CHAPTER 4

THE KBGIS DEVELOPMENT

4.1 Introduction

As mentioned earlier, this research aims to develop a prototype problem specific knowledge-based GIS (KBGIS) for the evaluation of compatibility between development activities and their physical environmental settings. This was done by reconfiguring an existing model (see previous chapter) with the purpose to present a practical example of using GIS in automating semi-structured decision making tasks and, more importantly, to illustrate the usefulness of incorporating elements of knowledge-based techniques in enhancing "the level of intelligence" of current GIS. The model was ideal for this research project because it applies to a problem domain that would benefit substantially from both GIS and KBS.

In the context of the assessment procedure, GIS is regarded as a superior tool to support the collection, presentation, analysis, reclassification and retrieval of environmental data from a spatial database, i.e. environmental zone map. On the other hand, it is regarded as an inferior tool for analysing relationships between development and environment and identifying concerns (potential conflicts) in environmental compatibility assessment and impact prediction. Since these tasks, can obviously not be interpreted without the intervention of experts, the inferiority of GIS in supporting the model, is re-solved by incorporating (embedding) the elements of an expert (or knowledge based) system in a GIS. Its perceived role in the model's implementation is to act as an interactive front end to GIS with the ability to provide:

1) An easily accessible repository of domain knowledge (facts and expert opinions) concerning various project development implications/sensitivities (Impact Identification Checklist);

2) A set of generic rules for assessing their potential conflicts with environmental resources/hazards factors (Development-Environment Interaction Matrix)

3) Reasoning capabilities similar to those of experts (inference mechanism) for identifying, grading and presenting concerns (potential conflicts) in the process of site-specific environmental compatibility assessment and development-environment impact prediction.

This chapter explains the strategy used in this research to develop the prototype KBGIS system. It is divided into two parts. The first part describes the components of the model, namely the Environmental Zone map, the Project Impact Identification Checklist and the Development-Environment Interaction Matrix from the point of view of their organization, types and formats.

The second part explains the GIS - KBS integration (interfacing) strategy. It starts with a brief illustration of the prototype KBGIS system structure, along with a description of its components and functions. It then continues with an overall view of the system's modules and capabilities. Emphasis is placed to the procedures of the system operation.

4.2 Components of the Model

The steps to develop the components of the model using manual procedures were briefly explained in the previous chapter. This section illustrates how the model can be constructed and organised within a computerised KBGIS environment. It starts with an explanation of how an Environmental Zone Map can be established by using a GIS. Emphasis is placed on issues concerning database preparation and organisation to support the zoning task. This task is currently detached from the KBGIS environment, which means that it needs to be executed independently before setting up the system. The following section briefly explains the approach to the construction of the Project Impact Identification Checklist and Development-Environment Interaction Matrix.

4.2.1 GIS Approach to Environmental Zoning and Construction of Environmental Zone Maps

As mentioned in chapter 3, environmental zoning is a task that aims at providing input to the definition of a composite Environmental Zone Map by means of combining a comprehensive set of environmental factors. It can, fundamentally, be thought of as a mapping method (one problem-one map) that provides the option of overlaying the problems one over the other in order to delineate zones that feature homogeneous sensitivity levels to external initiatives.

In a manual processing technique, this task is accomplished by transparent overlays of environmental factor maps coordinated in terms of scale, coverage and reference grid. In practice, however, due to the large number of maps usually required, this process was usually scaled down because it was a tedious, non-flexible and time consuming process.

In order to overcome the constraints of the manual method, this research project proposes a strategy based on the use of GIS to automate environmental zoning tasks. Figure 4.1 illustrates this approach.

Because environmental zoning relies on a relatively large amount of data the correct choice and quality of data is more important than the tools used for handling and analysing the data. There is a widespread agreement that in the establishment of any information system, the end performance of the system is greatly affected by the organization of its database. In the case of a GIS database, this is even more important due to the spatial component of the data. Consequently, data input without proper organisation is usually not efficient. This issue justifies the use of a GIS database to support environmental zoning. As Figure 4.1 illustrates, database design involves two phases, namely a conceptual and a physical design.

The conceptual database design includes several mutually related activities including:

1) Identification of data requirements, collection and categorization of available data and evaluation of their usefulness for the task.

2) Formulation and ranking of environmental objectives according to their significance in supporting environmental zoning for the area concerned (Prioritisation of data sets required for environmental zoning tasks).

3) Determination of the final scope and contents of the GIS database (identification of layers, logical database organization, formal data structure, standards and tolerances, database documentation etc.)

This phase is considered important as it aims at providing the answer to the question of which environmental data and attributes should be included and how to organize them to enhance database performance.

The physical database design, starts immediately after or parallel to its conceptual design and includes the following:

1) Preparation of the base map to ensure appropriate registering and spatial referencing of data layers;

2) Thematic map manuscripts preparation along with identification of the master and component templates. Their purpose is to ensure that coincident component features of the various thematic data layers involved in construction of a GIS database are coordinate-coincident. (Spatial data normalization)

3) Map automation, which includes: (a) acquisition of layers through digitising, digital data conversion, processing of satellite images, generation from numerical data, scanning and raster-vector conversion; (b) establishment of topology, attribute code assignment and verification and quality control (positional and attribute accuracy, logical consistency and completeness).

4) Final database creation and the preparation of an Environmental Zone Map to be used by the prototype KBGIS.

Some practical issues concerning the database construction and implementation are discussed in chapter 5.
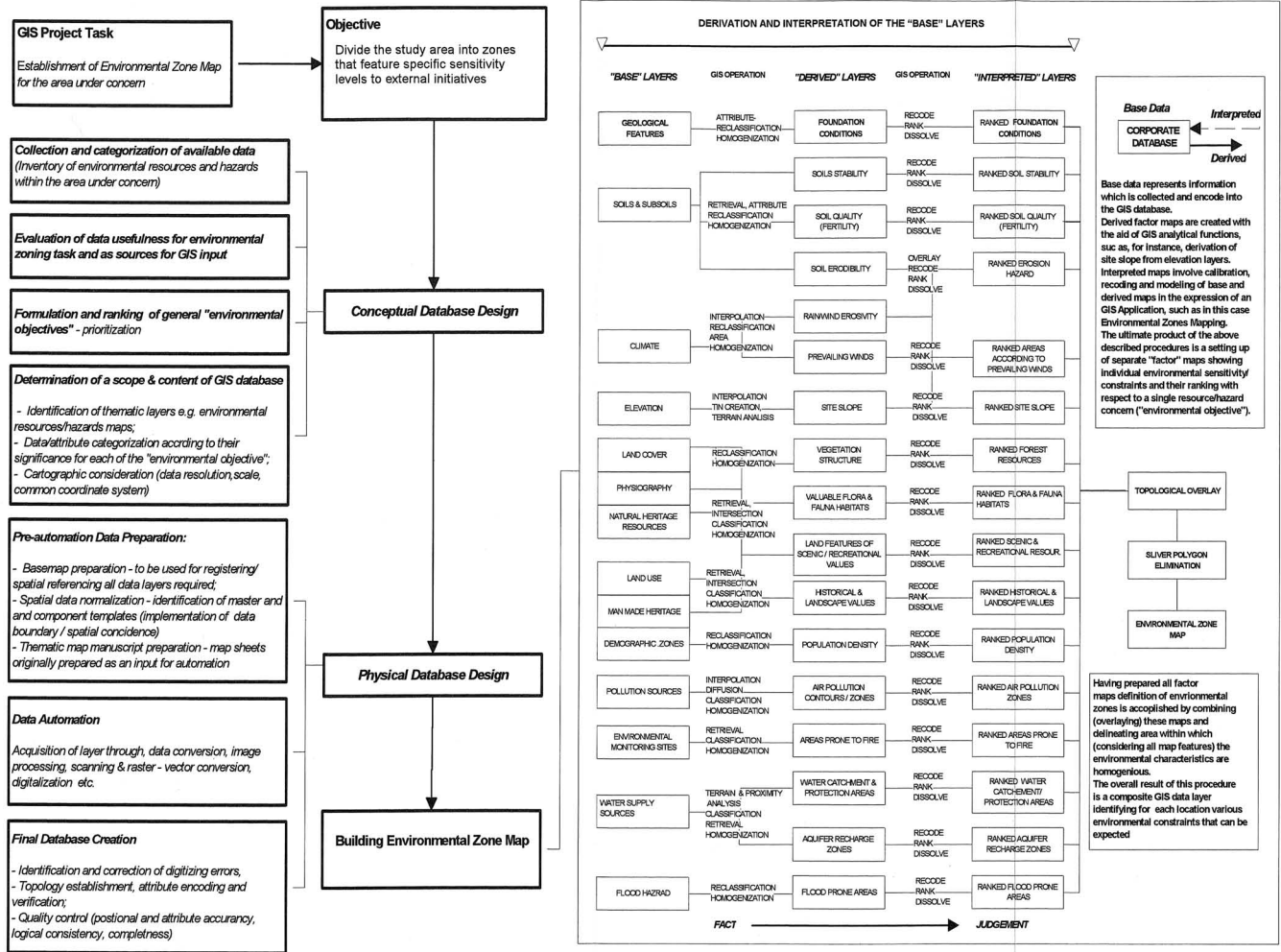
4.2.2 Summary of a GIS Data Organisation and Generation of an Environmental Zone Map

A typical GIS for environmental zoning can be seen as an inventory-related database created to provide a realistic and comprehensive environmental profile of the study area. It may contain various environmental data sets organized into layers that are mutually referenced to a common co-ordinate system. Each layer contains data grouped by thematic coherence starting from geology, groundwater potential, and proceeding upward through soil types, land cover types, topography, aquifer boundaries, environmental hazards features, etc. To this, agricultural, forest and water supply sources, and the man-made impacts to the environment such as existing land use, recreation and natural heritage resources are added.

These layers are composed of basic map features (points, line, polygons) showing boundaries and distribution of a single resource/hazard factor and associated descriptive attributes serving to identify and/or categorize map features.

Separation of a GIS database into a number of layers can be understood as a thematic approach to representing the environmental profile of the study area. This database organization is considered appropriate in supporting environmental zoning. Firstly, it leaves open the possibility of manipulating and combining different thematically associated data (layers) only when they are needed. Secondly, it eliminates risks of burdening the resulting composite layer (Environmental Zone Map) with superfluous data.

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GIS Project Task

Establishment of Environmental Zone Map for the area under concern

Objective

Divide the study area into zones that feature specific sensitivity levels to external initiatives

Collection and categorization of available data
(Inventory of environmental resources and hazards within the area under concern)

Evaluation of data usefulness for environmental zoning task and as sources for GIS input

Formulation and ranking of general "environmental objectives" - prioritization

Determination of a scope & content of GIS database

- Identification of thematic layers e.g. environmental resources/hazards maps;
- Data/attribute categorization accrding to their significance for each of the "environmental objective";
- Cartographic consideration (data resolution, scale, common coordinate system)

Pre-automation Data Preparation:

- Basemap preparation - to be used for registering/ spatial referencing all data layers required;
- Spatial data normalization - identification of master and and component templates (implementation of data boundary / spatial concidence)
- Thematic map manuscript preparation - map sheets originally prepared as an input for automation

Data Automation

Acquisition of layer through, data conversion, image processing, scanning & raster - vector conversion, digitalization etc.

Final Database Creation

- Identification and correction of digitizing errors,
- Topology establishment, attribute encoding and verification;
- Quality control (postional and attribute accurancy, logical consistency, completness)

Conceptual Database Design

Physical Database Design

Building Environmental Zone Map

DERIVATION AND INTERPRETATION OF THE "BASE" LAYERS

"BASE" LAYERS	GIS OPERATION	"DERIVED" LAYERS	GIS OPERATION	"INTERPRETED" LAYERS
GEOLOGICAL FEATURES	ATTRIBUTE-RECLASSIFICATION HOMOGENIZATION	FOUNDATION CONDITIONS	RECODE RANK DISSOLVE	RANKED FOUNDATION CONDITIONS
SOILS & SUBSOILS	RETRIEVAL, ATTRIBUTE RECLASSIFICATION HOMOGENIZATION	SOILS STABILITY	RECODE RANK DISSOLVE	RANKED SOIL STABILITY
		SOIL QUALITY (FERTILITY)	RECODE RANK DISSOLVE	RANKED SOIL QUALITY (FERTILITY)
		SOIL ERODIBILITY	OVERLAY RECODE RANK DISSOLVE	RANKED EROSION HAZARD
CLIMATE	INTERPOLATION-RECLASSIFICATION AREA HOMOGENIZATION	RAIN/WIND EROSIVITY		
		PREVAILING WINDS	RECODE RANK DISSOLVE	RANKED AREAS ACCORDING TO PREVAILING WINDS
ELEVATION	INTERPOLATION TIN CREATION, TERRAIN ANALISIS	SITE SLOPE	RECODE RANK DISSOLVE	RANKED SITE SLOPE
LAND COVER	RECLASSIFICATION HOMOGENIZATION	VEGETATION STRUCTURE	RECODE RANK DISSOLVE	RANKED FOREST RESOURCES
PHYSIOGRAPHY / NATURAL HERITAGE RESOURCES	RETRIEVAL INTERSECTION CLASSIFICATION HOMOGENIZATION	VALUABLE FLORA & FAUNA HABITATS	RECODE RANK DISSOLVE	RANKED FLORA & FAUNA HABITATS
LAND USE	RETRIEVAL INTERSECTION CLASSIFICATION HOMOGENIZATION	LAND FEATURES OF SCENIC / RECREATIONAL VALUES	RECODE RANK DISSOLVE	RANKED SCENIC & RECREATIONAL RESOUR.
MAN MADE HERITAGE		HISTORICAL & LANDSCAPE VALUES	RECODE RANK DISSOLVE	RANKED HISTORICAL & LANDSCAPE VALUES
DEMOGRAPHIC ZONES	RECLASSIFICATION HOMOGENIZATION	POPULATION DENSITY	RECODE RANK DISSOLVE	RANKED POPULATION DENSITY
POLLUTION SOURCES	INTERPOLATION DIFFUSION CLASSIFICATION HOMOGENIZATION	AIR POLLUTION CONTOURS / ZONES	RECODE RANK DISSOLVE	RANKED AIR POLLUTION ZONES
ENVIRONMENTAL MONITORING SITES	RETRIEVAL CLASSIFICATION HOMOGENIZATION	AREAS PRONE TO FIRE	RECODE RANK DISSOLVE	RANKED AREAS PRONE TO FIRE
WATER SUPPLY SOURCES	TERRAIN & PROXIMITY ANALYSIS CLASSIFICATION RETRIEVAL HOMOGENIZATION	WATER CATCHMENT & PROTECTION AREAS	RECODE RANK DISSOLVE	RANKED WATER CATCHMENT/ PROTECTION AREAS
		AQUIFER RECHARGE ZONES	RECODE RANK DISSOLVE	RANKED AQUIFER RECHARGE ZONES
FLOOD HAZRAD	RECLASSIFICATION HOMOGENIZATION	FLOOD PRONE AREAS	RECODE RANK DISSOLVE	RANKED FLOOD PRONE AREAS

FACT ────────────► JUDGEMENT

Base Data → Interpreted
CORPORATE DATABASE
→ Derived

Base data represents information which is collected and encode into the GIS database.
Derived factor maps are created with the aid of GIS analytical functions, suc as, for instance, derivation of site slope from elevation layers. Interpreted maps involve calibration, recoding and modeling of base and derived maps in the expression of an GIS Application, such as in this case Environmental Zones Mapping.
The ultimate product of the above described procedures is a setting up of separate "factor" maps showing individual environmental sensitivity/ constraints and their ranking with respect to a single resource/hazard concern ("environmental objective").

