8.0 Application of Expert Systems

The various methods, approaches and techniques presented in chapters three to seven for identifying, measuring, and assessing impacts all have two aspects in common. First, they are designed to deal with the considerable amount of information that must be processed and analyzed as a part of an environmental impact assessment (EIA). Second, they rely on expert judgement.

The challenge of collecting, processing, analyzing, and reporting information can be partially met by use of various computer and information technologies. The use of predictive computer models (Chapter 4) is becoming more prevalent. The use of geographic information systems (GIS) (Chapter 3) for handling spatial data is also becoming more frequent where there are adequate personnel skills and financial resources to acquire the necessary data. In most cases, however, environmental problem solving is conceptual and cannot always be reduced to quantitative analysis (that is, modeling). Often, available information is incomplete, subjective, and inconsistent.

Experts are heavily involved in all aspects of the assessment. Many checklists, matrices, and models used in EIA are accumulations of the experience of many experts gathered over many years. Experts are used to help identify the potential for significant impacts, plan data collection and monitoring programs, provide judgement on the level of significance for specific impacts, and suggest ways of reducing or preventing impacts. The discussion, in Chapter 2, of constraints on implementing EIA processes in developing countries concluded there is a critical lack of environmental scientific expertise to help government, industry, and development banks apply existing knowledge to meet the EIA requirements. When there are a large number of projects to consider, contracting outside experts for each one is not always practical, and EIAs may be undertaken by those lacking either sufficient training or time to make sound decisions.

Expert systems are promising technologies that manage information demands and provide required expertise. They thus seem well suited to many of the tasks associated with EIA. Additional advantages of using expert systems for EIA are:

1. expert systems help users cope with large volumes of EIA work;
2. expert systems deliver EIA expertise to the non-expert;
3. expert systems enhance user accountability for decisions reached; and
4. expert systems provide a structured approach to EIA.

Because the application of expert system technology to EIA is relatively new, one might consider the technology as “too” advanced and not appropriate for developing countries. This is not true, and expert systems are slowly being disseminated throughout developing countries in Asia and the Pacific.

Before discussing the current application of expert systems in developing Asia and the Pacific, it is necessary to better describe the technology itself and discuss its present and potential application to EIA.

8.1 Terminology

Developers of expert systems strive to provide systems with the ability to:

1. mimic the reasoning capability of human experts;
2. deal with incomplete and imprecise knowledge;

3. explain and provide a rationale for conclusions;
4. provide alternate options for consideration;
5. provide wider distribution and access to scarce expert knowledge; and
6. provide systematic and consistent application of knowledge.

Reasons for developing and implementing expert systems vary, but are most often characterized by one or more of the following:

1. human expertise is lost due to retirement, transfer, etc.;
2. average practitioners perform inconsistently;
3. tasks are not repetitive (algorithmic), but require extensive thought each time; and
4. human experts are scarce, and a *knowledge bottleneck* exists.

Expert systems technologies have bewildered many outsiders (such as engineers and technical specialists who do not specialize in artificial intelligence). This is, in part, because of the use of complex terminology and unclear definitions. To establish a common base of understanding, some definitions are suggested here (Finn, 1989):

Artificial Intelligence: The sub-field of computer science concerned with understanding the concepts and methods of human reasoning, and the application of this understanding to the development of computer programs that exhibit intelligent behavior.

Expert System: A computer program that performs difficult, specialized tasks at the level of a human expert. Because of the reliance of these programs on varied types of knowledge, these programs are also known as Knowledge-Based Systems.

Heuristic Knowledge: Judgmental knowledge underlying expertise — often consisting of *rules-of-thumb* acquired through personal experience. This heuristic knowledge is usually implicit, not necessarily being explicit even to the expert.

Domain Knowledge: The term *domain* refers to the specific area of application, such as pump failure diagnosis, or chemical analysis. Domain knowledge is that knowledge which is specific to the domain, rather than general knowledge, or common sense knowledge.

Knowledge Base: That part of the program in which the knowledge is stored, using some method of representation, such as rules.

Inference Mechanism: Also known as the "Inference Engine," this controls the reasoning operations of the expert system. This is the part of the program that deals with making assertions, hypotheses, and conclusions. It is through the inference mechanism that the reasoning strategy (or method of solution) is controlled.

8.2 Expert Systems Fundamentals

The general structure of an expert system (Figure 8-1) can be described in terms of six main components:

1. The external data acquisition systems, which provide the input data for the specific application. These systems may be manual (that is, data must be collected and entered by hand) or automated (for example, remote sensing);
2. the knowledge base, which is a collection of domain specific knowledge usually represented as rules based on IF-THEN logic;
3. external application programs, with which the system exchanges information and data. For example, computer simulation models may provide quantitative estimates of air and water quality parameters or GIS may provide spatial data on the location and characteristics of key environmental components. Reports from expert systems may be exported to common wordprocessing or database software programs;
4. the user, who controls the system, inputs information, selects options, and generates reports;
5. the user interface, which is the means by which the user communicates with other components. Most user interfaces are menu driven and have a number of display and reporting features; and
6. the inference engine, which is the reasoning mechanism that manipulates the rules in the knowledge base to provide conclusions. These specific conclusions depend on the information supplied by the user, external data acquisition systems, and external programs.

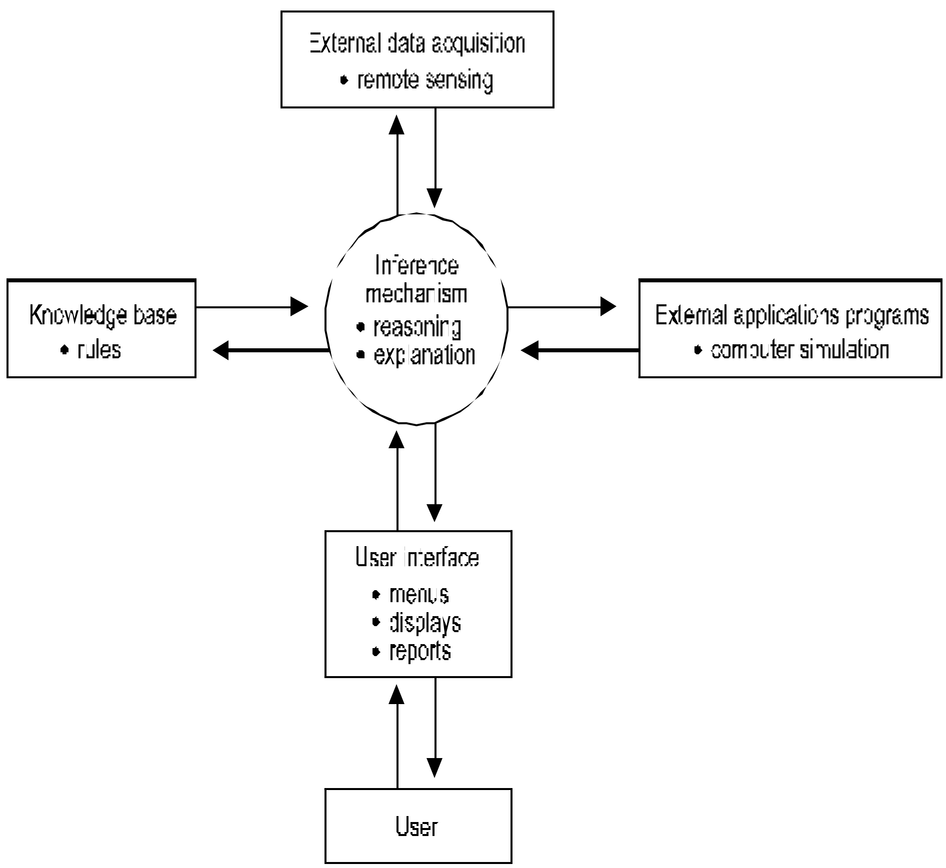

Figure 8-1: General structure of expert systems.

Knowledge bases in expert systems are based on collections of rules. These rules are constructed by codifying the experience and knowledge of a group of experts. These rules are often represented in the following form:

IF	<a set of conditions is true>
THEN	<certain conclusions can be drawn>

For example:

IF	there is a discharge of a pollutant
and	the loading of the pollutant is a relatively large volume
and	the discharge is into a water body
THEN	the water body's water quality will significantly decline
and	IF the water body's ambient water quality is within environmental standards
THEN	ambient water quality will decline below environmental standards.

