- A comprehensive advisory system containing hypertext information on best practice, regulations and auditing. It also contains a contacts database, glossary and index.
- Independent modules to help identify site-specific best practice, e.g. fertiliser recommendations, soil erosion risk, pesticide information and waste management.
- Environmental performance evaluation.
- A unique eco-rating system which compares actual practices with best practices on a site-specific basis to provide personalised advice and support.
- Audits for a variety of farming enterprises including arable, beef and dairy, grassland, other livestock, energy, water and farmland conservation.
- Estimates of site-specific emissions inventory.

EMA is sponsored by the Ministry of Agriculture, Fisheries and Food, and is designed for UK applications.

Due for release early 1998.

Further reading:
K A Lewis, J A Skinner and K S Bardon, "A computerised decision making tool for the environmental management of agriculture". *Proceedings of IAIA 1996,* Lisbon, 1996.

K A Lewis, M J Newbold, J A Skinner and K S Bardon, "A decision support system for environmental management of agriculture". *Proceedings of Eco-Informa 1996,* Florida, 1996.

K A Lewis, J Tzilivakis, J A Skinner, J Finch, T M Kähö, M J Newbold and K S Bardon, "Scoring and ranking farmland conservation activities to evaluate environmental performance and encourage sustainable farming". *Sustainable Management* (forthcoming).

A.10 GEM (General Ecosystem Model)

Purpose: Ecosystem simulation.

Source: Maryland International Institute for Ecological Economics
Attn. Roel Boumans, University of Maryland, Box 38, Solomons, MD 20688-0038, United

States
Email: boumans@cbl.cees.edu

Platform: Macintosh

Approximate price: Free of charge.

Description:
The General Ecosystem Model (GEM) is designed to simulate a variety of ecosystem types using a fixed model structure. Driven largely by hydrologic algorithms for upland, wetland and shallow-water habitats, the model simulates the response of macrophyte and algal communities to entered levels of nutrients, water, and environmental inputs. It also models ecological processes that determine water levels, plant production, nutrient cycling associated with organic matter decomposition, consumer dynamics, and fire.

The basic model can be replicated as a unit to build a model of a heterogeneous, grid-based, time-varying spatial area, using different parameter sets for each habitat.

A basic version was used to simulate the response of sedge and hardwood communities to varying hydrologic regimes and associated water quality. Sensitivity analyses provided examples of the model dynamics, showing the varying response of macrophyte production to different nutrient requirements, with subsequent changes in the sediment water nutrient concentrations and total water head. Changes in the macrophyte canopy structure resulted in differences in transpiration, and thus the total water levels and macrophyte production.

Further reading:
H C Fitz, E B DeBellevue, R Costanza, R Boumans, T Maxwell, L Wainger and F H Sklar, "Development of a general ecosystem model for a range of scales and ecosystems". *Ecological Modelling,* **88**, 263–295, 1996.

A.11 GEMS

Purpose: Model base, database and associated tools

Source: US Environmental Protection Agency
Attn. Ms. Lynn Delpire, 401 M Street, SW, Washington, DC 20460, United States
Tel: +1 202 260-3928
Email: delpire.lynn@epamail.epa.gov

Platform: PC, MS-DOS

Approximate price: Public Domain

Description:
GEMS is a model-base system which supports exposure and risk assessments by providing access to single-medium and multimedia fate and exposure models, physico-chemical property estimation techniques, statistical analysis, graphics and mapping programs with related data on environments, sources, receptors and populations. Under development since 1981, GEMS provides analysts with an interactive, easily learned interface to various models, programs, and data needed for exposure and risk assessments on the EPA VAX cluster. PC-GEMS is a stand-alone version of GEMS to be run on a PC.

Atmospheric, surface water, land unsaturated (soil) and saturated (groundwater) zones, and multimedia models are available. It contains methods for estimating octanol–water partition and adsorption coefficients, bioconcentration factors, water solubilities, melting and boiling points, vapour pressures, Henry's constants, acid dissociation constants, lake/stream volatilisation rates and atmospheric half-lives. It contains associated environmental and 1980 population data encompassing most of the US.

A.12 HSPF (Hydrological Simulation Program Fortran)

Purpose: Simulation of quantity and quality of runoff from catchments and receiving waters.