TOPOLOGICAL OVERLAY

SLIVER POLYGON ELIMINATION

ENVIRONMENTAL ZONE MAP

Having prepared all factor maps definition of environmental zones is accoplished by combining (overlaying) these maps and delineating area within which (considering all map features) the environmental characteristics are homogenious.
The overall result of this procedure is a composite GIS data layer identifying for each location various environmental constraints that can be expected

An overview of the typical content of a GIS database for environmental zoning, and its layer separation is provided in Figure 4.1. The layers in the GIS database are normally categorized into two groups:

1) Primary ("base") layers and

2) Secondary ("derived" and/or "interpreted") layers:

This categorization essentially resembles the whole process of environmental zoning. The primary data layers represent spatial and related attribute data that are captured and encoded into the GIS database by means of digitising analogue thematic maps or through other methods (digital data conversion, processing of satellite images, generation from numerical data, scanning and raster-vector conversion etc.). Often these layers cannot be used in their original form to support the environmental zoning task. For example, an original soils layer and related attributes classification must be translated into levels of bearing-capacity in order to identify foundation constraints, into levels of fertility to identify agricultural potential, etc. Furthermore, original spatial data sets only provide data on potential (such as elevation points or contours) while the environmental zoning task requires its interpretation and categorisation (e.g. the slope of terrain ranked with respect to different levels of sensitivity to external initiatives). In addition, to solve the problem of graphic interpretation of the accessibility to roads, the primary layer using lines to show the existing road network must be transformed into a polygon layer showing levels of accessibility (distance buffers). Also, in order to identify the runoff coefficient for assessing and categorising the risk of flooding, data on soils need to be combined with topographical and climate information and translated into levels of permeation.

In accordance with the aforementioned examples, it is apparent that the original data sets must very often be processed and interpreted to become relevant for the environmental zoning task. This, within a GIS environment, is accomplished by means of generating new data sets with the aid of the various spatial analysis and modelling tools of GIS (spatial data retrieval, re-coding, aggregation, attributes calculation and re-classification, etc.). These new data sets, as illustrated in Figures 4.1 and 4.2 could be the results required for environmental zoning task ("interpreted layers") or they could constitute input to further analysis and interpretation ("derived layers"). In either case, the new data sets need not be stored physically because they can be generated rapidly when required with the GIS tools.
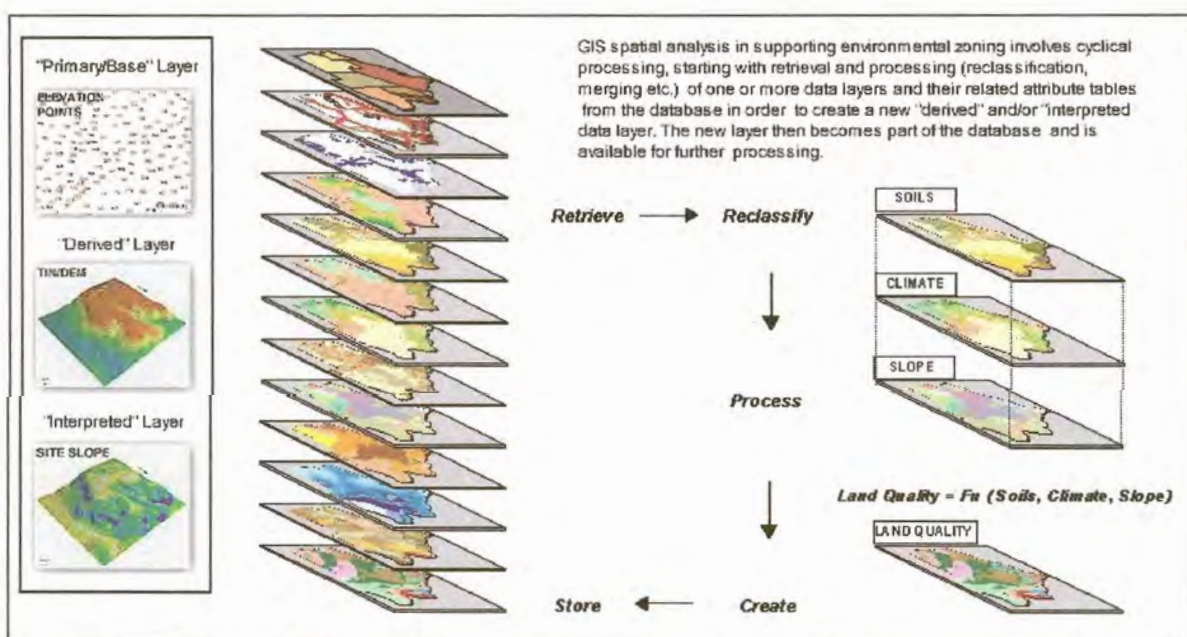
Figure 4.2 An Illustrative example of the process of GIS data sets derivation and interpretation with the aid of GIS analytical and modelling functions

The ultimate goal of the above mentioned procedures is to set up the separate ("interpreted") factor maps (layers), dividing the study area into zones featuring a specific type and level of sensitivity in respect of a single resource/hazard concern. Once the factor maps (layers) are adequately prepared, it is possible to proceed with the final step in the environmental zoning task. It involves the construction of an "Environmental Zone map" seeking to aggregate these factor maps and accordingly delineate areas within which the environmental characteristics are homogenous. As illustrated in Figure 4.1 this is achieved by using GIS topology overlay procedures allowing the creation of a new layer from intersections of the existing factor layers.

As briefly summarized above, the final result of the whole environmental zoning task is the creation of a composite GIS layer ("Environmental Zone Map") containing a combination of map features and associated descriptive attributes of all original input (factor) layers. Its perceived role within the prototype KBGIS implementation is:

1) To provide a basis for the identification of site-specific environmental constraints (resource-related sensitivities and hazard-related risks) that can be expected within the area of concern, and

2) To serve as data source (environmental input) for the construction of the Development-Environment Interaction Matrix.

Currently the prototype KBGIS only supports a vector data structure. This means that the Environmental Zone composite layer should be created and then stored within the system's database in vector data format with polygon topology. This data structure seeks to preserve exact boundaries of environmental (geographic) features, thus maximizing the accuracy of spatial presentation. Discussion concerning the selection of the GIS data structure to support environmental zoning is provided in chapter 5.

4.3 Approach to the Organization of the Project Impact Identification Checklist and Development-Environment Interaction Matrix within the Prototype KBGIS Environment

The Project Impact Identification Checklist and Development-Environment Interaction Matrix are the other two fundamental components of the prototype KBGIS. While the Environmental Zone Map must be constructed independently and made available before setting up the system, the establishment and maintenance of these two components are completely reliant on the KBGIS toolbox. The following section illustrates how this research project resolved the issue of their type and format within the prototype KBGIS.
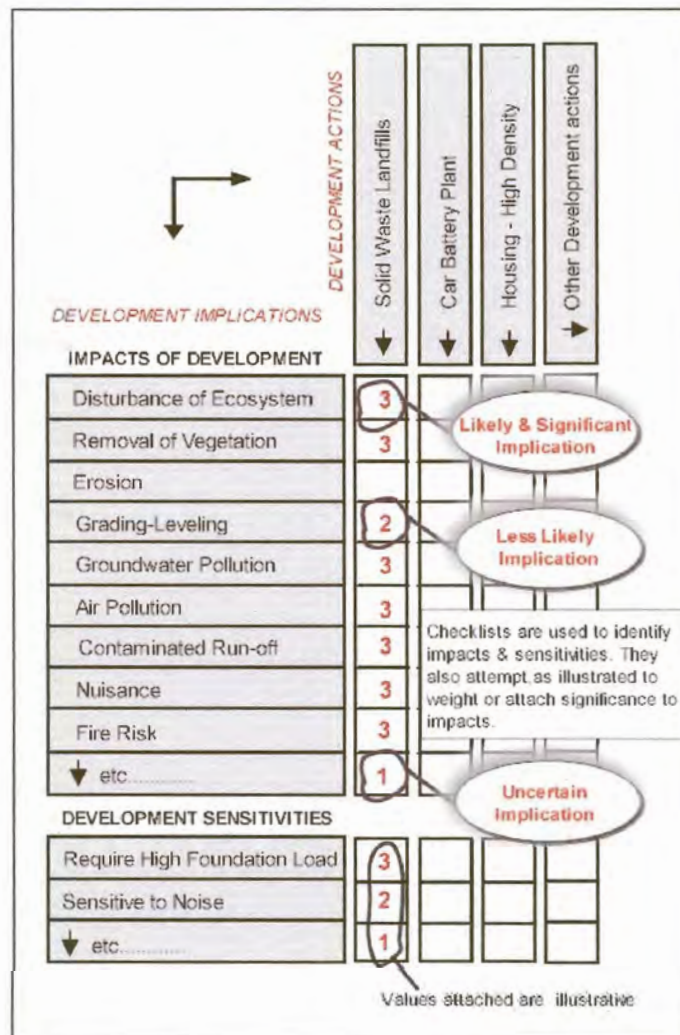
4.3.1 Project Impact Identification Checklist

The role of the Project Impact Identification Checklist within the system implementation environment is to provide the means for:

1) Definition of development actions, and

2) Determination of how the development actions will influence the environment and/or how they could be affected by the environmental hazards and resource shortages.

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For this purpose the system, as illustrated in Figure 4.3, uses a Simple Impact Identification Checklist approach. It is considered practical and suitable for several reasons. Firstly, it is not complex in terms of data and resource requirements. As such, it is regarded as an appropriate, low-cost method in providing inputs for the evaluation procedure supported by the system.

This approach, furthermore, allows development of a standard, site-independent checklist that can be defined in advance and then used as a template for identification of the project's development implications/sensitivities. As illustrated in Figure 4.3, it uses a tabular presentation format in which columns hold information about projects (development actions) while rows provide a generic and extendable list of potential development implications/sensitivities. This simple checklist approach can be best described as a tool that acts like a "prompt" to the user. He/she is allowed to identify, through use of a "tick-to-confirm-this" method, the likelihood and even significance of the impacts for the particular development action. This checklist approach provides a way of systematically ensuring that all likely implications of the relevant development action are considered.

Figure 4.3 An illustrative example of a Simple Impact Identification Checklist used in this research for identification of development actions and their implications likely to have significant effects on the environment

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4.3.2   Development-Environment Interaction Matrix

Development-Environment Interaction Matrix is the cornerstone of the prototype KBGIS. Its task is to provide a site-independent overview of all the potential "development implications-environmental constraints" conflicts that can be expected within a study area. As illustrated in chapter 3, the construction of such an overview involves cross-referencing the list of compiled development implications/sensitivities in respect of their potential interactions with each environmental resource/ hazard factor retrieved from the "Environmental Zone Map".

For this purpose the prototype KBGIS system uses the approach that closely resembles a simple Interaction Matrix method. The approach is considered appropriate and practical. It uses a tabular presentation format in which columns hold description of each individual environmental resource/hazard factor found within the area of concern, while rows contain a generic list of potential development implications/sensitivities. The matrix allows the user to identify direct "development implications-environmental constraints" interactions using the aforementioned "tick-to-confirm-this" method. Where there is no interaction the relevant matrix box is left empty. An example of the simple Interaction Matrix approach applied within the prototype KBGIS environment is given in Figure 4.4.

Figure 4.4   An Illustrative Example of the simple Interaction Matrix approach used by the prototype KBGIS for identification of development-environment interactions (potential conflicts) within an area concerned

4.4 The prototype KBGIS Architecture

This section describes the strategy applied in this research to develop the prototype KBGIS. It is focused on issues concerning the architectural basis of the integration between GIS and KBS.

4.4.1 Integration Approach

In the deliberation of the integration approach, it is appropriate to start the section with an overview of the basic KBGIS functions. They can briefly be described as a set of computer assisted procedures with abilities to:

1) Store and offer an easily accessible repository of domain knowledge concerning various development actions (Project Impact Identification Checklist) along with a set of generic rules for assessing their potential conflicts with environmental resources/hazards (Development-Environment Interaction Matrix);

2) Provide automated procedures (reasoning capabilities) for identifying concerns in site-specific development-environment compatibility assessment;

3) Facilitate spatial data visualisation, query and retrieval by the users not trained in GIS;

4) Display information concerning development-environment impacts in the language familiar to the user.

In order to provide an environment in which users are able to access the above functions it was necessary to combine the basic functionality of GIS with elements of knowledge based techniques. As indicated in chapter 2, there are different levels of integrating GIS and KBS. This research developed an example of a GIS-KBS integration in which the elements of knowledge-based techniques are actually one of the functions available inside the GIS. The idea for the system design was to put the data, the model and the decision analysis (reasoning) process all together into a GIS environment and within one single application with shared communication routines and a common interface.

The software used for the prototype KBGIS development is ArcView desktop GIS developed by ESRI (Environmental System Research Institute, Inc.). It features a user-friendly working environment and provides users with the fundamental functions for analysis, visualization and integration of spatial data and related attributes. Data storage, query and retrieval capabilities in ArcView give the prototype KBGIS a convenient method for a location-based inventory that is required by the system in the process of identifying the site-specific environmental constraints.