Note that the rules are represented in natural language (in this case English). One benefit of this natural representation of rules is that knowledge bases can be developed rapidly without the need to perform extensive programming. Another benefit is that once a knowledge base has been developed, it is relatively easy to maintain. Adding, modifying, or deleting rules does not usually require making extensive system changes. The end-user also benefits by this natural-language format since questions are posed in language which can be colloquial and familiar to the users. Typically, answers are selected from *menus*, rather than users being required to type full sentences.

Another feature of expert systems is their ability to perform some form of explanation, or justification. This means that once a conclusion is reached, the end-user may ask the expert system to explain its answer, and the system will step back through its solution procedure, or explain its answer in some other way. It is possible to perform this function because the separation of inference and application allows for the development of application-independent tracing or explanation mechanisms. In addition, many systems allow users to pause in the midst of a solution procedure and examine the system's current knowledge about the problem at hand, and its current reasoning path.

8.3 Applications of Expert Systems to EIA

Gray and Stokoe (1988) reviewed a number of expert systems and decision support tools in environmental assessment and natural resource management. They found only a few examples of systems applied specifically to EIA, however they found many more applied to natural resources management. Systems were identified for forestry, hazardous wastes, risk assessment, weather forecasting and a number for specialized applications that were difficult to categorize. Page's (1989) comparative analysis of environmental expert systems in Canada and the then Federal Republic of Germany also revealed only a small number of applications specifically directed to EIA. He found a number of systems that applied to natural resource management. Page's review revealed that most of the systems were either in a prototype or demonstration stage. His study found a number of promising directions in the environmental expert systems being developed, namely:

1. more "intelligent" (that is, AI-based) user interfaces, employing colored graphics, object oriented techniques, window systems, flexible help functions on different user levels, explanation facilities and eventually performing some natural language processing;
2. "Intelligent" user access support and orientation on environmental databases (for example, literature of chemical substances), as well as more efficient database search techniques;
3. training and instructional systems allowing for an efficient transfer of environmental expert knowledge; and
4. straightforward diagnostic/interpretation expert systems for well-bounded domains, which are well understood in AI, and where powerful tools are already available, as problem solving aids (for example, in early stages of the EIA process).

Hushon (1990) identified sixty-eight applications of expert systems to a wide range of environmental problems. Again, very few of those identified were useful as EIA tools. By the early 1990s, a number of expert systems for environmental assessment had been developed or were in the prototype phase. Geraghty (1993) reported on eleven expert systems for environmental assessment, of which the majority were in the prototype phase. Most recently, Beanlands (1994) prepared a bibliography listing expert system applications specific to EIA.

Although the theoretical benefits of expert systems for EIA have been known for some time, to date there are still only a small number of these systems. A number of limitations to using expert systems for EIA help to explain this dearth:

1. the high level of effort required to develop the knowledge base, rule base, and/or geographic setting within the expert system;
2. the frequent need to customize expert systems for each organization (thus making them impractical for simple one time applications);
3. the training and computer hardware that must be available to the EIA team so they can adequately use the expert system; and
4. the lack of suitability of such systems for performing algorithmic problem solving tasks.

8.3.1 Applications of EIA Expert Systems in Developed Countries

This section and the next (8.3.2) present brief descriptions of selected expert systems for EIA. It is important to note that there are very few fully operational systems, and thus, many of the systems described below are research prototypes that have not been applied to real world situations. It is unclear whether any prototypes will become fully operational expert systems — this is due, in part, to the previously mentioned limitations of expert systems, and the inability to accurately predict technological breakthroughs and large funding commitments that are required to develop each expert system to a fully operational phase.

SCREENER™

SCREENER is a computer assisted environmental expert system that screens projects for potential environmental impacts. The user selects from a menu of options both the proposed activity and the environmental features where the activity will take place. The program receives this information and refers to its knowledge and rule bases to assign a code that describes the potential impact of the activity in the environment designated by the user (1 - no impact; 2 - insignificant impacts; 3 - mitigable impacts; 4 - unknown impacts; 5 - significant impact). Based on the code, SCREENER recommends the level of environmental impact assessment required for the project. SCREENER also provides the user with suggested mitigation measures to help prevent or reduce environmental impacts. In Canada, SCREENER has been implemented at about forty sites by Canadian government departments. SCREENER was based on the DOS operating system and has been replaced by the Calyx™ technology for Windows.

Calyx™

ESSA Software Ltd. ("ESSA"), through its Calyx™ group of products ("Calyx"), provides a suite of decision support software tools. The Calyx group of products are PC-based, with applications that allow decision makers (usually project managers) the ability to assess likely environmental and socio-economic impacts of their activities before they happen. With Calyx, users can devise several different scenarios for projects, compare their environmental impacts and recommended mitigations, and reach a conclusion about the most acceptable solution. From entering the characteristics of the project site and the project activities, to printing the final reports, Calyx takes users step-by-step through the process.

The core technology and knowledge base associated with its expert system is adaptable to many applications. The first applications involve the analysis, classification, and mitigation of various environmental and land management issues and their impacts. Specifically, software applications have been created for the design and operation of military-bases and power projects, while additional applications are available for international financial organizations and government agencies for the review & analysis of a variety of issues associated with infrastructure development projects.

ESSA Software has released two applications of its knowledge-based software to date: Calyx EA (Environmental Assessment), and Calyx-ADB (Asian Development Bank). A third application, Calyx RM (Range Management), is currently being evaluated and beta tested by key clients in the military both in Canada and Australia, and is scheduled for general release in late 1997. Initial development on a fourth product (Calyx EA-Power) is under way with CH2MHill Ltd., a large U.S.-based international engineering firm, with a client in Russia. A final product, Calyx - Emergency Preparedness, is currently under development at this time.

The version of Calyx developed in conjunction with the Asian Development Bank for application in ASEAN countries is described in detail in section 8.3.2.

In contrast to stand-alone, special-purpose software tools currently available in the market, Calyx offers several unique characteristics, including the ability to successfully integrate relational databases, GIS-based information, and other software models and applications into its software.

ORBI

This expert system for EIA was developed by the Universidade Nove de Lisboa for the Portuguese Department of Environment (Geraghty, 1993). It is written in Prolog with a natural-language interface

(Portuguese). This is one of the few expert systems for EIA which currently has such a facility. This facility makes using and communicating with the system more straightforward and easier than with the usual expert system shells or programing languages, as the user can program and update the system in the user's own language rather than using computer code.

The system consists of four separate programs: the first is in BASIC for digitizing a subject region (a region is broken down into a locational grid); the second is for receiving and storing the digitized information; the third is for knowledge updating; and the fourth comprises two modules in Prolog (the first is a natural-language interface, and the second is an evaluation and explanation module; each of which runs independently of the other).

ORBI has expertise in several disciplines, including geology, hydrology, ecology, and microclimate. The system makes judgments about the suitability of a particular subject region for uses such as industry, agriculture, and recreation. Quantified values are obtained via inferencing rules that indicate the suitability of the environmental assets available relative to development requirements (for example, intensive agriculture). ORBI can produce graphic output in the form of maps, via a plotter.

IMPACT: An Expert System for Environmental Impact Assessment

IMPACT is an environmental analysis screening tool for the U.S. Department of Energy's Savannah River Site in South Carolina (Geraghty, 1993). It uses a simplified GIS approach to assess several types of impacts, including proximity effects, air and water pollution, and groundwater effects (Loehle and Osteen, 1990). Objects such as wetlands or wildlife habitat are represented by circles that cover the area of concern; they are stored as an x-y pair and a radius. This simplified approach is possible because the problem of concern was screening for possible impacts, thus false alarms (warning of an impact when none is likely) are acceptable. Each object has a characteristic influence zone extending out from its boundaries. Any activity within this zone generates a warning of possible impact. The rule base for IMPACT consists of: 1) the radii of zones of influence for each object type; 2) the manner in which objects interact (for example, wells do not adversely affect roads, but waste sites affect wells); and 3) specific regulatory provisions such as necessary permits. The program communicates its results by producing a written tabular report. IMPACT has been tested by its developers on a number of situations. It continues to undergo testing to improve its efficacy (Geraghty, 1993).