Source: US Environmental Protection Agency
Center For Exposure Assessment Modeling, Athens, Georgia, United States
Email: ceam@epamail.epa.gov
URL: ftp://ftp.epa.gov/epa_ceam/wwwhtml/hspf.htm

Platform: PC, MS-DOS

Approximate price: Public Domain

Description:
HSPF is a comprehensive modelling package for the simulation of the quantity and quality of runoff from multiple-use catchments, and of processes occurring in streams or fully-mixed lakes receiving catchment runoff. It allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of the simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at any point in a catchment.

Water quality algorithms include BOD/DO dynamics, carbon, nitrogen, and phosphorus cycles, suspended and attached phytoplankton, and one species of zooplankton. Submodels also include sediment transport, pesticide routing and degradation kinetics, and sediment–pesticide interaction. The transformation processes included in the model are hydrolysis, photolysis, oxidation, volatilisation, sorption and biodegradation. The kinetic reactions are formulated as second-order processes. Secondary or “daughter” chemicals are also simulated; up to two daughter chemicals can be analysed in a single simulation.

The one-dimensional formulation limits application of the model to river systems where pollutants are uniformly mixed both laterally and vertically; the kinematic wave formulation of flow in rivers is not applicable to rivers where the gradient is very small or where backwater effects are present; data requirements for the model may be quite extensive depending on the particular application; and the zero-dimensional representation of lakes assumes that pollutants are uniformly mixed throughout and that the lake is not stratified.

A.13 INM (Integrated Noise Model)

Purpose: Simulation model for noise from airports.

Source: ATAC Corporation
Attn. Ms. Lois Masin, 757 N. Mary Ave., Sunnyvale, CA 94086, United States
Tel: +1 (408) 736-2822

Fax: +1 (408) 736-8447
Email: loismasin@atac.com
URL: http://aee.hq.faa.gov/aee-100/AEE-120/INM/index.html

Platform: Windows 95 and Windows NT 3.51 and higher.

Approximate price: US$250 (site licence)

Description:
The Integrated Noise Model (INM) has been the Federal Aviation Authority's standard tool since 1978 for determining the predicted noise impact in the vicinity of airports. Outputs of INM include noise contours used in land use compatibility studies, noise impacts by aircraft on individual flight tracks, and user-defined point analysis of noise impacts. The model is capable of processing US Census population data, terrain data, and flight schedules from the Official Airline Guide. Graphic displays include navigational aids from the National Flight Data Center database, terrain contours, Census population and street map data, and airport layouts.

The current version is Version 5.1 (released January 30, 1997).

A.14 LUCAS (Land-Use Change Analysis System)

Purpose: Decision support tool for land use environmental assessment.

Source: University of Tennessee
107 Ayres Hall, Knoxville, TN 37996-1301, United States
Tel: +1 615 974-3838
Fax: +1 615 974-4404
Email: lucas-info@cs.utk.edu
URL: http://www.cs.utk.edu/~lucas/

Platform: Sun SPARCstation running SunOS 4.1.3
Requires GRASS version 4.1 (public-domain GIS)

Approximate price: Free of charge.

Description:
The Land-Use Change Analysis System (LUCAS) is a prototype computer application designed to integrate socioeconomic and ecological information using a GIS, in order to:

- provide a multidisciplinary modelling environment for addressing research questions concerning land use and its impacts,
- apply adaptive management approaches in order to address management questions concerning landscape-impact assessment

Ecological dynamics in human-influenced landscapes are strongly affected by socioeconomic factors that influence land-use decision making. Landscape properties such as fragmentation, connectivity, spatial dynamics and the degree of dominance of habitat types are influenced by market processes, human institutions, landowner knowledge and ecological processes. Simulations using LUCAS generate new maps of land cover representing the amount of land-cover change so that issues such as biodiversity conservation, assessing the importance of landscape elements to meet conservation goals, and long-term landscape integrity can be addressed.

LUCAS consists of three subject modules linked by a common database. The first module contains the socioeconomic models that are used to derive transition probabilities associated with changes in land cover. These probabilities are computed as a function of socioeconomic driving variables including:

- transportation networks (access and transportation costs)
- slope and elevation (indicators of land-use potential)
- ownership (land holder characteristics)
- land cover (vegetation)
- population density.

For example, a preliminary analysis of the Little Tennessee River Basin showed that land-cover change is most likely to occur on private land, near a paved road, on flat low elevation land, and close to the major urban centre of the catchment. Most of the transitions in land cover are forest converting to grassy/brushy and unvegetated cover types.