A major feature of ArcView that took an important role in the GIS-KBS integration is its Avenue macro language. It provides ArcView with the ability to extend its functions directly through programming and customisation routines. Three tools available within ArcView were employed in the prototype KBGIS system development. Firstly, ArcView's customisation routines were used to develop the common window and icon-based menus. Secondly, ArcView's Dialog Designer extension was used to develop various forms and dialogues required by the system for interactive data and knowledge acquisition. Finally, Avenue programming served to link dialogues, forms and menus and to isolate the user from the technicalities of the computer and the model. It was also used to develop the problem processor (inference mechanism) for identifying, grading and reporting concerns in the process of development-environment impact prediction.

The Environmental Zone composite layer along with related attribute tables constitutes the core of the system's spatial database. It is brought into the system and stored as an ArcView shapefile. The Project Impact Identification Checklist and Development-Environment Interaction Matrix represent the system's knowledge bases. Both of them can be understood as collections of domain specific information. They are organized within the system as internal Dbase files capable of replicating their conceptual forms illustrated in the pervious section.

The *analysis and query module* is the system's key module. It is developed within the "View" subsystem of ArcView, which provides tools for display, selection and retrieval of information from the system's GIS and ArcView's knowledge databases. All the generic spatial and database search and retrieval functions needed by the model are available to the user along with the new ones developed with the aid of the Avenue macro language and embedded within the same interface.

The core of this module is the *problem processor (inference engine)* composed of:

1) *Query and scenario manager* – capable to interact with the user in order to get basic input or additional information required by the evaluation model;

2) *Working memory* - hidden from the user and used to store input data and the intermediate results of the evaluation;

3) *Analysis and evaluation or reasoning mechanism* - capable to direct the search through GIS and knowledge databases in order to draw conclusions, identify and grade development-environment concerns (potential conflicts) from a set of expertise (facts) about the problem at hand.

4) *Justifier* - used to store assumptions underlying the system's reasoning process.

The role of the *display and report generator* is to report the evaluation results in a language familiar to the user. It is an essentially sub-module of the aforementioned analysis and query module and contains several point-and-click button-based options embedded into the main interface. The key options provided by this sub-module are:

1) A list of environmental constraints (resource related sensitivities, hazard related risks) found at selected locations;

2) A list of pre-defined development implications and sensitivities to environmental hazards for the selected development action (project);

3) A list of environmental concerns (potential conflicts) that can be expected for the proposed development action at the selected site.

4.4.3 The System Modes and Capabilities

The prototype KBGIS presented in this research has been created to function as a fully integrated GIS-KBS DSS aiming to replicate a specific domain of expertise. It was designed to include all of the necessary functions required for developing and running the system.

What made this possible is the separation of the system's database management module retaining specific knowledge on a problem domain, and its query and analysis module containing mechanism (inference engine) for applying that knowledge. As illustrated in Figure 4.5 this feature could be interpreted as a "plug-in" architecture. It is characterized by editing functions for entering required GIS

and knowledge databases that are coded separately from the system's analysis and evaluation mechanism (inference engine). It furthermore permits the existing spatial and knowledge databases to be detached from the system and new databases containing different sets of data and knowledge to be inserted into it.

The "plug in" architecture contributes to scalability of the system making it open and capable to reproduce a specific domain of expertise it is designed for without a need to rewrite any portion of the computer program. In accordance with this, the prototype KBGIS developed in this research can be regarded as an application specific and GIS-enabled Expert System Shell. It consists of two basic modes:

1) Development (Knowledge Acquisition) mode and

2) Consultation (Running) mode.

The system's "Mode and GUI Manager" controls these two modes. It is a start-up program designed to verify and validate the status of the system in terms of the existence and consistency of all its components (GIS and Knowledge databases) required by the consultation mode. The output of this program, as illustrated in Figure 4.6, is the "Main Start-up GUI". Being in dialogue form, it provides appropriate explanation and button-based menu options critical for the effective use of the system.
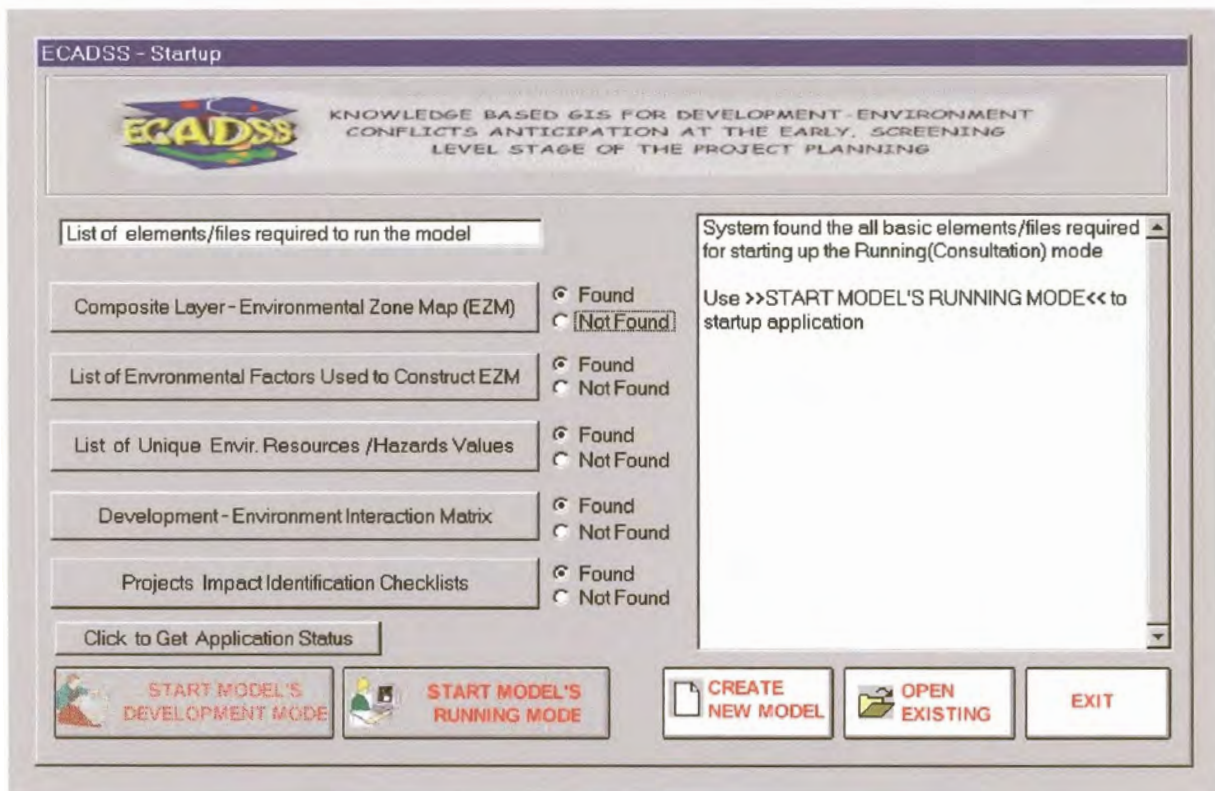
Figure 4.6 The KBGIS Start-up GUI

When the mode manager detects that some of the components (GIS and knowledge databases) are missing or not yet defined, it will act appropriately by:

1) Disabling the menu option that starts the consultation mode;

2) Enabling option that opens the development (knowledge acquisition) mode along with the relevant GUI;

3) Providing information on what is missing and what should be done before enabling the consultation mode.

If the mode manager verifies and validates the existence and consistency of all components (databases) required it will enable the consultation mode option along with its relevant GUI.

The following section provides a more in-depth explanation of the aforementioned functions and capabilities.

4.5 The KBGIS Data and Knowledge Acquisition Mode

As already indicated, the prototype KBGIS is designed as an open system that can be used to anticipate development-environment conflicts at various levels (urban, regional) and for different areas. To make this possible, the system provides tools for capturing environmental data and "domain" knowledge and organising it in area-specific data and knowledge bases.

The capturing of data and domain knowledge into the prototype KBGIS relies on its Knowledge Acquisition Unit. It is a collection of several tools designed to interact with the expert in order to acquire all the components (i.e. data and domain knowledge) relevant for the consultation mode. As illustrated in Figure 4.7, they are embedded in an appropriate Knowledge Acquisition (and now KA) Interface in various formats of interactive dialogues and form-filling schemes. These forms and dialogues tend to emulate a "paper and pen" environment in which the user enters required information into dialogue fields shown on the screen, or selects options from the list boxes and menus built into the system. This has earlier been referred to as an intuitive (directly apprehended) knowledge acquisition method capable of leveraging large amounts of knowledge (Gruber & Cohen, 1988).
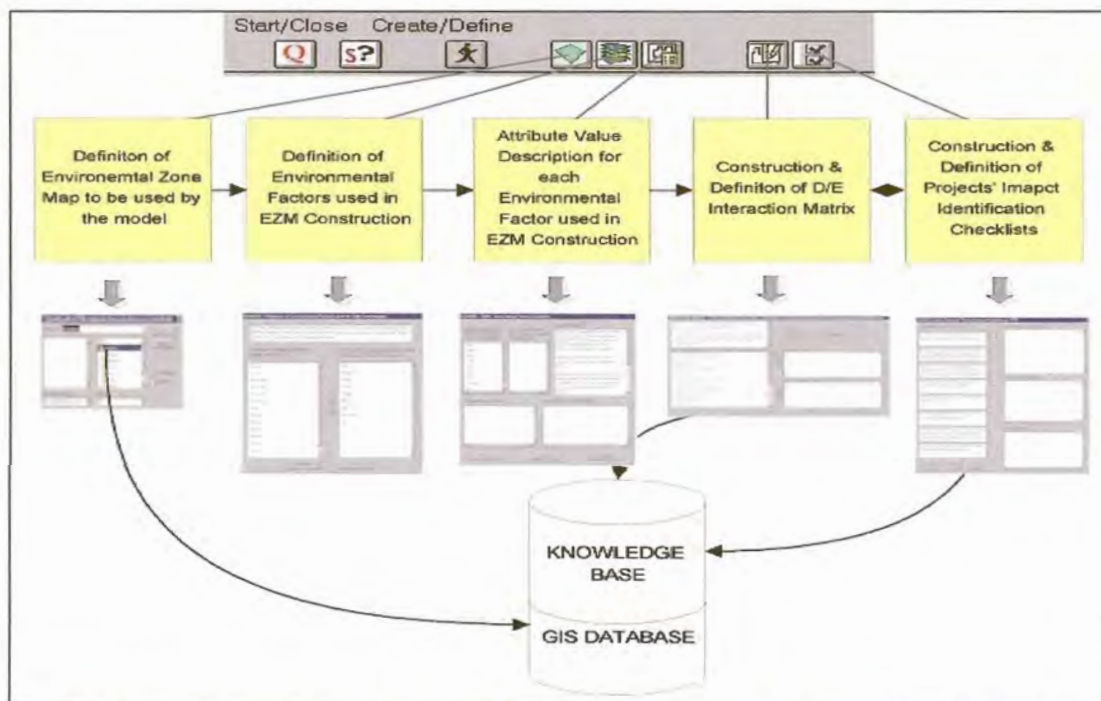
Figure 4.7 The KBGIS Knowledge Acquisition GUI and the steps involved in a typical data and knowledge acquisition session supported by the system

4.5.1 Acquisition of GIS Data

(1) GIS Data Source selection

The first step in a typical data and knowledge acquisition session is the selection of the Environmental Zone composite layer (EZM) that will be used for the identification of site-specific environmental resource/hazard constraints within an area of concern. As already indicated, this composite layer should be prepared before setting up the KA session. From the design point of view, an option for the selection of the EZM composite layer is provided in a File Dialogue form. It is essentially a modified ArcView Source Dialogue window enabling the user to browse and return the selected data source from a file system. As illustrated in Figure 4.8, the user is prompted to simply point-and-click on the existing data source (EZM composite layer) that he/she wants to use.
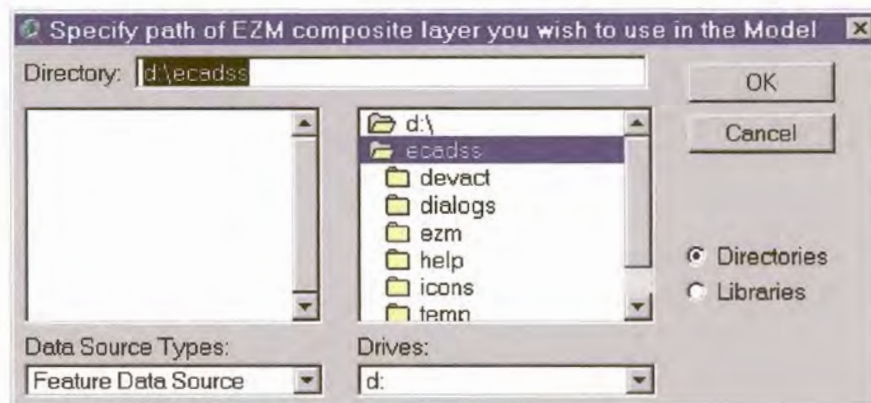
Figure 4.8   The KBGIS Data Source dialogue window for selection of the Environmental Zone composite layer

As soon as the user selects the EZM composite layer, the system fires up internal procedures of checking the format of the data source, its topology and the logical consistency. After that the system, if necessary, converts the selected EZM composite layer into the ArcView format (shapefile), and stores it in the database of the system for further processing. A feedback report is provided notifying the user about problems encountered during the data source validation process.