8.3.2 Applications for Developing Countries

Calyx-ADB

Calyx-ADB was specifically designed to assist EIA practitioners in the Association of Southeast Asian Nations (ASEAN) countries. The software, developed during an Asian Development Bank regional technical assistance project, is based on Calyx EA, a computer system developed for environmental applications by ESSA Software Ltd. of Vancouver, Canada. Calyx-ADB provides assistance in: 1) screening, 2) scoping the terms of reference for EIA studies and reports, 3) identifying key issues and impacts to consider during the review of EIA reports, and 4) developing monitoring requirements and mitigation measures to attach to approvals. In addition, the system provides information on environmental standards, mitigation measures, guideline documents, and laws and regulations. The information and knowledge on environmental impacts and mitigation measures contained in the system are based on experience gained in EIA throughout the ASEAN region. Calyx-ADB was developed over a two year period by ESSA Technologies Ltd. of Vancouver, B.C. in conjunction with international and local experts in EIA.

The regional technical assistance project was implemented within four countries in the ASEAN region: Indonesia, Malaysia, Philippines and Thailand. The implementing agencies are:

- Indonesia - Badan Pengendalian Dampak Lingkungan (BAPEDAL)
- Malaysia - Department of Environment
- Philippines - Environmental Management Bureau, Department of Environment and Natural Resources
- Thailand - Office of Environmental Policy and Planning, Ministry of Science, Technology and Environment.

Each of the countries has slightly different needs for computerization of their EIA procedures and practices. To make the system useful in each of these countries and within the Asian Development Bank itself, the system was designed to accommodate these different institutional requirements.

The overall objective of the project was to design, develop, test, and implement a computer-based system for EIA in support of environmental assessment activities in the Bank's developing member countries (DMCs) in the ASEAN. The specific objectives were to: 1) to produce a computer system to increase the effectiveness of the preparation and review of EIA through systematic scoping for environmental impact assessment; 2) to produce software to facilitate the determination of appropriate terms and conditions to be attached to approvals of EIA reports; 3) to test/demonstrate the system in each of the four developing member countries, as well as at the Asian Development Bank; and 4) to increase accessibility to existing information on environmental standards and guidelines for EIA. The first version of the system covers four sectors: Irrigation, Urban Wastewater and Water Supply, Power, and Transportation.

The major components of the ADB expert system are shown in the context diagram (Figure 8-2). The diagram shows the EIA tasks for which the system provides assistance and the end users. In addition to these tasks, the complete Calyx-ADB allows knowledge engineers and database administrators to maintain system knowledge bases and databases.

To date over 150 copies of the software have been distributed throughout Asia and the Pacific (including Bhutan, Nepal, Tonga as well the original four ASEAN countries). Over 150 people have been trained in the use of Calyx-ADB. In Thailand, the Environmental Impact Evaluation Division of the Office of Environmental Policy and Planning used Calyx-ADB as training tool to provide in-depth training on EIA. Current proposals provide for the introduction of Calyx-ADB into Viet Nam, Cambodia, Lao PDR, and Myanmar.

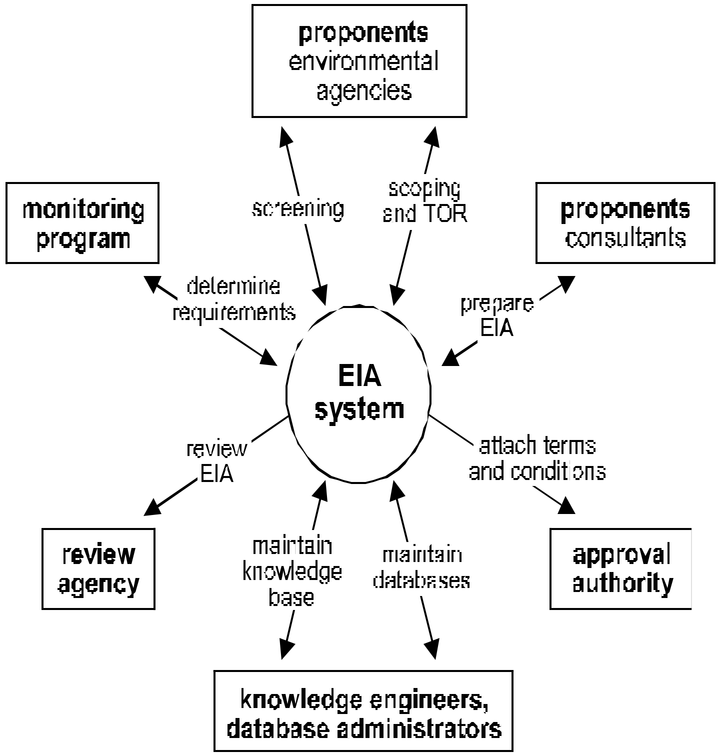

Figure 8-2: Context diagram for the Calyx-ADB computerized EIA system.

MEXSES: Mekong Expert System for Environmental Screening

MEXSES is a prototype expert system for environmental screening developed primarily for implementation by the Mekong Secretariat. The system is a computer program available from the International Institute for Applied Systems Analysis (Fedra, 1991). It draws on a number of established EIA techniques in an attempt to combine the most appropriate elements into one comprehensive and intelligent, knowledge-driven framework and easy-to-use tool. The system manages a database of project assessments and a geographical database of maps and geo-referenced data (Figure 8-3). MEXSES is designed for early assessment and screening of projects. It allows for evaluation of a project in terms of its potential environmental impacts at any early stage with a minimum of project specific information. The prototype draws on extensive knowledge and databases on project characteristics based on generic profiles and a hierarchial classification scheme. The prototype's knowledge base is limited to a few examples of checklists and rules for one problem class (that is, Dams and Reservoirs). MEXSES did not proceed past the prototype stage.

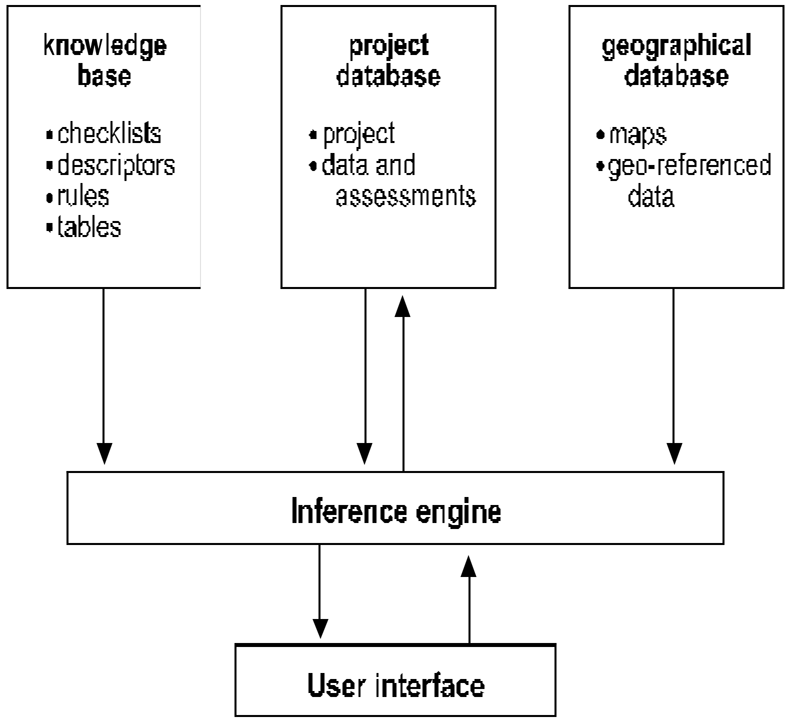

Figure 8-3: The basic structure and components of MEXSES.

8.3.3 Other EIA Decision Support Tools for Developing Countries

The system was developed as a component of the Australian-assisted Natural Resources Management and Development Project of the Department of Environment and Natural Resources. Its principal aim is to help strengthen the Philippine Government's EIA system by allowing quick retrieval of relevant information needed by project proponents, decision-makers, and compliance monitoring teams.

The computer-assisted EIA system is currently being pilot-tested in Cebu Province for two types of environmentally critical projects — sand/gravel quarrying and aquaculture. The system is characterized by the flow chart depicted in Figure 8-4. The system's four main features are:

1. the "Guidelines Routine;"
2. the "Assessment Routine;"
3. the "Review Routine;" and
4. the "Document Monitoring Routine."