The second LUCAS module contains the landscape-change model. This module uses the output of the socioeconomic models to produce a map of land cover that reflects socioeconomic motivations behind human land-use decision making.

The third module of LUCAS contains impact models, which utilise the land-cover maps produced by the landscape-change module to estimate impacts to selected environmental and resource-supply variables. These environmental variables include the amount and spatial arrangement of habitat for selected species and changes in water quality caused by human land use. Potential resource-supply variables include timber yields and real estate values.

Contains data for a small region in western North Carolina only.

Further reading:
M W Berry, R O Flamm, B C Hazen, R L MacIntyre, "Lucas: A System for Modeling Land-Use Change". *IEEE Computational Science & Engineering,* **3(1)**, 24–35, 1996.

A.15 M

Purpose: Model development environment.

Source: RIVM (The National Institute of Public Health and the Environment)
Attn: Jos de Bruin, PO Box 1, 3720 BA Bilthoven, The Netherlands
Tel: +31 30 274 91 11
Fax: +31 30 274 29 71
Email: m-support@rivm.nl
URL: http://www.m.rivm.nl/

Platform: Unix using X Windows (Motif or OpenLook). PC with Windows 95 or Windows NT. Minimal video resolution of 1024 * 768 and at least 256 colours.
A C compiler is required for the developers version (Borland or Visual C++ under Windows).

Approximate price: Free for non-commercial use.

Description:

M is an integrated software environment for the development, visualisation and application of interactive, dynamic models based on algebraic, difference and differential equations. M consists of a non-procedural mathematical formalism, an efficient compiler, a design tool for drawing user interfaces without any programming and a powerful scenario management tool. By a combination of speed, animation, dynamic control, direct access to all data in graphs or tables, integrated Web publishing and support for both Unix and Windows platforms, M has proven a useful instrument in the development and application of complex integrated models of public health and climate change.

Often, model implementations can only be understood by their developers, even when the underlying specifications are quite simple. M is designed to make model implementation as similar to the model specification as possible. This means that, for example, assumptions can be clearly identified from the model code. The importance of this is partly to improve the productivity of the developers, but most importantly to improve communications between developers and decision-makers.

M is designed to make it possible to distribute interactive, easy-to-use and well-documented versions of the simulation models themselves to a wider audience. Such models could provide effective illustrations of the complex interactions and interdependencies that characterise most environmental problems and make them often so hard to tackle. These interactive models would enable a greater number of policy analysts and others to explore alternative scenarios. This should contribute to a better understanding of the limitations of a model and enhance the participation of interested parties in the formulation or evaluation of policies and scenarios.

The Windows 95/NT version may be downloaded from RIVM's web site for a 90-day evaluation.

A.16 MMSOILS

Purpose: Multimedia simulation of releases of contamination from hazardous waste sites.

Source: US Environmental Protection Agency
Center For Exposure Assessment Modeling, Athens, Georgia, United States
Email: ceam@epamail.epa.gov
URL: ftp://ftp.epa.gov/epa_ceam/wwwhtml/mmsoils.htm

Platform: PC, MS-DOS

Approximate price: Public Domain

Description:
The MMSOILS model is a methodology for estimating the human exposure and health risk associated with releases of contamination from hazardous waste sites. The methodology is a multimedia model addressing the transport of a chemical in ground water, surface water, soil erosion, the atmosphere, and accumulation in food. The human exposure pathways considered in the methodology include: soil ingestion, air inhalation of volatiles and particulates, dermal contact, ingestion of drinking water, consumption of fish, consumption of plants grown on contaminated soil, and consumption of animals grazing on contaminated pasture. For multimedia exposures, the methodology provides estimates of human exposure

through individual pathways and combined exposure through all pathways considered. The risk associated with the total exposure dose is calculated based on chemical-specific toxicity data.

The methodology is intended for use as a screening tool. It is critical that the results are interpreted in the appropriate framework. The intended use of the exposure assessment tool is for screening and relative comparison of different waste sites, remediation activities, and hazard evaluation. The methodology can be used to provide an estimate of health risks for a specific site, but the uncertainty of the estimated risk may be quite large (depending on the site characteristics and available data) and this uncertainty must be considered in any decision making process.

A.17 MULTIMED (Multimedia Exposure Assessment Model)

Purpose: Multimedia simulation of releases of contamination from hazardous waste sites.