(2) Definition of Environmental Factors and their unique attribute values

After selection of the EZM composite layer the user is asked to indicate all individual environmental resource/hazard factors that were used in the EZM construction (such as slope stability, soil quality, etc.). These factors are contained in the associated EZM Polygon Attribute Table. For this purpose the user is provided with a simple point-and-click interactive dialogue whose left part, as illustrated in Figure 4.9, lists all item names contained in the EZM's Polygon Attribute Table. The user is then requested to select the items that represent environmental resource/hazard factors.
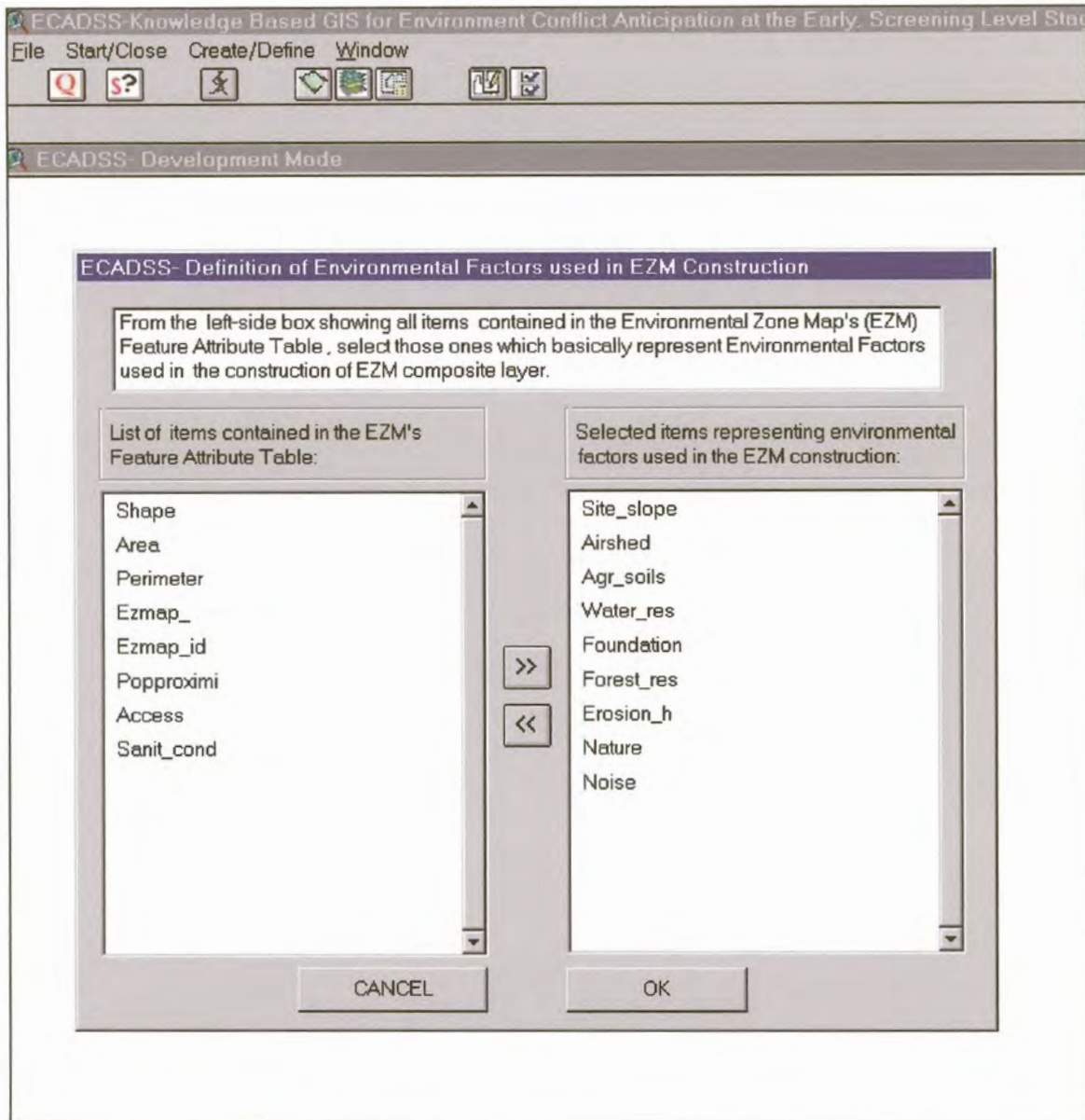
Figure 4.9   The KBGIS interactive dialogue for the selection of environmental resource/hazard factors
to be used by the system for identification of environmental constraints within a study area

After identifying all relevant environmental factors, the system automatically starts searching through
the EZM polygon attribute table in order to extract the combination of unique attribute values for each
of the selected factors. The user is then requested to verify their attribute value descriptions in terms of
how explicable they portray the individual resource/hazard concerns. It has been explained in section
4.2 of this chapter that the EZM composite layer is based on the aggregation (overlay) of individual
"factor" layers. Each of these layers portrays unique environmental resource/hazard attributes (such
as slope stability, soil quality, susceptibility to erosion etc.) and its variation (ranking) by the level of
environmental constraint it may pose to external initiatives. Sometimes, however these attribute
rankings contained in the attribute table are simply coded as integers or string abbreviations and
therefore may not be easily understandable in terms of the environmental concerns they portray. Lets
for example consider an attribute value classification (ranking) of an individual factor layer such as the

slope of the terrain. Very often the attribute classification for this factor is expressed in a form of slope percentage categories such as 0-0.5%, 0.5-10%; 10-20%; 20-30%; >30%. This attribute classification is meaningless from the prototype KBGIS point of view since it does not describe the specific resource/hazard concern in a language familiar to users. This especially refers to the users who are not in a position to understand the meaning of the aforementioned attribute categories in terms of the environmental constraints they pose to various external initiatives. Therefore, instead of 0-0.5% or >30%, the site slope attribute categorization and description expressed in a form such as "To flat (run off constraint)" or "Steeply dissected terrain" is considered more appropriate from both, the user and the proposed system point of view.

For this purpose the system provides an interactive, dialogue form whose upper left part, as illustrated in Figure 4.10, presents the list of the previously selected environmental factors to be used for identification of environmental constraints. The user is prompted to point-and-click on each environmental factor (item) in order to get its unique attribute value descriptions contained in the EZM attribute table. The user is then requested to re-define each of these value descriptions in order to provide the new ones that will portray the relevant resource/hazard concerns more effectively. (Examples: high erosion risk, severe foundation constraints, naturally flooded area, scenic area, very suitable agricultural land, hilly terrain, no significance, etc.).
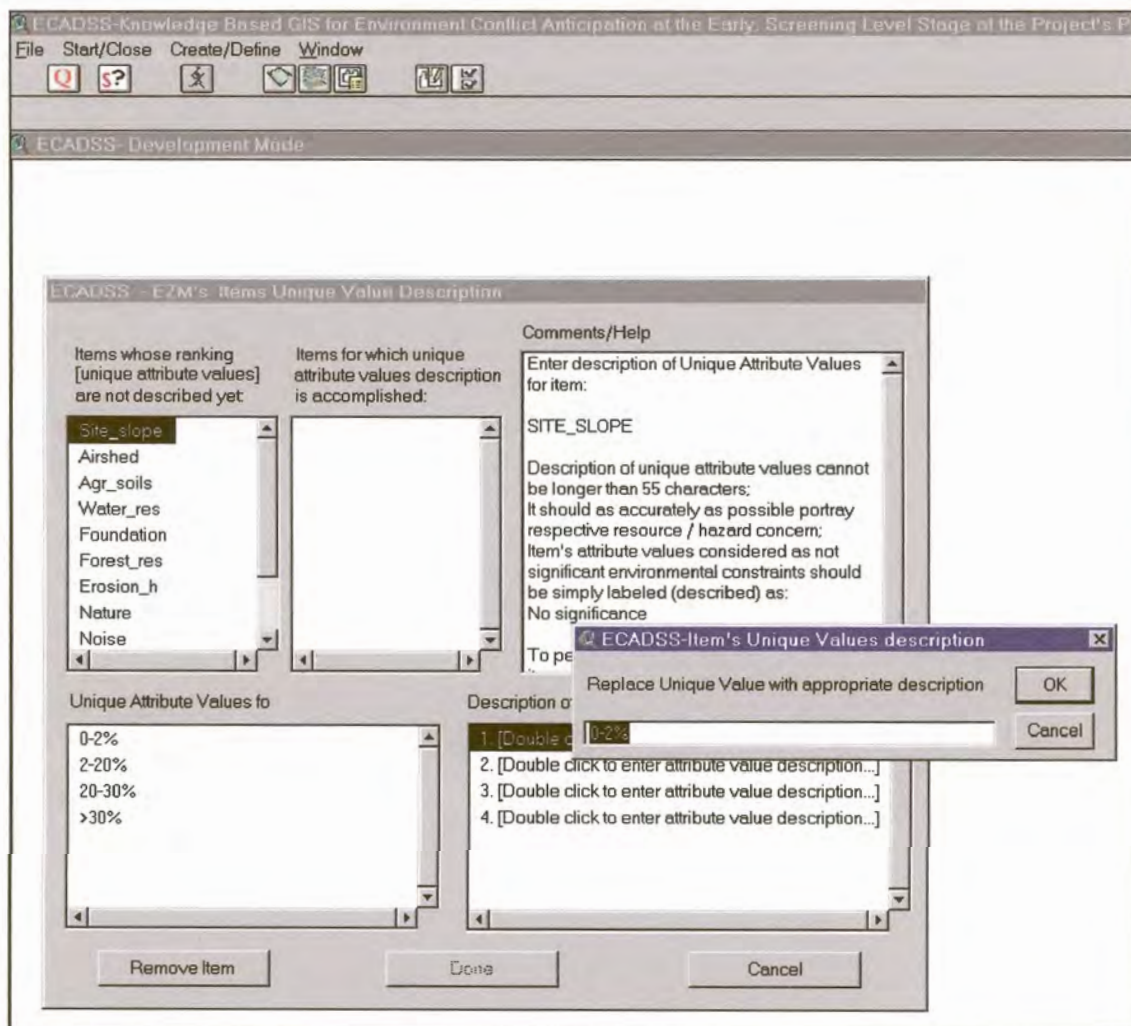

Figure 4.10 The KBGIS interactive dialogue designed to support viewing and typing in descriptions of unique attribute values for each environmental factor selected from the EZM attribute table

The unique attribute value descriptions for each of the selected environmental factors will become a part of the KBGIS knowledge base. They will be used by the system for:

1) Presentation of the site-specific environmental constraints in a language familiar to the user, and

2) As data source (environmental input) for the construction of the system's D/E Interaction Matrix.

4.5.2 Acquisition of Knowledge within the Prototype KBGIS Implementation Environment

The final steps in a typical data and knowledge acquisition session of the proposed KBGIS are the construction of the Development-Environment Interaction Matrix (D/E Interaction Matrix) and definition of the Project Impact Identification Checklist (PII Checklist)

(1)   D/E Interaction Matrix

D/E Interaction Matrix is the foundation of the prototype KBGIS with the task to provide a set of development-environment relations required for grading and assessing potential conflicts between site-specific environmental constraints and the project's development implications.

As illustrated in section 4.3.2 of this chapter, its construction involves cross-referencing a list of development implications/sensitivities with the previously selected environmental factors and their values. This procedure requires a strong element of human expertise and judgement about the array of possible development implications-environmental constraint interactions, especially in the situation where such identification attempts to attach significance to each of the identified interactions.

The judgmental process on the likely development-environment interactions and on their significance is achieved within the prototype KBGIS through the use of a so-called automated expert-driven knowledge-acquisition method. It allows the expert to construct a D/E Interaction Matrix without assistance of the knowledge engineer. Furthermore, it is based on an interactive dialogue form capable of:

1) Capturing the expert's opinion about the array of possible interactions between the aforementioned problem entities, and then

2) Automatically populating the related Interaction Matrix and knowledge base required by the consultation mode.

Figure 4.11 illustrates the form-filling dialogue implemented by the knowledge acquisition mode of the prototype KBGIS. It interacts with the user by generating a list of development implications / sensitivities, which need to be cross-referenced with each environmental factor (resource/hazard concern). The user is requested to select the development implications that according to his/her opinion might cause conflict with the environmental factor shown in the upper-right corner of the relevant dialogue. This procedure is repeated for all environmental factors identified by the data acquisition procedures explained above.

As already indicated, the knowledge acquisition method implemented by the system allows the user to attach weights (significance) to each of the identified potential development-environment interaction. However, the level of sophistication is rather shallow, but still in line with the basic goal of the prototype KBGIS system - that is to support screening and diagnostic process in site suitability

assessment and environmental impact prediction. An important aspect of such a process is to identify environmental concerns at the earlier stage of project planning. It would then encourage detailed investigation if found necessary.
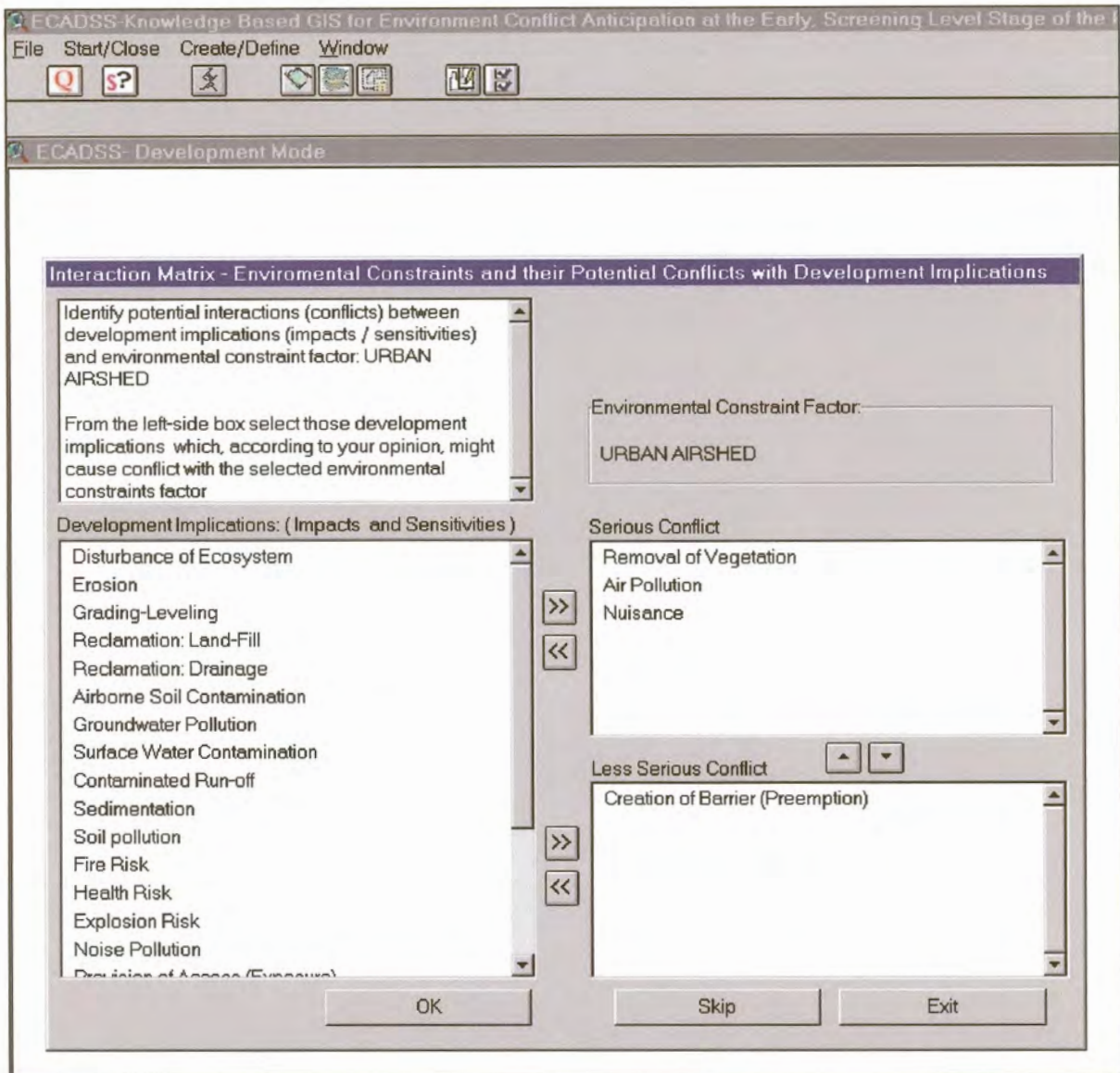

Figure 4.11 The KBGIS form-filling dialogue designed to support construction
of Development/Environment Interaction Matrix

(2)   Definition of the Project Impact Identification Checklist

Definition of a project impact identification checklist (and now PII Checklist) involves assembling a knowledge base that will contain the list of development actions (projects) along with their implications likely to have significant effects on the environment (impact of development) and vice versa (development sensitivities).