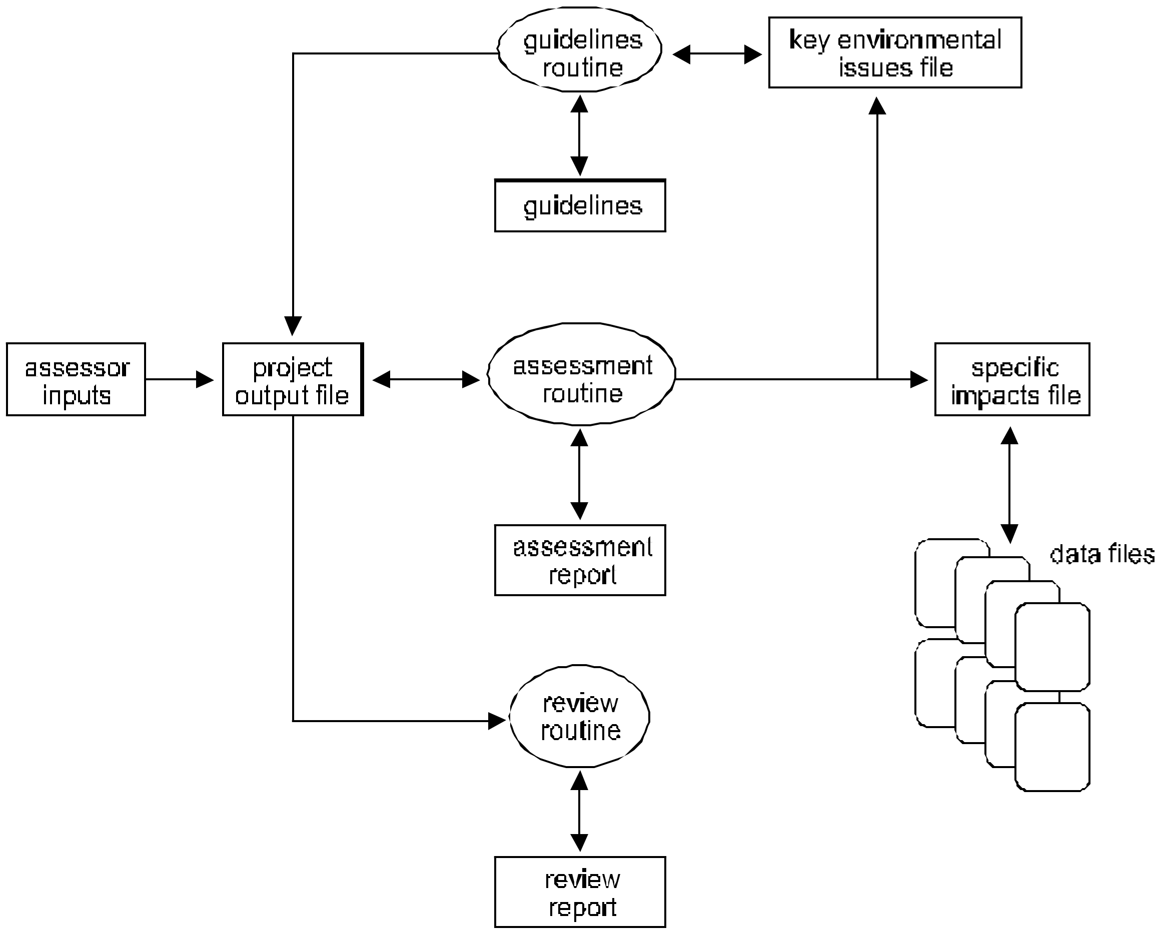

Figure 8-4: The basic organizational structure of the computer assisted EIA system.

The "Guidelines Routine" enables the user to print the scoping guidelines needed to direct project proponents in the preparation of EIA project documents for a specific project. The "Assessment Routine" includes three database files — the main file which is the assessment file, the reference file (issues file) which contains the environmental issues, and the reference file (impacts file) for the environmental impacts. The "Review Routine" provides a text editor to help the EIA Coordinator to consolidate the preliminary assessments made by the project evaluator. The text editor can generate a formatted review containing relevant issues and recommendations that should be addressed by the EIA Review Committee for final decision-making. It will access the project output file and process the project along with the assessor summaries to produce a review report. The "Document Monitoring Routine" generates reports useful in monitoring the processing status of the EIA project documents.

EIAMAN: Computerized Environmental Management System

EIAMAN is an operational prototype program for evaluating and managing development in the Marshall Islands (Carter, 1995). EIAMAN provides a filing and retrieval system for all documents associated with any development project proposed to the Marshall Islands Environmental Protection Agency. The program has a number of desirable features:

1. it provides easy access to important reference documents during the evaluation of a project;
2. it may be used to prepare documents that would serve as important elements of the EIA report;

3. it helps the user conduct a preliminary proposal evaluation;
4. it helps the user conduct scoping; and
5. It makes recommendations on additional studies that may be required.

The knowledge base is organized in terms of checklists for key environmental factors. It incorporates many social, biological, and political considerations, but is quite limited with respect to physical considerations. The user interface is simple to use. It allows the user to:

1. enter information about the preliminary proposal;
2. review the preliminary proposal;
3. conduct scoping;
4. propose additional studies be conducted; and
5. prepare appropriate EIA documentation.

The user interface also manages the interaction with various spreadsheets, memoranda, and documents that are produced by the system.

Summary of Applications

Expert systems are computer programs that perform difficult, specialized tasks at the level of a human expert. They have been implemented in a variety of applications, including games (for example, chess) and public works projects (for example, wastewater engineering). The heuristic reasoning capabilities of expert systems technology seem well suited to many of the tasks associated with undertaking an EIA, however, to date, only a few such systems have been developed. Most of these are in the prototype phase. Some of those systems developed are fully operational at a large number of sites (Table 8-1). Until now, the development of expert systems in developing countries has been funded by International Assistance Agencies, in particular, the Asian Development Bank. While there is interest in EIA expert systems in developing countries, the degree to which these systems will be adopted is uncertain. The degree to which expert systems will be used depends on whether or not practitioners in developing countries can acquire the necessary skills to effectively use the systems.

Table 8-1: Summary of selected expert systems for EIA.

Name	Description	Use in Developed Country	Use in Developing Country
SCREENER™	EIA screening tool	fully operational in forty federal government sites in Canada	
Calyx EA	determines potential environmental effects of projects (no GIS)	operational system being tested in Canada by two government agencies.	complete system being tested in a number of South Pacific island states.
Calyx GIS	determines potential environmental effects of projects using GIS	Calyx GIS prototypes being tested by federal governments of Australia and Canada	
ORBI	expert system for EIA that produces graphic outputs	used by Portugal's federal Department of Environment	
IMPACT	EIA screening tool	operational system being tested by U.S. Department of Energy at the Savannah River Site	
Calyx ADB	determines potential environmental effects of projects		complete system being tested in Bhutan, Nepal, Viet Nam, Thailand, Philippines, Indonesia, Malaysia
MEXSES	EIA screening tool		prototype system developed for the Mekong Secretariat
Computer Assisted EIA	information retrieval system		prototype being tested in Cebu Province of Philippines
EIAMAN	provides filing and retrieval systems for all development project documents		prototype being used in Marshall Islands

8.4 Anatomy of an Expert System

To provide a more in depth understanding of workings and capabilities of expert systems, this section presents a detailed look at the Calyx-ADB expert system for EIA. ***The illustrative examples presented are often simplifications of the information contained in a Calyx-ADB knowledge base. Knowledge bases are constantly being updated as new knowledge is gained and the current knowledge base for Calyx-ADB may contain different information.***

Calyx-ADB has seven core components (Figure 8-5):

1. a knowledge base that is a collection of domain-specific information;
2. databases that provide information about specific environmental components;
3. databases that contain information on laws, regulations, and environmental standards;
4. an inference engine, which implements problem solving strategies to utilize the knowledge base and derive new conclusions;
5. a user interface that controls and guides the practitioner-machine dialogue, including an explanation component that can, on request, explain the system's inference procedures;

6. a reporting system to present the conclusions of the expert system; and
7. output databases that store the results of EIA tasks performed by the system.