Source: US Environmental Protection Agency
Center For Exposure Assessment Modeling, Athens, Georgia, United States
Email: ceam@epamail.epa.gov
URL: ftp://ftp.epa.gov/epa_ceam/wwwhtml/multimed.htm

Platform: PC, MS-DOS

Approximate price: Public Domain

Description:
The Multimedia Exposure Assessment Model (MULTIMED) simulates the movement of contaminants leaching from a waste disposal facility or contaminated soils. The model includes two options for simulating leachate flux and one option for simulating pre-existing soil contamination in the unsaturated zone. The infiltration rate to the unsaturated or saturated zone can be specified directly or a landfill module can be used to estimate the rate. The landfill module is one-dimensional and steady-state, and simulates the effect of precipitation, runoff, infiltration, evapotranspiration, barrier layers (which can include flexible membrane liners), and lateral drainage. A one-dimensional, semi-analytical module simulates flow in the unsaturated zone.

The output from this module, water saturation as a function of depth, is used as input to the unsaturated zone transport module. The latter simulates transient, one-dimensional (vertical) transport in the unsaturated zone and includes the effects of longitudinal dispersion, linear or non-linear adsorption, and first-order decay. Output from the unsaturated zone modules — i.e. steady-state or time series contaminant concentrations at the water table — is used to couple the unsaturated zone transport module with the steady-state or transient, semi-analytical saturated zone transport module. The latter includes one-dimensional uniform flow, three-dimensional dispersion, linear adsorption, first-order decay, and dilution due to direct infiltration into the groundwater plume. Contamination of a surface stream due to the complete interception of a steady-state saturated zone plume is simulated by the surface water module. Finally, the air emissions and the atmosphere dispersion modules simulate the movement of chemicals into the atmosphere.

The fate of contaminants in the various media depends on the chemical properties of the contaminants as well as a number of media- and environment-specific parameters. The uncertainty in these parameters is quantified using the Monte Carlo simulation technique.

Separate interactive pre- and post-processing software have been developed for use in creating and editing input and in plotting model output.

A.18 OTTER

Purpose: Multimedia simulation tool for heavy metal transport in the freshwater environment.

Source: AEA Technology
Attn: Jon Hancox, Thomson House, Risley, Warrington WA3 6AT, United Kingdom
Tel: +44 (0)1925 254667
Fax: +44 (0)1925 254570
Email: jon.hancox@aeat.co.uk

Platform: PC, Windows 3.1

Approximate price: N/K

Description:
OTTER is a model for the transport of heavy metals and radionuclides through the freshwater environment, typically for simulating the after-effects of deposition from the atmosphere. It integrates models of catchment areas (both surface runoff and subsurface flow), rivers and lakes. Doses to humans from drinking water and fish consumption are calculated. Generic environments may be modelled, with catchment, lake and river modules fitted together as required. Validated against measured data from the UK Lake District.

A.19 PEMS

Purpose: Life Cycle Assessment tool.

Source: Pira International
Randalls Road, Leatherhead, Surrey, KT22 7RU, UK
Tel: +44 (0)1372 802000
Fax: +44 (0)1372 802238
URL: http://www.pira.co.uk/environment/

Platform: PC, Windows 3.1
Requires Microsoft Excel version 4.

Approximate price: N/K

Description:
Assists product designers and manufacturers conduct Life Cycle Assessments for their products.

PEMS contains a wide range of standard life cycle inventory analysis studies in the form of detailed inventory tables. In addition, PEMS has four main databases containing environmental data on materials manufacture, transportation, energy generation and waste management.

The user can create a life cycle inventory analysis incorporating company-specific data or using data from the built-in databases. The inventory can be produced directly from a flow diagram. Complex systems such as those involving internal recycling of materials and energy can be modelled. The user can trace the source of particular environmental burdens and conduct determinations of impact assessment using either a problem oriented (classification, characterisation and valuation) or medium oriented (critical volumes) approach.

A.20 PRAIRIE

Purpose: Environmental Risk Assessment tool for releases of chemical substances into rivers.

Source: AEA Technology
Attn: Jon Clark, Thomson House, Risley, Warrington WA3 6AT, United Kingdom
Tel: +44 (0)1925 254523
Fax: +44 (0)1925 254570
Email: jon.clark@aeat.co.uk

Platform: PC, Windows 3.1

Approximate price: N/K

Description:
PRAIRIE is a risk assessment software tool for predicting the risks associated with accidental releases of hazardous materials into rivers or estuaries. The program was developed on behalf of the UK HSE, Department of Environment and National Rivers Authority. It can be used for either deterministic or probabilistic assessments.