This step is optional in a typical knowledge acquisition session supported by the prototype KBGIS. This is mostly due to the fact that during model construction the user cannot anticipate all development activities that could be proposed. Therefore, definition of PII Checklists and assembling the relevant knowledge base is available in both modes of the KBGIS (the development and the consultation mode). This contributes to the system's flexibility since the user can add a new PII checklist without the need to repeat the whole process of assembling the relevant knowledge base.

Apart from being used by the system's inference engine for the identification of site–specific development-environmental conflicts, the PII Checklist knowledge base also plays a role as a provider of the compiled list of development implications/sensitivities required for the construction of the D/E Interaction Matrix. Therefore, one can conclude that if it is not defined a priori, it could disqualify the D/E Interaction Matrix construction. To overcome this problem the system maintains an internal (generic) list of development implications/sensitivities that could be utilized to provide inputs required for the construction of D/E interaction Matrix. This list is automatically updated with the new development implications/sensitivities attached to a project impact identification checklist during its definition and/or refinement.

The process of assembling the PII Checklist knowledge base is achieved within the prototype KBGIS through the implementation of a number of interactive dialogues. They are designed to assist and lead the user through the construction of each PII checklist. For this purpose a common list of basic screening questions (see Box III) along with the related development implications/sensitivities has been pre-defined and built into the system.

Box III

Checklist of Screening Questions designed as an aid for assessing the likelihood of the project's implications that might affect environmental sensitivity

1) Does the project involve any land disturbance or site clearance, or extensive earthworks or underground works?

2) Does the project generate emissions to air (odours, blowing litter, airborne pathogens, dust emission, toxic fumes, gaseous and particulate emissions) from fuel combustion, production processes, materials handling, disposal of waste through burning in the open air and other sources?

3) Does the project involve/or generate disposal of considerably large volumes of solid wastes or sewage, industrial effluent and/or contaminated wastewater discharge?

4) Does the project involve the storage, handling, use or production of toxic and hazardous substances?

5) Does the project include the use of pesticides, herbicides or fertilizers or other chemicals?

6) Does the project release noise and vibration into environment (including blasting, piling etc.)?

7) Does the project require/involve the construction of roads, ancillary utilities and/or construction of significant structures (buildings, production halls, warehouses, protection walls etc.)?

8) Are there any other project related factors that might affect environment and which are not mentioned above?

As illustrated in figure 4.12 this list is embedded into the main, question-like dialogue designed to support the PII checklist construction. Its task is to ensure that the most relevant project-related factors and their associated implications on the environment are considered. At the same time, its purpose is to maintain a level of knowledge required and supported by the prototype KBGIS. Answering the questions provided by the dialogue is not meant to require studies or investigations. On the contrary, the user of the dialogue is expected to base his/her answers on existing information or knowledge he/she possesses about the project whose Impact Identification Checklist is being defined. Recognizing that there may be issues not included in the common list of project-related screening questions, an option is provided within the relevant checklists' construction dialogue for further questions that might be added.
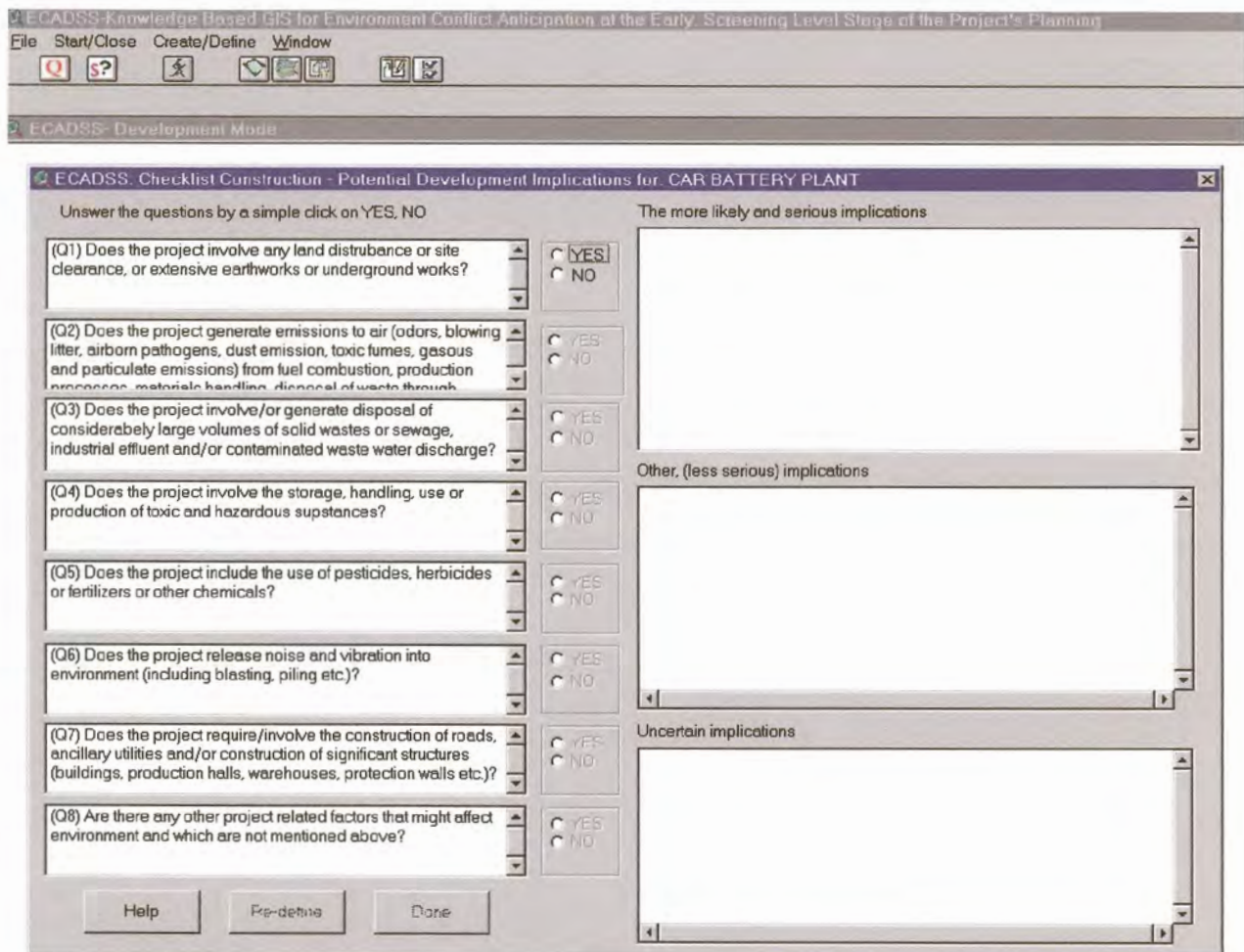

Figure 4.12   The KBGIS question-like dialogue designed to support construction of the
Project Impact Identification Checklist

A "YES" answer on each of the questions provided by the main checklist construction dialogue, triggers another dialogue that contains the list of potential development implications associated with the related question. To give an example, if the user answers positively on the question of whether the project under consideration involves any site clearance, a dialogue containing the list of the related potential implications that might affect the environment will show up. As illustrated in Figure 4.13, the user is then requested to assess the likelihood and significance of each implication from the point of

view of the project being considered. The user is also allowed to add other development implications not provided by the dialogue, but perceived as applicable for the relevant screening question.
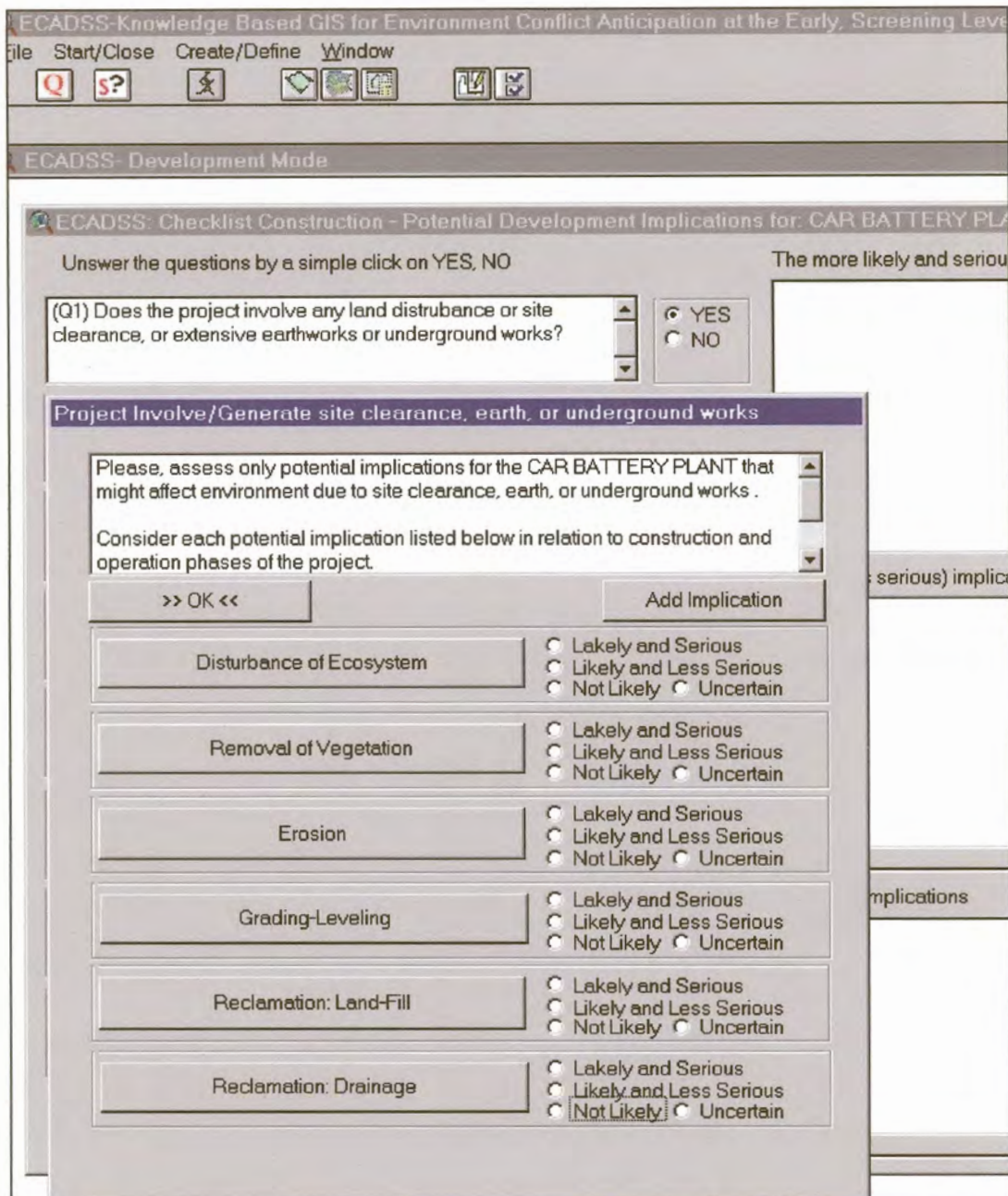

Figure 4.13 The KBGIS point-and-click dialogue for assessing the likelihood and significance of the project's implications associated with the related screening question