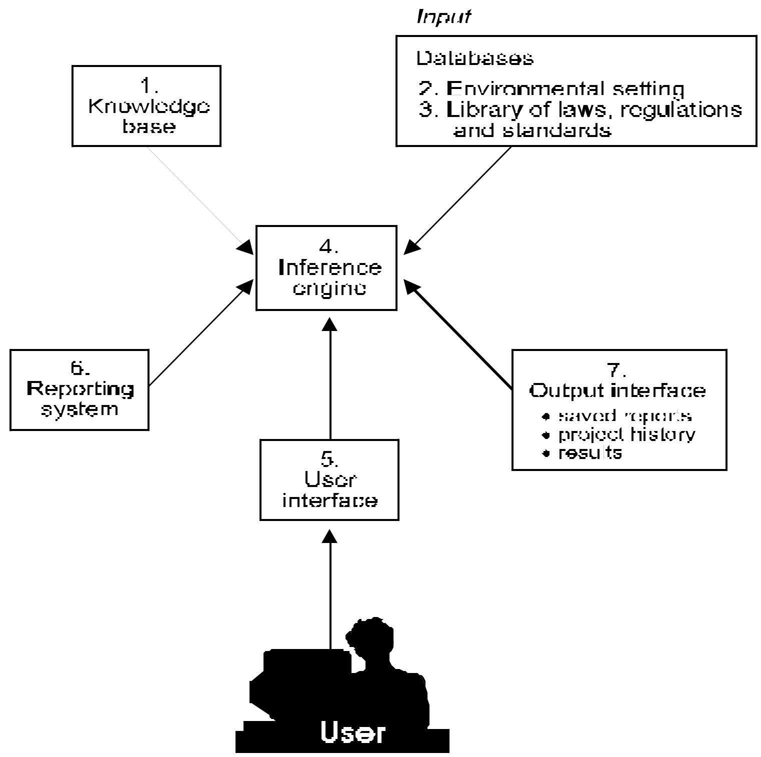

Figure 8-5: Components of ADB expert system.

8.4.1 Knowledge Base

The computerized expert system for EIA developed for the ADB (ESSA Technologies Ltd., 1996) uses a sophisticated knowledge representation system. The system requires information about the project activities and the environmental setting. Each rule states the conditions under which a project activity will have a degree of impact on an environmental component.

Elements of an Impact Rule

The generic elements of a rule (Table 8-2) are:

1. *activity*: which is the basic element of a project or plan that has potential to affect any aspect of the environment. Projects are composed of activities;
2. *activity characteristics*: which define the magnitude, duration, intensity, or extent of an activity;
3. *component*: which is a basic element of the physical, biological, social, or economic environment. Environmental components receive environmental impacts from activities;
4. *component characteristics*: which define the susceptibility, sensitivity, or vulnerability of a component to an impact;
5. *impact mode*: which defines the mechanism by which the impact may occur;

6. *relationship*: which defines the spatial and temporal relationship between the activity and the component; and
7. *site characteristics*: which define characteristics of the site that may influence the nature and degree of impact.

In terms of the IF-THEN format, a rule may be stated:

IF	the activity occurs
and	the activity has certain activity characteristics
and	the component exists
and	the component has certain component characteristics
and	the activity and component have a specific spatial and temporal relationship
and	certain site characteristics exist
THEN	the activity will have a degree of impact on a component acting through the mechanism defined by the impact mode

For example,

Activity:	IF emissions occur
Activity Characteristic:	and the emissions are in large volume
Component:	and an airshed for a population center exists
Component Characteristic:	and the population is very large
Relationship:	and the emissions occur upwind of or into the airshed of the population center
Site Characteristic:	and the atmosphere conditions at or near population are subject to inversions
First Order Impact:	THEN there is potential for significant impacts on air quality in the airshed through increasing concentration of pollutants.

Table 8-2: Generic elements of a rule.

Element	Description
Activity	• project activity; only one identified per rule • e.g., blasting/drilling, asphalting/paving, truck traffic/hauling
Activity Characteristic	• attribute(s) of the project activity; one or more may be identified • e.g., volume, toxicity, areal extent, frequency, duration
Component	• environmental component; only one identified per rule • e.g., terrestrial birds, trees, soil, rivers, aboriginal peoples
Component Characteristics	• attribute(s) of the environmental component; one or more may be identified • e.g., root depth, life stage, rare/endangered, flow rate
Impact Mode	• mode of potential impact; only one may be identified per rule • e.g., contamination, erosion, destruction, change in behavior
Relationship	• descriptor of spatial or temporal relationship between impact mode and component; one or more may be identified • e.g., on/in, up slope of, upwind of, near, coincident with, adjacent to
Site Characteristic	• other characteristics that may be necessary to include in a rule, but describe something about the site or location rather than about the activity or component; one or more may be identified • e.g., heavy rainfall, in a valley, subject to earthquakes • the information on site characteristics will be part of the setting information, and will be identified on a setting-specific or location-specific basis

Triggering Higher Order Rules

First order rules describe the direct impacts of a project on a component. The knowledge base contains higher order rules to ensure that higher order impacts are identified. The structure of first order and higher order rules is almost identical. The only difference is in the initiator portion of the rule: for first order impacts, it is an activity, and for higher order rules it is a component that has been affected by a previous impact and the mode of that impact. Higher order rules are similar to the cells of component interaction matric es (described in Chapter 4). For example, a higher order rule may describe the relationship between changes in air quality and health of residents in a nearby city.

For example,

Mode/Component:	IF air quality in the airshed is reduced through pollution
Component Characteristic	and ambient air quality was within acceptable limits
Component:	and there are local residents
Relationship:	and local residents reside in the area that defines the airshed
Higher order impact:	THEN there is potential for significant impact on the health of local residents.

Linkages to Other Databases

In the ADB knowledge base, the rulebase is linked to three other main databases (Figure 8-6): 1) information requirements; 2) monitoring requirements; and 3) mitigation measures. The information requirements database contains a description of the information that must be gathered to conduct the assessment. This information is made available during scoping to help define the terms of reference. The monitoring requirements database contains suggestions on data that should be collected to monitor project impacts. The mitigation database contains recommended mitigation measures that will prevent or reduce project impacts. Both the monitoring requirements and mitigation measures are available to help the user in specifying terms and conditions of approvals.

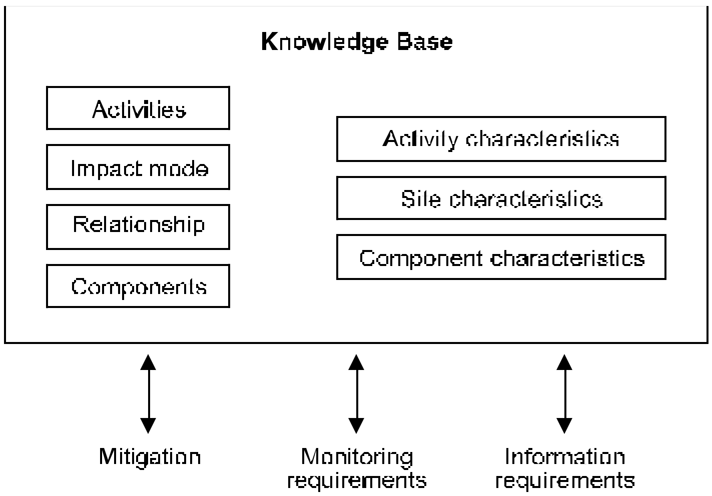

Figure 8-6: Major databases in the ADB knowledge base.

Box 8-1: Information requirements for the first order rule: *Site clearing and preparation damages/destroys terrestrial flora*.

adjacent to: Determine the proximity (distance) from the various project activities to the various environmental components.

ecologically sensitive: Determine whether there are any ecologically sensitive areas present. Such areas include: protected forest land, wildlife sanctuaries, national forest land, wetland (Thailand has a Wetland Directory), mangrove, sites of high biodiversity (e.g., areas that may contain herbal medicines), sites containing rare/endangered species, national parks, watershed classification areas, and areas of genetic importance for particular species (e.g., gold teak in Thailand).

area cleared: Determine the length of time (in months) that any portion of the area will be without vegetation, and the total area to be cleared at any one time.