The model's aquatic dispersion calculations are based on methods advocated by the US EPA and account for volatilisation, photolysis, hydrolysis, oxidation and cationic exchange. The effects of weirs, and chemical partitioning between the dissolved and undissolved phase and interaction with suspended sediment, are also simulated. Databases include chemical specific data, toxicological data and river-specific hydrological data.

A.21 PV-Wave

Purpose: Data visualisation and analysis tool.

Source: Visual Numerics, Inc.
5775 Flatiron Parkway, Ste. 220, Boulder, Colorado 80301, USA
Tel: +1 800 447 7147 or +1 303 939 8797
Fax: +1 303-245-5301
Email: info@boulder.vni.com
URL: http://www.vni.com

Platform: UNIX, Open VMS, Windows NT or Windows 95

Approximate price: N/K.

Description:

PV-Wave is a family of specialist tools for data visualisation and analysis. It provides functionality for representing, importing, exporting, filtering, transforming, analysing, visualising, and communicating data and graphics. Two interfaces are available, a command-line type interface and a point-and-click interface. It can display data in a number of ways, including 2-D, 3-D, 4-D, surface, contour, and bar plotting. Sundry data transformation and manipulation functions are included.

The purpose is to enable users to interactively visualise, explore, and analyse large amounts of data. However, it seems to be aimed less at ad-hoc users, who want to analyse individual datasets that they have obtained for a particular purpose, than at developers of professional graphical and numerical analysis applications. As such, it may be over-powered for most readers of this report.

A.22 QUAL2E

Purpose: Simulation tool for river water quality.

Source: US Environmental Protection Agency
Center For Exposure Assessment Modeling, Athens, Georgia, United States
Email: ceam@epamail.epa.gov
URL: http://www.epa.gov/ORD/WebPubs/QUAL2E/

Platform: PC, MS-DOS

Approximate price: Public Domain

Description:
Simulation of pollutant transport in rivers. QUAL2E is a stream water quality model designed primarily to simulate conventional constituents (e.g., nutrients, algae, dissolved oxygen) under steady-state conditions, both with respect to flow and input waste loads. It uses a finite difference solution to the one-dimensional advective–dispersive mass transport and reaction equation. For each computational element (reach of the stream), a hydrologic balance in terms of flow, a heat balance in terms of temperature, and a materials balance in terms of concentration is written. Both advective and dispersive transport are considered in the materials balance.

A.23 RAINS

Purpose: Decision support tool for acid deposition assessment.

Source: International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria
Tel: +43 2236 807 0
Fax: +43 2236 71313
Email: tapasia@iiasa.ac.at
URL: http://www.iiasa.ac.at/~heyes/docs/rains.asia.html

Platform: PC, Windows 3.1

Approximate price: US$200–US$2000 depending of type of institution.

Description:
Tool for integrated assessment of strategies to reduce acid deposition. Applicable to any part of the world, provided appropriate databases have been prepared. (These have been developed for Europe and south-east Asia.) The RAINS model provides data on energy scenarios, emission control technologies and abatement costs, atmospheric transport and critical loads. RAINS allows the user to examine the costs and effectiveness of different emission control strategies under various energy-use scenarios. RAINS contains modules to do the following:

- enable the creation of alternative regional energy pathways;
- estimate future energy trends for a variety of socioeconomic and technical assumptions;
- estimate the pollutant (SO_2) emissions for a given energy scenario;
- estimate the costs of emission control (various abatement options available);
- estimate acid deposition, based on a transfer matrix for long-range transport calculated by an atmospheric transport/deposition model, NOAA's Branching Atmospheric Trajectory (BAT) model;
- provide estimates of deposition as a function of changing emissions;
- compare deposition estimates with critical loads, providing maps showing the exceedance of critical loads.

Further reading:
J Alcamo, R Shaw and L Hordijk (eds.), "The RAINS model of acidification: science and strategies in Europe". Dordrecht, Netherlands: Kluwer Academic Publishers, 1990.

G Carmichael et al. "Acid Rain and Emissions Reduction in Asia: An International Collaborative Project on Acid Rain in Asia". Proceedings of the International Conference on Environment and Climate Change in East Asia, Taipei, Taiwan, November 30 – December 3, 1993.