As soon as the question's relevant development implications for the project are assessed, the system automatically appends their likelihood and significance to the project impact identification checklist. This checklist is then displayed within the main checklist construction dialogue allowing the user to review or re-define it (see Figure 4.14). The whole procedure is repeated until the last question is answered and related development implications are assessed.
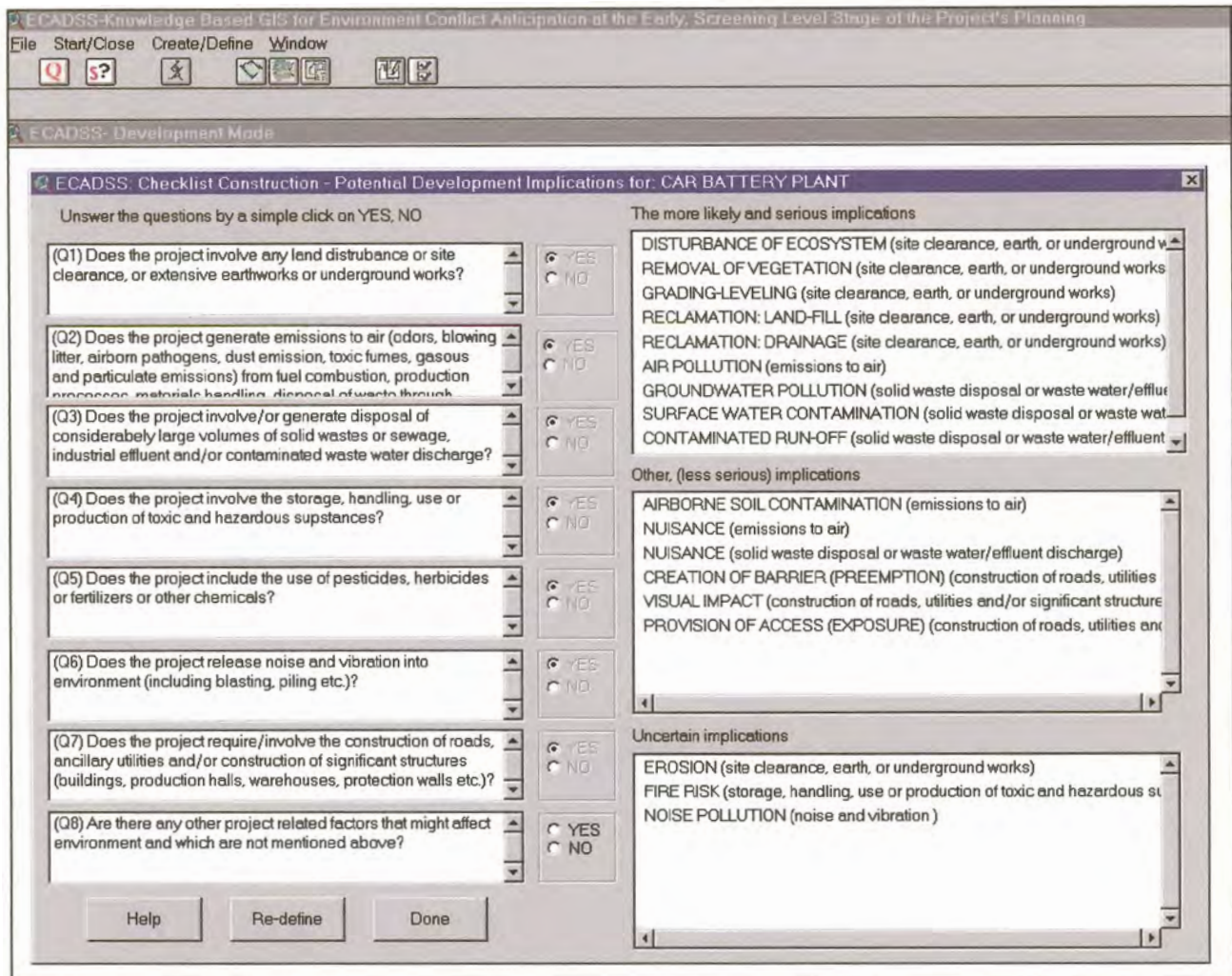
Figure 4.14 An Example of the project Impact Identification Checklist displayed in the main construction dialogue for the purpose of being reviewed and re-defined, if required

The final step involved in the construction of the PII checklist for the project under consideration refers to the assessment of its development sensitivities. For this purpose the user is provided with the simple point-and-click interactive dialogue whose left part, as illustrated in Figure 4.15, offers the list of generic (system compiled) development sensitivities. The user is then requested to select or append those that are considered to be of significance for the project. The system then automatically appends the identified development sensitivities to the impact identification checklist of the project, and finally inserts it into the relevant knowledge base.
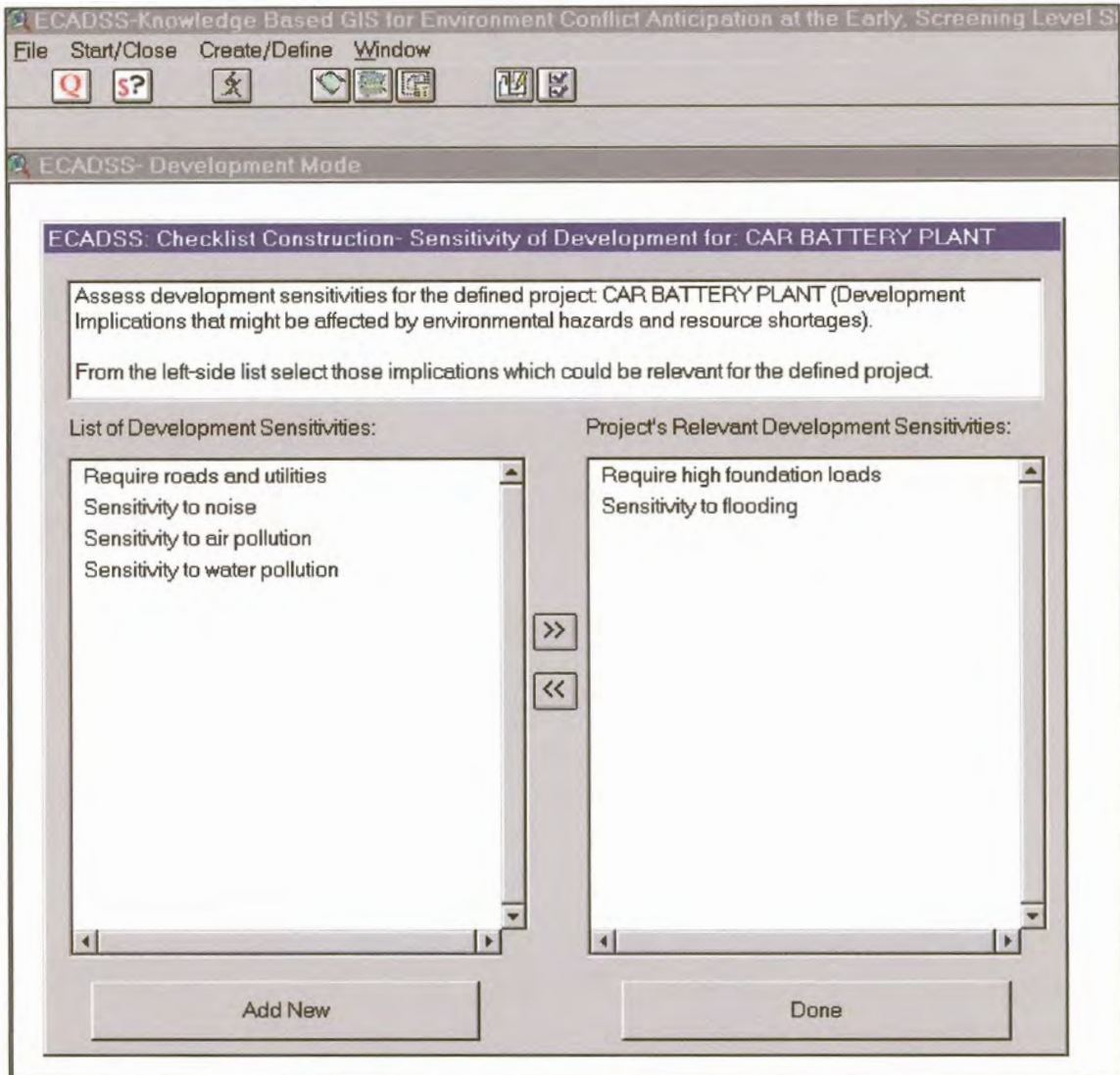
Figure 4.15 The KBGIS interactive, point-and-click dialogue for assessment of the project's development sensitivities

4.5.3 Knowledge Representation within the prototype KBGIS Environment

Several different approaches to knowledge representation within knowledge-based systems (KBS) have been developed over the last few decades. Among them, the production or declarative rules (IF premise THEN conclusion) seems to be the most commonly used, especially by the KBS designed to support location problem-solving tasks. This research is different since it implements the type of knowledge representation that is based on a so-called "domain (truth) table", rather then on production rules. The reasons for this are mostly related to the fact that knowledge required by the system can lead to the construction of a large number of "IF-THEN" rules. This in turn might create problems for both, the knowledge base search and the knowledge base maintenance. Because of this the domain (true) table approach is considered to be more appropriate and provides for a much easier knowledge presentation scheme. By this approach, knowledge is represented and organized in a spreadsheet (tabular) format. It uses columns and rows to develop lists of the problem domain entities and to assign their interactions by utilizing modified Boolean (true and false) values (see Figure 4.16). This

type of domain (true) table is furthermore easy to understand and what is even more important it can be developed and manipulated within the knowledge management environment of the KBGIS in a simple Dbase file format.
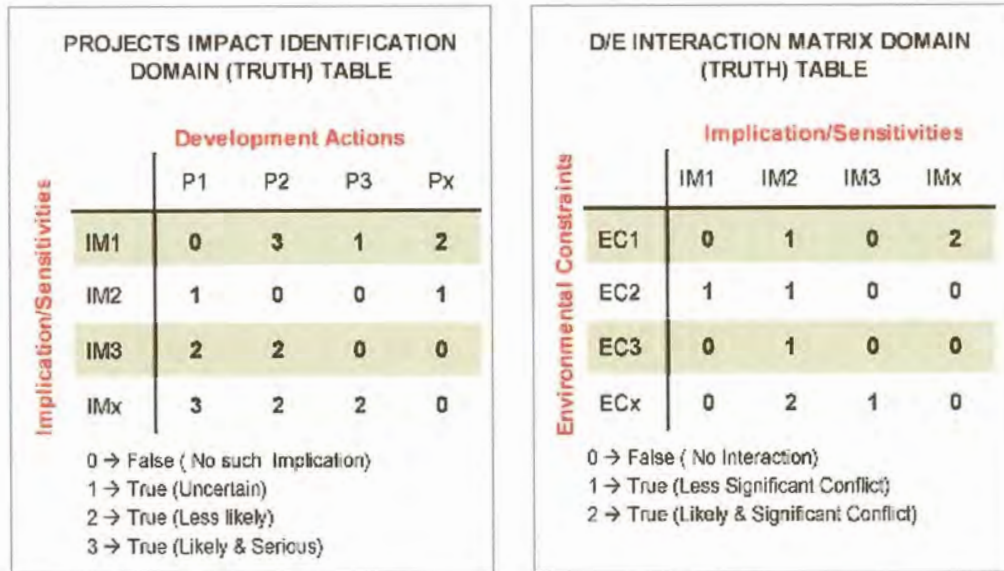

PROJECTS IMPACT IDENTIFICATION DOMAIN (TRUTH) TABLE				
	Development Actions			
	P1	P2	P3	Px
IM1	0	3	1	2
IM2	1	0	0	1
IM3	2	2	0	0
IMx	3	2	2	0

0 → False (No such Implication)
1 → True (Uncertain)
2 → True (Less likely)
3 → True (Likely & Serious)

D/E INTERACTION MATRIX DOMAIN (TRUTH) TABLE				
	Implication/Sensitivities			
	IM1	IM2	IM3	IMx
EC1	0	1	0	2
EC2	1	1	0	0
EC3	0	1	0	0
ECx	0	2	1	0

0 → False (No Interaction)
1 → True (Less Significant Conflict)
2 → True (Likely & Significant Conflict)

Figure 4.16   Illustrative example of the knowledge representation approach implemented within the prototype KBGIS

In this research the domain (true) table knowledge presentation scheme was used for developing both of the knowledge bases (Project Impact Identification Checklist, and Development/ Environment Interaction Matrix). By themselves they do anything apart from being searched and interpreted by the problem processor (inference engine) during the process of the site-specific environmental impact prediction and site compatibility assessment. Therefore, they can be thought of as a sort of meta-database stored and manipulated within the prototype KBGIS in a type of internal Dbase file.

4.6   The KBGIS Consultation Mode

The KBGIS consultation mode aims at providing the environment that is capable of supporting the identification of the site-specific development-environment concerns at the early, screening level stage of project planning. It is the core of the system and composed of the following two basic parts:

1) *The ArcView desktop GIS data manipulation and mapping tools - used for* storage, visualization, selection and retrieval of spatially referenced data;

2) *The problem-specific knowledge based reasoning system* (KBS) - developed with the aid of Avenue programming language and embedded into ArcView GIS environment. It consists of the *Knowledge meta-databases* and *the KBGIS inference engine* (problem processor).

The GIS part, within this mode, is conceived as a slave to KBS. As mentioned above, its function is to provide the means for displaying, managing, analysing and retrieving environmental data from a spatial database ("what" and "where") and to pass them to the inference engine of the system for

further analysis. The perceived role of the KBS, on the other hand, is to overcome the inferiority of GIS in analysing relations ("why") by furnishing the system with domain knowledge as well as with the search mechanism and reasoning capabilities for identifying development-environment concerns in a language familiar to users.

From the functional point of view, the KBGIS consultation mode is nothing else but a collection of tools each serving a related set of functions that are controlled either by the user or the system itself. They are embedded into a common graphical user interface (GUI). From the users perspective the GUI operates mostly as a window or icon-based graphic menu. It is designed to guide the user quickly and easily through the consultation session. Simply by "pointing-and clicking" the user can invoke appropriate options from the GUI to perform as many or as few changes during the evaluation session in order too see the results immediately.

From the system design point of view, the GUI provided by the consultation mode is essentially a generic ArcView GUI that is associated with its "View" subsystem and designed to provide a means for displaying, exploring, querying and analysing geographic data and their attributes. Those original tools from the GUI that are regarded as not vital for the consultation mode have been disabled and replaced by the new ones required by the system and developed with the aid of the Avenue macro language. As illustrated in Figure 4.17, the new tools embedded into the generic ArcView GUI are:

1)   The KBGIS query and scenario manager toolbox;

2)   The KBGIS analysis and evaluation toolbox;

3)   The KBGIS inference engine justifier tools;

4)   The KBGIS knowledge refinement toolbox.

The first three toolboxes are essential parts of the proposed consultation mode. They basically represent the system's control and reasoning (inference) mechanism, which is the brain of the whole system.
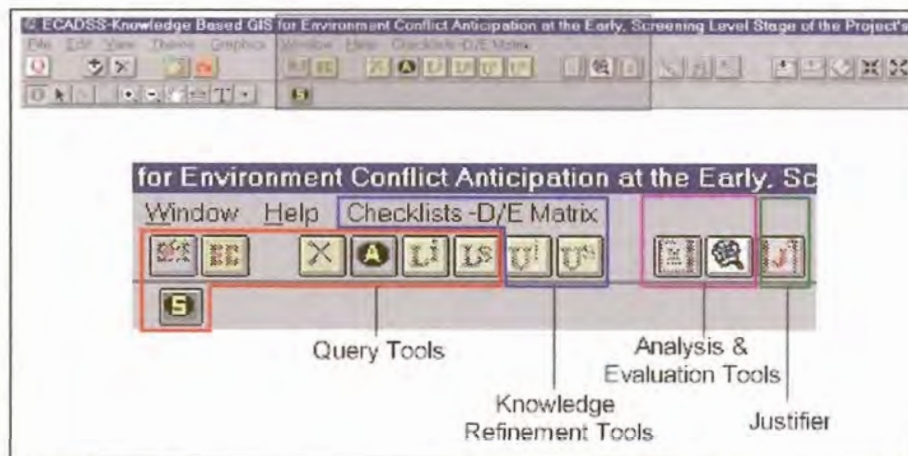

Figure 4.17   The KBGIS consultation mode toolbox developed with the aid
of Avenue macro language and embedded into the ArcView GUI

The purpose of the *"Query and Scenario Manager toolbox"* is twofold, namely: (1) to interact with the user in order to get input information, and (2) to forward them to the working memory which is hidden from the user and controlled by the system itself.