Information Requirements

During the scoping stage of EIA it is often necessary to determine the information required to conduct the assessment. In Calyx-ADB, most elements in an impact rule are linked to specific information requirements. Consider the first order rule:

IF	site clearing and preparation occurs
and	the area to be cleared is large
and	terrestrial flora exist
and	the terrestrial flora are adjacent to the site clearing
and	the site is characterized as ecologically sensitive
THEN	there is potential for significant impact on terrestrial flora through damage and destruction by site clearing and preparation.

Each of the rule elements (that is, activity characteristic, component characteristic, site characteristics, and relationship) is linked to specific information requirements. The expert system will let the user know about these information requirements whenever *Site clearing and preparation* is identified as one of the project activities, and specific *terrestrial flora* is identified or if the user is uncertain about the presence of *terrestrial flora* (Box 8-1).

Mitigation Measures

Each of the impact rules in the knowledge base is linked to one or more mitigation measures. For our example impact rule, *Site Clearing and Preparation damages/destroys terrestrial flora*, one mitigation measure is:

> *Shifting flora from the project site*: Check for the presence of any rare and endangered species. Record the number of different species present. Where possible relocate rare and endangered species If this is not possible avoid areas where the species are present and prevent access.

The system will present the user with this mitigation option whenever there is potential for an impact on rare and endangered terrestrial flora.

Monitoring Requirements

Each of the impact rules in the knowledge base is linked to one or more monitoring requirements. For our example impact rule, *Site Clearing and Preparation damages/destroys terrestrial flora*, one monitoring requirement is:

> *Protection of trees during construction*: Check for the presence of any rare and endangered species as well as protected species. Monitor the number of different species present before and after the project in the area. Such monitoring should be done once in a year during the first five years and later can be done once in every five years.

In developing terms and conditions for approval, the system will present this monitoring requirement as one of a number of suggested monitoring requirements.

8.4.2 Knowledge Acquisition

The rules in the knowledge base are representations of expert judgement. In the Calyx-ADB system, this expert judgement was acquired in three ways: 1) interviews with individual experts; 2) interdisciplinary workshops focusing on industrial sectors; and 3) review of numerous environmental impact statements and other documents. The task of developing the knowledge base is referred to as "knowledge engineering."

Procedure for Knowledge Acquisition

Issues are broad statements about the potential of a project to generate environmental impacts. For example, an issue statement might relate to effects of wastewater of thermal generation stations on human health (Box 8-2). A number of rules are required to represent issues in the knowledge base.

Box 8-2: Wastewater from thermal power stations — statement of issue.

There are generally three kinds of wastewater from thermal power plants:

1. Domestic wastewater from the canteens, dormitories, and offices, which can be categorized as high BOD wastewater. In the case that the sewer system is a combined one, rainwater may dilute the wastewater, causing it to bypass the system into the receptors outside the plant. Treatment is by biological process (i.e aeration, activated sludge treatment).
2. Spent water from processes. This includes the boiler water, cleaning water, cooling tower water. The water is characterized by high mineral content or high grease and oil content. Nitrogenous compounds (i.e hydrazine used for antifouling) may be found. Treatment is by chemical precipitation and oil and grease removal.
3. Once-through water for cooling for the power plant, which will have about +9 ºC added to the existing water temperature. The volume is enormous, about 7-12 m^3 for a 300 MW power plant. The characteristics are the same as at intake, except that the living organisms are likely to perish from temperature shock. Heat dissipation when released to receiving body of water is required to minimize impact to the living organisms.

The wastewater issue can be significant only in the following cases:

1. The project design does not include provision for needed treatment facilities (for reducing contaminant levels and for effective heat dissipation method for cooling water).
2. Faults in the design and operation of the treatment plants (under capacity, bypassing in the case of combined sewers, etc.) which can be evaluated by wastewater treatment experts.
3. There are sensitive receptors downstream:

3.1 The receiving body of water may be too small, such that the effluents from the power plant can effect the characteristics of the)D, COD, temperature, chemicals).

3.2 Inadequate dispersion, such as the still water in lakes and lagoons, rivers with low current speed or with tidal effects that alternate rections often.

3.3 Uses of the water downstream which require exceptionally good quality of water, such as aquaculture, recreation, potable water

In developing Calyx-ADB, the first step was to define a preliminary set of issues that might arise in the conduct of an EIA for projects in the power, urban water supply and wastewater, irrigation, and transportation sectors. These issues were developed by preliminary review of EIA documents and written submissions by domain experts. The next step was to define a set of rules for each issue. In working with experts and/or EIA documents, knowledge engineers first tried to obtain answers to the questions listed in Table 8-4. The answers to these questions were recorded in special rule templates. The information from rule templates was entered into a Knowledge Acquisition Tool (KAT™). KAT™ allows easy entering and editing of all elements of the knowledge base. KAT™ is used to generate the knowledge base in a format that may be used in computer systems.

Table 8-3: Basic questions asked by knowledge engineers.

1. **Under what conditions will a significant impact occur?**

   In answering this question, knowledge engineers are expected to identify the activity, component, impact mode, relationship(s) and attributes(s) for each impact (preferably from the existing lists, but adding new ones if needed). This information should be recorded on the rule templates. Once the conditions for a significant impact are identified, determine the conditions under which the impact might be insignificant (as opposed to there being no impact at all). For ex ample, would it be insignificant if the degree of impact were smaller? If the component were less susceptible/vulnerable? The conditions for an insignificant impact should be documented at the bottom of the rule template.

2. **What information will be needed to assess the significance of the impact?**

   This is a double-check to ensure that all the conditions for an impact are identified; it may also provide a useful list of information requirements.

3. **What mitigation measures will prevent or reduce this impact?**

   The mitigation keywords should be written on the rule templates, and then the complete mitigation information should be filled out on the mitigation templates (or entered directly into the Knowledge Acquisition Tool). The minimum information we need for the mitigation is the name or keyword of the mitigation, a description of the mitigation, the reference for the mitigation, and the activities and/or components and/or impact modes to which it applies. *For every mitigation you list on the rule templates, there must be a detailed entry in the mitigation templates.*

4. **If the project were to proceed, what monitoring will be required?**

   These monitoring requirements may be to track project impacts, track the success of mitigation measures, or both. If the monitoring requirements refer specifically to the mitigation measures, this information should be entered into the mitigation template for that mitigation.

8.4.3 Environmental Setting Databases

The system requires information about: 1) the project activities; 2) the environmental setting (including all biophysical, social, and economic components); and 3) the relationship between the project activities and the environment. For Calyx-ADB, activities lists have been developed for four sectors: urban wastewater/water supply, irrigation, power, and transportation. The activities lists are similar to those developed for various checklist and matrix methods. Sets of characteristics that might be necessary to further describe these activities have also been developed. For example, the activity "Application of herbicides" has the following characteristics:

toxicity (strong, moderate, weak)
quantity (large, medium, small)
frequency (high, medium, low)

The significance of the impact will be affected by the values chosen for each of the activity characteristics.

Environmental Settings

In very sophisticated computer systems, environmental information may be gathered by automated systems through remote sensing or by linking to already existing GIS data. In most systems, however, it must be entered by the user. In Calyx-ADB, the information must first be gathered by the user. During the session with the system, the user inputs the necessary information through the user interface. A hierarchy of environmental components has been developed to guide the user. This hierarchy contains all of the environmental, social and economic components that might be affected by a project. Table 8-4 illustrates the component hierarchy for physical resources. The complete hierarchy is presented in Table 8-6. A set of characteristics that might be necessary to further describe these components has also been developed. For example, the component "canals" has the following characteristics:

dissolved oxygen concentration (well above 4 mg/l, at or just above 4mg/l, < 4 mg/l)
public water supply (yes, no)
source for domestic/industrial water (yes, no)
used for fisheries (yes, no)
used by wildlife (yes, no)
size (small, large)
N content (high, low)
P content (high, low)
flow rate (slow, fast)
volume of water (low, high)
BOD (above standards, below standards)
suspended solids (above standards, below standards)
fecal coliform (above standards, below standards)
provides aquifer recharge (yes, no)
normal iron concentration (yes, no)

Note that some characteristics (for example, *dissolved oxygen concentration*) are expressed as quantitative ranges, while others (for example, *used for fisheries*) are expressed as qualitative choices. In some cases, the characteristics in the expert system are represented as qualitative choices (for example, *flow rate*) where normal EIA data collection practices will provide quantitative data for the parameter values. In these cases, the user must exercise their judgement in making the qualitative choices.