L Hordijk "Integrated Assessment Models as a Basis for Air Pollution Negotiations". *Water, Air and Soil Pollution*, **85(1)**, 249-260, 1995.

A.24 RAISON

Purpose: Environmental assessment tool.

Source: National Water Research Institute, Environment Canada
PO Box 5050, Burlington, Ontario, L7R 4A6, Canada
Tel: +1 905 336-4916
Fax: +1 905 336-4430
Email: nwri.software@cciw.ca
URL: http://www.cciw.ca/nwri-e/software/raison.html

Platform: PC, Windows

Approximate price: US$975

Description:
A framework for integrating environmental assessment tools, including databases, maps, statistical functions, graphical functions, spreadsheet, expert system and models. It uses a modular, open architecture design to allow additional functionality to be added.

For example, in the case of acid rain integrated assessment, data for atmospheric emission, deposition, geochemistry and ecology are brought together under one dataset in RAISON. In addition, mathematical models for atmospheric long-range transport of sulphur dioxide and other pollutants, geochemistry models for chemical pathways in groundwater and surface waters, and species-richness and damage models for fish, wildlife and forestry are linked together into a customised system. With the data and models all integrated under one system, the user can then change the emission scenario and assess the impact on fish and forestry.

Existing models (e.g. simulation or pollutant transport models) not built in to the system may be incorporated by either:

- rewriting the codes in a programming language acceptable for running under Windows,
- emulating the model by a simplified version such as an input–output model, or
- running the executable codes as given off-line, manually transferring the model input and output.

The first two options require customisation by the developer.

Advanced applications may also use expert systems to control and advise the correct operation of models and data analysis, and use optimisation procedures (linear programming and genetic algorithms) to find the optimal economic cost of pollution control for a given ecological objective. Such advanced customisation is usually done by the developers. However, for simple cases the basic RAISON system offers sufficient linkages to data and models to be used as a stand-alone system.

Further reading:

W G Booty, I W S Wong, D C L Lam, J P Kerby, R Ruddock and D F Kay, "Application of an expert system for point source water quality monitoring". In: G Guariso and B Page (Eds.), Computer Support for Environmental Impact Assessment. North-Holland: Elsevier Science BV, 1994.

D Lam and D Swayne, "A hybrid expert system and neural network approach to environmental modelling: GIS applications in the RAISON system". *HydroGIS 96: Applications of Geographic Information Systems in Hydrology and Water Resources Management* (Proceedings of the Vienna Conference, April 1996). IAHS Publ. no. 235, pp. 685–693, 1996.

D C L Lam, I Wong, D A Swayne and J Storey, "A knowledge-based approach to regional acidification modelling". *Environmental Monitoring and Assessment,* **23**, 83–97, 1992.

A.25 SimaPro

Purpose: Life Cycle Assessment tool.

Source: PRé Consultants BV
Plotterweg 12, 3821 BB Amersfoort, The Netherlands
Tel: +31 33 4555022
Fax: +31 33 4555024
E-mail: info@pre.nl
URL: http://www.pre.nl/sp31.html

Platform: PC, 286 processor or higher (486 recommended), MS-DOS, 4 Mb RAM (8 Mb recommended).

Approximate price: NLG 4800 (single-user licence). Multi-user licences available.

Description:
Assists product designers and manufacturers conduct Life Cycle Assessments for their products. It is an expert system which uses impact rules and databases to deduce both direct and indirect environmental impacts of a product. Databases can be updated by the user. Alternative scenarios can be considered.

A.26 STELLA

Purpose: Model development environment.

Source: High Performance Systems, Inc.
45 Lyme Road, Suite 200, Hanover, NH 03755, United States
Tel: +1 603 643 9636
Fax: +1 603 643-9502
Email: support@hps-inc.com
URL: http://www.hps-inc.com

Platform: Macintosh, System 7 with a minimum 8Mb RAM.
PC, 486 or better, Windows 3.1 or 3.11, 8Mb RAM recommended.

Approximate price: UK£500 (Strategy version), UK£875 (Analyst version). Educational rates available.

Description:
STELLA is a widely-used tool that lets you construct and run mathematical models using a simple graphical interface. It is easy to use and is used for teaching as well as research. It uses a "System Dynamics" approach, modelling stocks of substances in compartments and flows between compartments. It is widely used in the field of ecological modelling, and a closely related program, ithink, is used for simulation of businesses.