The purpose of the KBGIS "Analysis and Evaluation toolbox" is to provide reasoning mechanisms capable to direct (based on input data) the search through the system's GIS and knowledge databases and to draw conclusions about the problem at hand. In essence it represents the KBGIS inference engine which is also controlled by the system for the benefit of isolating users from the "what next and how to do" type of tasks. The inference engine is composed of two components: (a) the scenario analysis, and (b) the evaluation mechanism (interpreter). The former has the purpose of interacting with the system's working memory in order to acquire input data provided by the user and to enable the system's scenario evaluation tools that are requested. The latter basically represents the computer algorithm that controls and carries out the reasoning process in order to generate final results for the problem at hand in a form of expert advice.

There is only one scenario currently supported by the analysis and evaluation toolbox. As illustrated in 4.18, it refers to the assessment and listing of the potential development-environment conflicts that can be expected if the proposed development action and its tentative location are known. Additionally another scenario might be added to the system with the task to identify the most and least suitable sites. This scenario can be useful in the situation where the user specifies only the intended development action (project) without its tentative location.

The purpose of the KBGIS *"Inference Engine Justifier tools"* is to provide a variety of displays that allow the user to examine the reasoning process in order to refine it, if necessary, by means of updating or even changing the underlying assumptions.

Finally, *the KBGIS "Knowledge Refinement toolbox"* embedded into the consultation mode GUI acts as a standalone unit separated from the system's inference mechanism. It was primarily designed to allow the user to modify and update the knowledge bases and to add new information (knowledge) about the domain even when using the consultation mode.
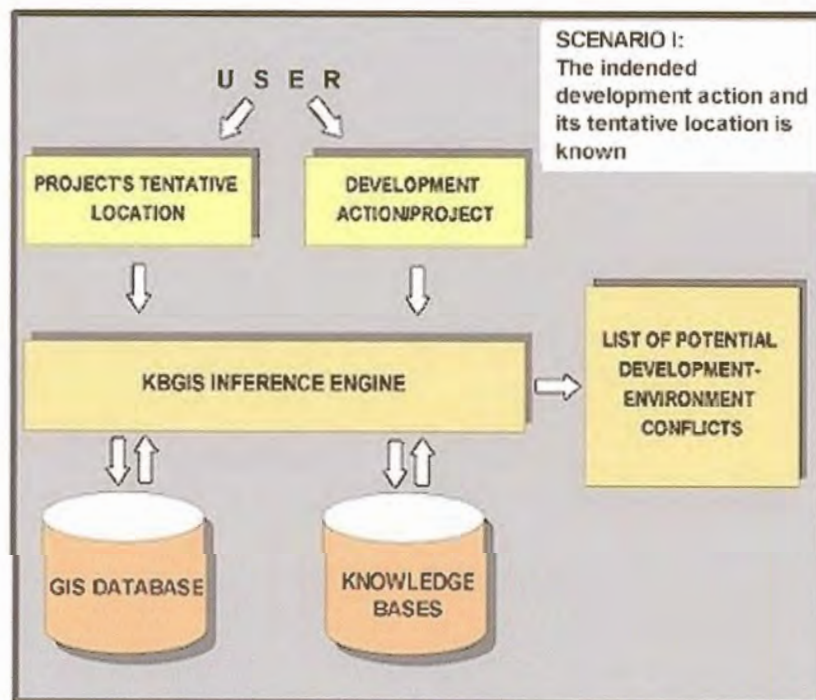

Figure 4.18 Analysis and evaluation scenario that is supported by the prototype KBGIS

4.7 The KBGIS Inference Mechanism: How it works

This section illustrates the basic steps of a typical consultation session as supported by the prototype KBGIS along with the reasoning procedure that tries to reach conclusions at the end of the consultation stage.

1) The first step of a typical consultation session supported by the system includes interaction with the user for the purpose of the input data acquisition. This interaction is controlled through the GUI, which provides two icon-based controls (Figure 4.19). They allow the user to simply point-and-click in order to invoke interactive data input procedures for the two basic types of information required by the system:

    1.1. Specification of the intended project (development action), and

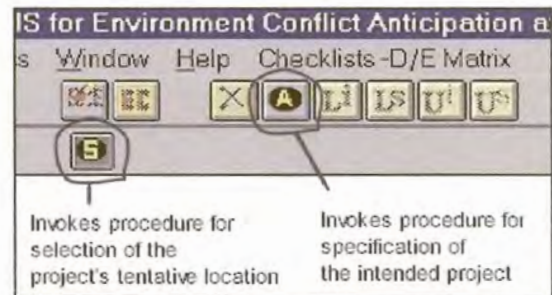   1.2. Selection of its tentative location.

Figure 4.19 The KBGIS data input controls

Specification of the intended project is accomplished through the interactive dialogue facility. It provides the user with the list of all projects (development activities) whose Impact Identification Checklists are already defined and stored within the relevant knowledge base. (See Figure 4.20)
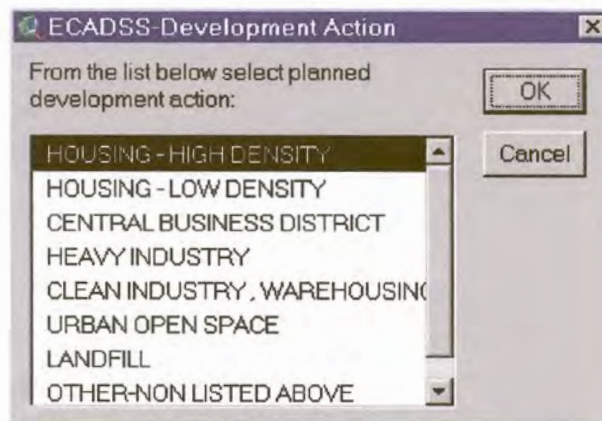

Figure 4.20 An Example of the interactive dialogue designed to support selection of the intended project

As soon as the project (development action) is identified, the system automatically takes over the control by passing on information to its working memory. The working memory furthermore forwards information to the inference engine, which automatically fires up the search through the relevant knowledge database in order to extract the project's impact identification checklist and its pre-defined development sensitivities. It then enables the controls from the GUI that allow the user

to re-view the project's impact identification checklist and its development sensitivities. (See Figure 4.21)
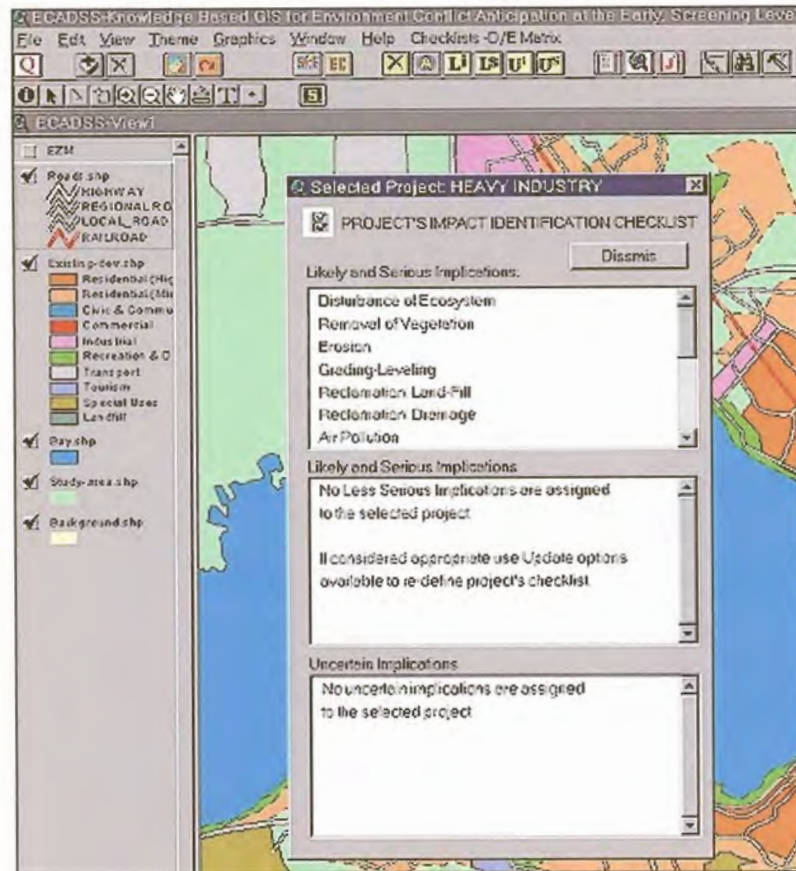

Figure 4.21 The Screen snapshot illustrating the KBGIS's ability to extract the Impact Identification Checklist of the selected project from the knowledge database and allow the user the review it

If the user cannot locate the intended project or, at least its counterparts from the relevant list provided by the system, he/she would be permitted to define the project impact identification checklist and then append it to the existing knowledge base. This is achieved with the aid of the knowledge refinement toolbox (see section 4.8)

The selection of the project's tentative location is accomplished through the icon-based tool button. When invoked, it firstly activates the graphic window containing the visual presentation of the study area and then prompts the user to move the cursor and pinpoint the project's desired location. For this purposes the user is provided with various generic GIS tools (zoom, pan, etc.) in order to locate the project's desired site as precisely as possible.

As soon as the desired location of the project is identified, the system again takes over control and passes on the users inputs to the working memory. Then, on the basis of the data forwarded from the working memory, the system's inference engine employs generic GIS search and data retrieval functions in order to acquire the environmental constraints at the proposed project site from the EZM composite layer. It then enables the control that allows the user to review the site-specific environmental constraints (see Figure 4.22).
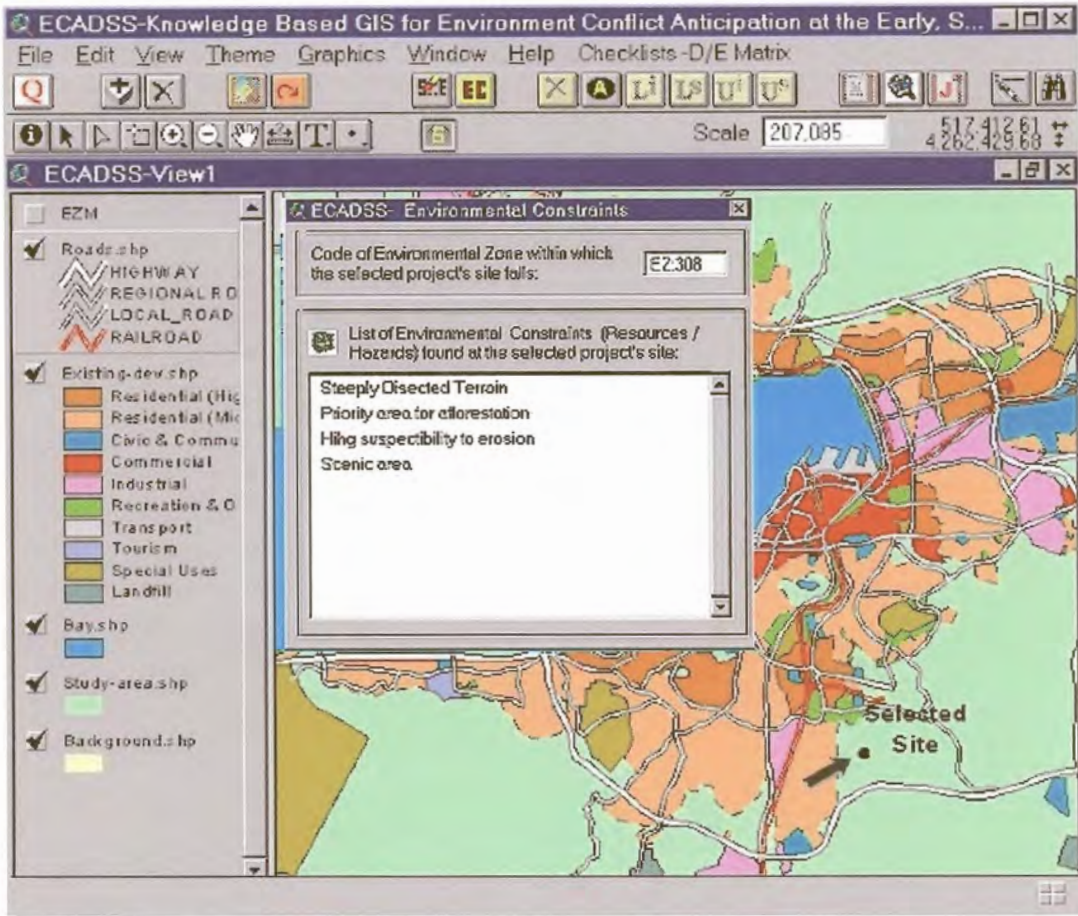
Figure 4.22 The screen snapshot illustrating the KBGIS ability to extract from its
GIS database all environmental constraints found at the selected location

2) Once the system has obtained all the information from the user and the data and knowledge base it becomes "ready-to-reason" in order to reach the conclusions and to provide the expert advice for the problem at hand. For that purpose the user is provided with the icon-based GUI controls that allow him/her to simply point-and-click in order to invoke appropriate reasoning procedure (see Figure 4.23).

Control embedded into the GUI to support identification of the most and least suitable sites for the specified project.