The significance of the impact will be affected by the values chosen for each of the characteristics. It is not necessary for the user to specify all the values for the characteristics. In cases where information is missing or unknown, the system simply assigns a greater range of uncertainty with respect to the significance of the impact.

All information on components and their characteristics and the relationships between components is stored in an environmental setting database. Separate databases may be created for each specific environmental setting.

Table 8-4: Component hierarchy for physical resources.

Physical Resources	**Atmosphere**	air quality micro-meteorology climate
	Groundwater	aquifers wells groundwater springs
	Surface Water	canals estuaries lakes/reservoirs rivers streams
	Hydrology	hydrological regime
	Land Resources	aquifer recharge areas aggregate resources floodplains barren land coastline/shoreline geology/seismology landforms/topography mineral resources soil river beds river banks

8.4.4 Library Databases

Calyx-ADB contains a hypertext library that lets the user view information on laws, regulations, EIA procedural guidelines, and environmental standards for Indonesia, Malaysia, Philippines, Thailand, and the Asian Development Bank.

8.4.5 Inference Engine

The inference engine is a computer software that manipulates the rules in the knowledge base to provide conclusions based on the information provided as input. The inference can provide answers to a question like:

1. What are all the potential impacts associated with hydroelectric dams?

If this question is asked in Calyx-ADB, hundreds of potential impacts will be presented. A more focused question might be:

2. What are the impacts of reservoir impoundment on people currently living in or near the reservoir area?; or
3. How will alteration of downstream flow affect drinking water quality?; or
4. What mitigation and monitoring is required to ensure that water quality remains within acceptable standards?

While the inference engine is highly efficient at manipulating the knowledge base, it relies on the user interface to tell it what to do.

8.4.6 User Interface

The user interface controls the interaction (in computer terms — the dialogue) between the user and the inference engine. Most expert systems are designed for a specific task or to help the user solve a particular problem. The user interface must guide the user through the performance of the tasks. For example, if a user wishes to develop a terms of reference for an EIA, the user interface must ensure that: 1) all necessary input is provided by the user; 2) necessary linkages to the inference engine to get the appropriate information are made; and 3) the information is assembled into a format suitable for reporting.

EIA Tasks Performed

Calyx-ADB has been designed to help with: 1) screening; 2) scoping; 3) assessment; 4) review of EIA reports; and 5) determining appropriate mitigation and monitoring requirements.

Screening

Screening is the process of deciding upon the level of environmental review required. In some countries, it is simply a decision as to whether an EIA is required or not. Prescribed lists or criteria are used to determine whether a project requires an EIA. In Calyx-ADB, screening criteria for the four countries and the Bank are contained within the system. The screening criteria are divided into two lists: 1) project criteria which relate to the magnitude and nature of the projects; and 2) site criteria which relate to the sensitivity of the environment to potential impacts. The user simply selects from the list and the screening is completed.

Scoping to Determine the Terms of Reference

As defined in Chapter 2, the scoping or IEE stage is the process of determining the issues to be addressed, the information to be collected, and the analysis required to assess the environmental impacts of a project. The primary output of scoping is the terms of reference for the information and analysis required to conduct an EIA and the preparation of an EIA report. In the Calyx-ADB system, the user provides available information about the project and the environment. Based on this information, the system provides a listing of:

1. issues that should be considered;
2. information that will be required to resolve the issues;
3. recommendations on mitigative or offsetting measures to be considered; and
4. recommendations on monitoring requirements to be considered for the project.

Assessment

In conducting the assessment, Calyx-ADB uses the inference engine to determine the significance of the environmental impacts. Based on information about the project activities, activity characteristics, components, component characteristics, relationships, and site characteristics, the inference engine determines a level of significance for each rule in the knowledge base. The system also identifies mitigation measures for each of the impacts and asks the user to choose those mitigations that will be incorporated in the project design.

Review of EIA Reports

The review of EIA reports is normally done by a review agency or by a special Standing Committee or Commission established to review projects in a given sector. In most cases, a technical evaluation of the EIA report is made by specialists. This technical evaluation provides the basis for the review. To assist in the technical evaluation, the Calyx-ADB system provides a checklist of the important elements that should be considered in the review of the EIA report. The review checklist generated by Calyx-ADB is based on the Terms of Reference for the EIA.

Mitigation and Monitoring Requirements

One output of the EIA review process is the terms and conditions that are attached to approvals. These terms and conditions define the environmental protection measures that must be integrated into a project. The terms and conditions may also specify environmental monitoring that must be undertaken in conjunction with the project. Calyx-ADB provides a draft of these terms and conditions for incorporation into project approval reports.

8.4.7 Reporting System

Before the results of an expert system can be of any use, it must be able to provide reports in an easily understandable format. Many matrix and checklist techniques have been adopted for organizing the output from expert systems. Experts systems that are linked to GIS can provide sophisticated map overlays indicating areal extent of impacts.

The reports in Calyx-ADB have five main blocks:

1. **registration blocks:** which contain specifics of the project, the agency preparing the report, any registration numbers, dates, etc.;
2. **person responsible blocks:** which contain names, addresses, and contact details for those people responsible for preparation of the report;
3. **comment blocks:** which represent user supplied comments
4. **report type fixed information:** which contain additional information that is specific to that report type or jurisdiction.
5. **the main body of the report:** which is generated by the system for a specific project. Depending on the report, one or more blocks of the following information will be included:

   i. Information Requirements;
   ii. Mitigation Measures (TOR);
   iii. Monitoring Requirements (TOR);
   iv. Activities and Activity Attributes;
   v. Components and Component Attributes;
   vi. Impacts Summary;
   vii. Impacts Detailed;
   viii. Issues Summary;
   ix. Issues Detailed;
   x. Screening Conclusion;
   xi. Mitigation Recommended; and
   xii. Monitoring Recommended.

Illustrative Example: Scoping of a Hydro Project

In our example, Calyx-ADB was used to develop the terms of reference for the Initial Environmental Examination of a hydro-electric project. Calyx-ADB's scoping module was used to generate a report on the recommended terms of reference (Table 8-5). The terms of reference presented in Table 8-5 has been condensed and is only a partial representation of the information that was provided by Calyx-ADB. Calyx-ADB has used a report template for the major headings in the terms of reference report. The information presented in *italics* in Table 8-5 is generated from the Calyx-ADB knowledge base by the inference engine.

Table 8-5: Sample scoping report produced by the Calyx-ADB computerized EIA system.

**TERMS OF REFERENCE FOR
INITIAL ENVIRONMENTAL EXAMINATION**

Project Registration

Assessment Number: 1
Project Title: *Hydro Project*
Project ID: 1
Project Location: *South East Asia*
Project Description: *An example hydroelectric project to illustrate reporting features of Calyx-ADB. Actual output condensed for presentation purposes*.
Size of the Project:
Project Proponent: *A large independent power producer*.

Terms of Reference

The initial environmental examination should have the following contents:

A. INTRODUCTION (½ page)

1. This section should include the purpose of the report, extent of the IEE study and brief description of any special techniques or methods used.

B. DESCRIPTION OF THE PROJECT

2. This section should include the type and the need for the project, location,, size or magnitude or operation and proposed schedule for implementation.

Project Activity Information
Specific information about the following activities is required to conduct the assessment.

<u>*Reservoir impoundment*</u>
Determine the surface area, the depth and the size of the reservoir, the amount of shallow water that it will contain, and the degree of fluctuation in surface level that is expected (particularly between wet seasons and times of drought). Also determine if the reservoir will result in reduced fluctuation levels in downstream waters.

Determine the expected reduction in flow in the watercourse being diverted to fill the reservoir, and/or in the watercourse being impounded, during the period in which the reservoir is being filled.

C. DESCRIPTION OF THE ENVIRONMENT

3. This section should include the physical and ecological resources, human and economic development and quality of life values.

Environmental Components Information
Specific information about the following types of components is required to conduct the assessment.

Physical Resources

Surface Water
rivers
Determine the flow rate of the watercourse, during both the wet and the dry seasons.