Models are entered through a very simple graphical user interface. Boxes on the screen represent a stock or amount of substance. Arrows between boxes represent flows of substances, or the effect of one box on another. Each arrow has a differential equation specifying how the content of each box changes. For example, one box might represent the concentration of a pollutant in the water of a lake, and another box the concentration in fish. An arrow would flow from the lake to the fish, representing ingestion of the pollutant by the fish, and another arrow would flow from the fish to the lake, representing metabolic elimination of the pollutant by the fish. Another arrow would represent the outflow of pollutant from the lake. You can run the model and obtain graphs to see how the concentrations in the water and in the fish vary over time.

STELLA makes it easy to develop and use your own models, as long as your problem can be represented by a compartment model. Many simple and straightforward models are of this type, but for more sophisticated and realistic simulations (including non-linear effects), a more powerful tool is required.

A.27 WaterWare

Purpose: Water resources management information system.

Source: Environmental Software and Services GmbH
PO Box 100 A-2352 Gumpoldskirchen, Austria
Tel: +43 2252 63305
Fax: +43 2252 633059
Email: info@ess.co.at
URL: http://www.ess.co.at

Platform: Unix

Approximate price: systems from US$25 000

Description:
WaterWare is a modular, interactive water resources management information system.

Implemented in an open, object-oriented architecture, it supports the integration of tools, databases and models into a common framework. This basic framework includes a multimedia user interface with Internet access, a hybrid GIS with hierarchical map layers, object databases, time series analysis, reporting functions, an embedded expert system, and a hypermedia help and explain system.

Linked to the data layer are a set of models, that can perform scenario analysis, i.e., answer "what-if" and "how-to" questions for various water quantity and quality issues, as well as related engineering, environmental, and economic aspects. WaterWare includes a number of simulation and optimisation models and related tools, such as:

- a rainfall runoff and water budget model
- an irrigation water demand estimation model
- a graphical river network editor
- dynamic and stochastic water quality models
- a groundwater flow and transport model
- a water resources allocation model
- an expert system for Environmental Impact Assessment.

These tools are embedded into a user interface that translates the specific functionality of a given model into a decision support tool: the component models and tools are restructured in terms of decision variables and performance variables, relating to the objectives, criteria, and constraints of various decision problems.

WaterWare is a modular and data driven system. It can be configured for customised installation with different sets of models and tools. Through shared data formats, and the respective filter programs, third-party tools can be used with the system for special tasks, for example, image processing or statistical analysis of observation data. Standard interfaces to data bases and the GIS make it possible to integrate additional models.

WaterWare is available as a customised system optionally including data preparation or training, under an open-ended, non-transferable site license with optional maintenance and support agreements. Source code for the development libraries and main programs are also available, allowing users to add their own models and tools. For remote support and maintenance, Internet access (email, FTP and Telnet) is highly recommended.

Appendix B: Sources of further information

B.1 Simulation models

B.1.1 General

A recent review of air transport models has been performed by the European Topic Centre on Air Quality ("Ambient Air Quality, Pollutant Dispersion and Transport Models", Topic Report 19, European Environment Agency, 1997).

A clearing-house for groundwater models is maintained by the International Ground Water Modeling Center at the Colorado School of Mines. They maintain a database of groundwater models, which can also be obtained from them for a small charge.
International Ground Water Modeling Center
Colorado School of Mines, 1500 Illinois St., Golden, Colorado 80401-1887, United States
Tel: +1 303 2733000
Fax: +1 303 2733278
Email: igwmc@mines.edu
URL: http://www.mines.edu/igwmc/

Numerous other organisations maintain lists of models. A selection of Web sites is:

- WWW-Server for Ecological Modelling, University of Kassel (large modelbase, mainly ecological).
  URL: http://dino.wiz.uni-kassel.de/ecobas.html

- LIVIA project, Fondazione Eni Enrico Mattei (list of simulation models).
  URL: http://www.feem.it/web/feem/livia/FIRST/mod_base.html

- Politecnico di Milano (list of miscellaneous environmental models and software, mainly groundwater-related).
  URL: http://abete.elet.polimi.it/~rizzoli/envmod.html

- Consortium for the Advanced Modelling of Regional Air Quality (list of mesoscale air transport models).
  URL: http://odysseus.owt.com/Camraq/mesoscale.html

- GAIA project, Environmental Software and Services GmbH (another list of lists).
  URL: http://www.ess.co.at/GAIA/models/modelrefs.html

B.1.2 EPA software

The US Environmental Protection Agency (EPA) has developed a large number of models which are in the public domain. A high-level index of software resources available on the EPA web site is at URL http://www.epa.gov/epahome/Data.html. Many of the most important EPA models are distributed by CEAM:
Center for Exposure Assessment Modeling (CEAM)
National Exposure Research Laboratory — Ecosystems Research Division

Office of Research and Development
US Environmental Protection Agency
960 College Station Road, Athens, Georgia 30605-2700, United States
Tel: +1 706 355 8400
Fax: +1 706 355 8302
Email: ceam@epamail.epa.gov
URL: http://www.epa.gov/epa_ceam/wwwhtml/ceamhome.htm

Two other good sources of EPA models are the Information Systems Inventory (ISI) and the Exposure Models Library and Integrated Model Evaluation System (EML/IMES).

The ISI is a database of summary-level descriptions of EPA's computer application systems, models, modules, and databases. It can be downloaded over the Internet from URL http://www.epa.gov/earth100/isi/. The database program runs on a PC under MS-DOS.

The EML/IMES is a CD-ROM package containing over 120 models which may be used for exposure assessments and transport modelling. The model files may contain source and/or executable code, sample input files and other data files, sample output files, and in many case, model documentation. The CD-ROM runs on a PC under MS-DOS and may be obtained from:
Richard Walentowicz
EPA Office of Research and Development
National Center for Environmental Research and Quality Assurance
401 M Street, SW (MC-8603), Washington, DC 20460, United States
Tel: +1 202 260 8922
Fax: +1 202 260 0929
Email: walentowicz.rich@epamail.epa.gov

B.2 Environmental Risk Assessment

Lists of software (and other information) for Environmental Risk Assessment have been compiled in another EEA report:
R Fairman, C D Mead and W P Williams, Environmental Risk Assessment — Approaches, Experiences and Information Sources. EEA Report (forthcoming).

This includes models for:
- risk assessment and management,
- exposure assessment and transport,
- hazard identification and release assessment.

B.3 Life Cycle Assessment

The prime mover in the establishment of the discipline of Life Cycle Assessment is the Society of Environmental Toxicology and Chemistry (SETAC). They may be contacted at:
Society of Environmental Toxicology and Chemistry (SETAC)
1010 North 12th Avenue, Pensacola, FL 32501-3370, United States
Tel: +1 904 469 1500
Fax: +1 904 469 9778
Email: setac@setac.org
URL: http://www.setac.org/

SETAC's LCA publications include A Technical Framework for Life-Cycle Assessment, A Conceptual Framework for Life-Cycle Assessment, Guidelines for Life-Cycle Assessment: A Code of Practice, and Life-Cycle Assessment Data Quality: A Conceptual Framework

EcoSite is "a virtual library, shop and forum for LCA users world-wide" with a large amount of LCA information, including software suppliers and consultants. It is principally a Web site but has a bimonthly newsletter available by fax or email.
15 Whitehall Park, London N19 3TS, UK
Tel: +44 (0) 171 281 4900
Fax: +44 (0) 171 281 0966
Email: editorial@ecosite.co.uk
URL: http://www.ecosite.co.uk/

A list of software and database suppliers can be found at an Internet page from Steve Young, of SB Young Consulting, and the University of Toronto Faculty of Engineering
URL: http://www.trentu.ca/faculty/lca/LCAsoftware.html

B.4 Climate change

Web sites with good links to climate change information include:

Socioeconomic Data and Applications Center (SEDAC)
Consortium for International Earth Science Information Network (CIESIN)
2250 Pierce Road, University Center, MI 48710, United States
Tel: +1 517 797 2727
Fax: +1 517 797 2622
Email: ciesin.info@ciesin.org
URL: http://sedac.ciesin.org/mva/

Center for Integrated Study of the Human Dimensions of Global Change
Department of Engineering and Public Policy
Carnegie Mellon University
Pittsburgh, PA 15213, United States
Tel: +1 412 2682678
Fax: +1 412 2683757
URL: http://hdgc.epp.cmu.edu/main.html

A recent review of climate change models is:
H Dowlatabadi, "Integrated Assessment Models Of Climate Change: An Incomplete Overview". *Energy Policy,* 1995. Available online:
URL: http://hdgc.epp.cmu.edu/public/publications/abstracts/OVERVIEW.html