Determine whether the water is used for domestic (e.g., drinking water, washing water), agricultural (e.g., irrigation) or industrial purposes (e.g., pulp and paper mills, textiles, food processing require high amounts of water). Also determine whether it is a source of water for local wildlife.

Determine whether the water contains normal concentrations of iron or normal salinity, and whether the dissolved oxygen concentration is above or below 4mg/L.

Ecological Resources
fish
Determine whether any of the species in the area are protected by law or regulation. Lists of protected species can be obtained from government wildlife or environment agencies. .

Determine whether any of the species in the area are of commercial value (harvested for sale in the marketplace). Information on whether a particular species is of commercial value can be obtained from the government wildlife, fishery or environment agencies.

Determine whether any of the species in the area is used for traditional purposes by the local people.

Determine the presence of fish species that migrate, or change habitat to other areas during different stages of its life cycle.

Determine whether the habitat in the area for local aquatic bird and animal species is critical for their survival. Critical habitat includes breeding areas, spawning grounds, feeding areas and migration corridors.

D. SCREENING OF POTENTIAL IMPACTS

4. This section should screen out "no significant impacts" from those with significant adverse impacts and should discuss the appropriate mitigation measures, where necessary.

Issues to be Addressed:

reduced downstream aquatic habitat and restricted human use of river
Reservoir filling can cause a short-term stoppage or significant decrease in river flow downstream of the dam. The reduction in flow can also occur in a source river if the reservoir being created is not in that river. Such dewatering can significantly affect downstream aquatic biota, and human uses of the river, such as water supply, recreation, navigation, and aquaculture.

water quality degradation in/below reservoir
Reservoir impoundment may lead to increased iron concentrations, increased heavy metal concentrations, increased salinity, increased turbidity, temperature changes in the water, and/or reduced dissolved oxygen concentrations in the reservoir. The kind of effect depends on the geology of the reservoir catchment, the nature of the reservoir (e.g., flushing rate, shape and depth). Reduced dissolved oxygen may result from eutrophication of the reservoir which may be the outcome of land uses in the watershed above the reservoir. If the reservoir water is used as a source for drinking or irrigation water, then the contamination will be significant. Contamination may also be

observed in the rivers and canals downstream of the reservoir. Again if these are used for drinking or irrigation significant problems may result. If the reservoir has reduced oxygen levels this may negatively affect fish populations. Conversely altered temperature and nutrient levels may lead to an increase in some fish populations.

E. MITIGATION

Mitigation
Information about the following potential mitigation measures to prevent, reduce, or ameliorate impacts is required to conduct the assessment.

Create artificial rapids downstream
Increase oxygen levels downstream by creating artificial rapids. This will increase the mixing of water and air, and thereby increase oxygen levels in the water.

Develop new spawning sites/stock fry
New natural spawning sites will be developed using diversion canals and permanent water depressions in the project area to make up for the loss of fish due to the construction of dams and/or reservoirs. Also pond fisheries, paddy fisheries through the incorporation of ring canals at the periphery of individual fields, and public stocking of canals will be studied and encouraged. If suitable areas can be identified then cage culture projects will be encouraged.

Fill reservoir during wet/rainy season
Reservoir filling should occur during the rainy season to minimize the impact of water shortage downstream, and should not reduce the downstream flow by more than 10%. This applies both to the watercourse on which the reservoir is located, as well as to the watercourse serving as the source of the impounded water (if the two watercourses are different).

F. INSTITUTIONAL REQUIREMENTS AND ENVIRONMENTAL MONITORING PROGRAM

5. This section should describe the institutional capability (both hardware and software needs) and the monitoring or surveillance program and submission of progress reports.

Monitoring Requirements
Information about the following potential monitoring requirements associated with potential impacts is required to conduct the assessment.

Monitor spawning habitat and fish yields
Monitor the area of spawning ground available to fish before and after the project. Also monitor the fish yields from the reservoir which would give an approximate idea of the fish population in the water.

Sample water quality parameters (DO, temp)
Sample the temperature of the receiving waters upstream, at the discharge point, and at several points downstream (location to be determined by the results from thermal plume modeling). Sample the water at 1 m depth for standard water quality parameters, as well as for microorganisms (zooplankton, phytoplankton). Sample the water downstream, if used for agriculture, for DO levels. Also, take sediment samples of the benthic community to monitor any changes in species composition or abundance.

Monitor river flow below impoundment
Monitor the flow rate of the watercourse below the reservoir (and below the diversion for filling the reservoir, if this is happening on a different watercourse) and compare the data to the flow rates in that watercourse prior to the impoundment.

G. FINDINGS AND RECOMMENDATIONS (1 or 2 pages)

6. This section should include an evaluation of the screening process and recommendations should be provided whether significant environmental impacts exist needing further detailed study or EIA. If further additional study is needed, then this section will include a brief terms of reference (TOR) for the needed follow-up EIA, including approximate descriptions of the work tasks, professional skills required, time required, and estimated cost.

H. CONCLUSIONS (½ page)

7. This section should discuss the result of the IEE and justification, if any, of the need for additional study or EIA.

PERSONS RESPONSIBLE

These terms of reference report was prepared by:
Name: *John Doe*
Title: *Environmental Specialist*
Agency/Division: *Consultant*
Telephone: *555-1234*
Fax: *555-1233*
Signature:
Date:

Name: *Jane Ray*
Title: *Project Manager*
Agency/Division: *International Power Inc.*
Telephone: *555-2345*
Fax: *555-3456*
Signature:
Date:

8.4.8 Output Databases

The results of the screening, scoping, assessment, review, and define appropriate conditions for mitigation and monitoring are stored in output databases. The user has direct access to report files which can be imported in third party word processing packages. In addition, all the information entered by the user, and record of all the EIA tasks performed to date is stored in a project file. The user can easily load previous work and complete or revise an EIA.

Table 8-6: Component hierarchy used in the ADB expert system.

Physical Resources

Atmosphere
air quality
micro-meteorology
climate

Groundwater
aquifers
wells
groundwater springs

Surface Water
canals
estuaries
lakes/reservoirs
marine waters
rivers
streams

Hydrology
hydrological regime

Land Resources
aquifer recharge areas
aggregate resources
floodplains
barren land
coastline/shoreline
geology/seismology
landforms/topography
mineral resources
soil
river beds
river banks

Ecological Resources

Aquatic Flora
emergent vegetation
free floating-vegetation
submerged vegetation

Aquatic Fauna
aquatic mammals
aquatic birds
aquatic reptiles/amphibians
aquatic invertebrates
benthic organisms
fish

Terrestrial Flora
crops
grasses/herbs/ferns
lichens/moss
shrubs
trees

Terrestrial Fauna
terrestrial mammals
terrestrial birds
terrestrial reptiles/amphibians
terrestrial invertebrates

Ecosystems
freshwater ecosystem
marine ecosystem
terrestrial ecosystem
wetland

Socio-Economic Resources

Land Use
agricultural land use
aquaculture land use
commercial land use
forestry land use
industrial land use
institutional land use
mining land use
recreational land use
residential land use
transportation land use
buffer zone
native land
planned development areas
parks and sanctuaries
potential mining areas

Built Environment
dams
dikes
bridges
buildings
communication structure
marine structures
transmission structure
hydro power facility
flood control system
oil/gas lines
electricity lines
telephone lines
roads/railways
sewerage system
trails
waste disposal sites
water supply system
water intake structure
infrastructure

Services
communication services
water supply
education
electricity
emergency response
firefighting
flood control/drainage
gas
general social services
government
green space
health services
irrigation water
law enforcement
mass transit
navigation
provision of goods and services
sewage treatment
solid waste disposal

Table 8-6: (continued).

Economy	Human interests/values	
employment	aesthetics	commercial resource users
inflation and property value	businesses	recreational resource users
local tax revenues	community structure	traditional resource users
personal income	family structure	current resource users
business income	social well-being	farmers
regional income	human health	religious groups
distribution of income	human safety	special status groups
regional economic activity	mobility	people
standard of living	archeological feature	population distribution
	religious features/cemeteries	local residents
	traditional/historic/cultural features	land owners
	tradition and culture	land prices/value
	artists/artisans	personal property
	commuters	water resource users
	developers	workers

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