Inference Engine Justifier

Evaluates and provides the list of potential conflicts that can be expected when the intended project and its tentative location area known
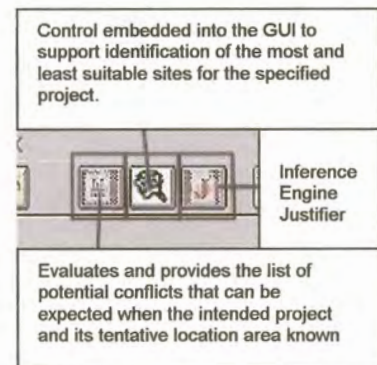
Figure 4.23 The KBGIS evaluation tools embedded into the system's GUI

The following is an explanation of a typical reasoning process currently supported by the prototype KBGIS. It refers to a situation where the system is required to evaluate and list potential conflicts with the proposed project and its tentative location known.

2.1 With the required user inputs (the proposed project and its location) stored into the working memory, the KBGIS inference engine (triggered by the user through GUI control) starts the reasoning process. Firstly, it searches through the Environmental Zone composite layer in order to extract environmental constraints (resources/hazards) found at the selected project's location and place them into the working memory as a part of the problem description.

2.2 Secondly, the inference engine also searches through the PII Checklist knowledge base in order to extract the list of development implications and sensitivities attached to the proposed project. The list is then forwarded to the working memory as a part of the problem description.

2.3 Once the site-specific environmental constraints and the project's development implications/ sensitivities are obtained from the GIS and knowledge databases and forwarded to the working memory, the system starts the reasoning (evaluation) process and draw conclusions (e.g. to provide a list of potential conflicts that might be expected for the proposed project at the selected location).

This process involves the application of procedural (inference) rules, usually called "pattern matching". It basically refers to an algorithm on how to search the system's D/E Interaction Matrix and infer conclusions on the basis of given facts (site-specific environmental constraints and the project's development implications) contained in the system's working memory. An example of a procedural rule, implemented by the proposed KBGIS inference engine is given below in its generic form:

---

*IF development implication **AND** environmental constraints = **TRUE** (interacts)*

***THEN** infer (return) interaction value significance*

***ELSE** continue*

The inference engine provided by the prototype KBGIS uses a so-called forward chaining inference method. As illustrated in Figure 4.24, it operates by comparing the facts available in the working memory to the premises of the inference rule illustrated above. In other words, all site-specific environmental constraints found at the proposed project's location and forwarded to the working memory are compared with each of the project's development implications also stored in the working memory. The comparison is done by means of searching the available D/E Interaction Matrix and inferencing the interaction values between them. If the interaction (conflict) exists, the rule "fires" by extracting its attached significance and placing it in the working memory as a conclusion. (The conclusion is basically an expression of the seriousness of the potential conflict forwarded to the working memory in a language familiar to user).
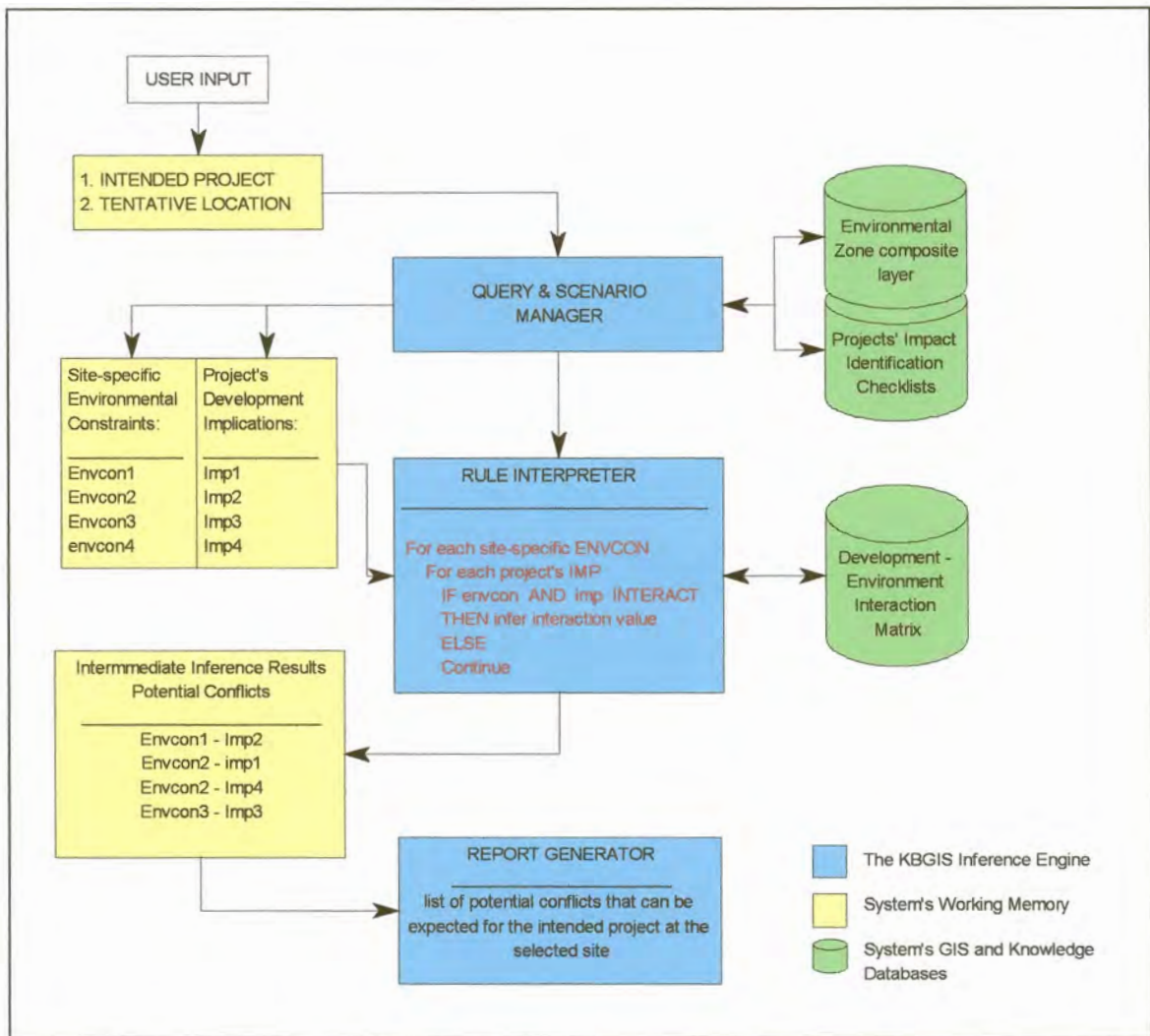
Figure 4.24   Schematic representation of the reasoning process currently supported by the prototype KBGIS

2.4   Finally, once the system has inferenced the existence and significance of all the interactions between site-specific environmental constraints and the project's development implications, it generates the report. This is done by extracting the intermediate inference conclusions stored in the working memory and then ranking them on the basis of their significance. At least two lists can be generated containing different levels of seriousness of the inferred conflicts that can be expected for the proposed project at the selected location. As illustrated in Figure 4.25, these lists are automatically shown to the user at the end of the consultation.
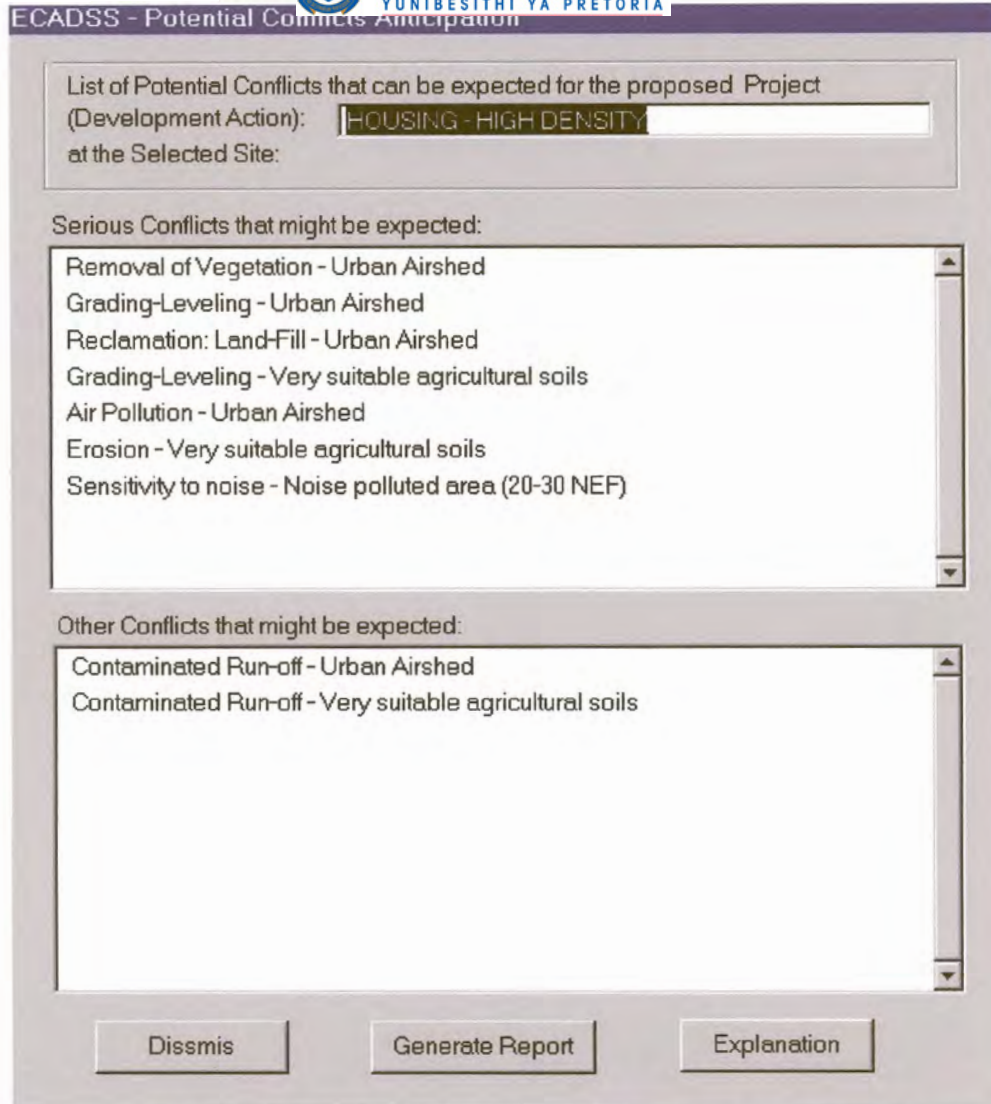
List of Potential Conflicts that can be expected for the proposed Project
(Development Action):   HOUSING - HIGH DENSITY
at the Selected Site:

Serious Conflicts that might be expected:

Removal of Vegetation - Urban Airshed
Grading-Leveling - Urban Airshed
Reclamation: Land-Fill - Urban Airshed
Grading-Leveling - Very suitable agricultural soils
Air Pollution - Urban Airshed
Erosion - Very suitable agricultural soils
Sensitivity to noise - Noise polluted area (20-30 NEF)

Other Conflicts that might be expected:

Contaminated Run-off - Urban Airshed
Contaminated Run-off - Very suitable agricultural soils

| Dissmis | Generate Report | Explanation |

Figure 4.25   An example of the system's inference conclusions provided in a language familiar to the user

2.5   Parallel to the inference conclusions described above, the system also keeps track of the whole consultation session by means of recording each and every line of the reasoning process. The results are stored in a temporary file controlled by the system and updated whenever the user restarts the consultation session. Its purpose is to allow both the user and the system's builder to observe, clarify and, if necessary, enhance the assumptions underlying the reasoning process.   Interaction with the user for the sake of reviewing or even printing the above-mentioned file is accomplished through the GUI control that becomes available as soon as the consultation session ends. Figure 4.26 shows an example of such a file.
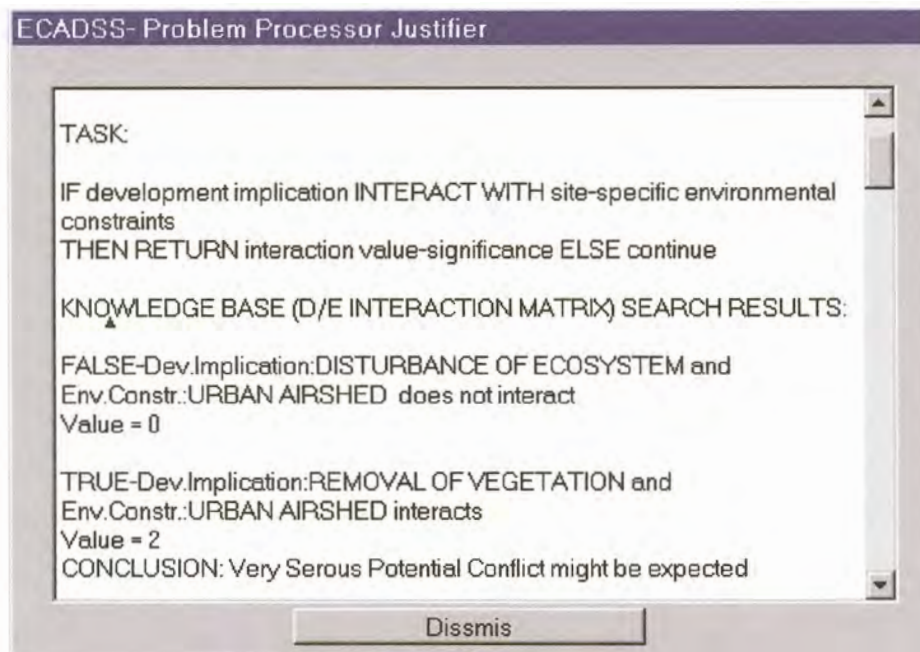
```
ECADSS- Problem Processor Justifier

TASK:

IF development implication INTERACT WITH site-specific environmental
constraints
THEN RETURN interaction value-significance ELSE continue

KNOWLEDGE BASE (D/E INTERACTION MATRIX) SEARCH RESULTS:

FALSE-Dev.Implication:DISTURBANCE OF ECOSYSTEM and
Env.Constr.:URBAN AIRSHED  does not interact
Value = 0

TRUE-Dev.Implication:REMOVAL OF VEGETATION and
Env.Constr.:URBAN AIRSHED interacts
Value = 2
CONCLUSION: Very Serous Potential Conflict might be expected

                        Dissmis
```

Figure 4.26   An example of a textual file generated by the system for the
purpose of storing assumptions underlying its reasoning process

4.8   The KBGIS Knowledge Refinement toolbox

The KBGIS knowledge refinement toolbox acts as a standalone unit separated from the inference
mechanism. Its purpose is to allow the user to not only modify and update the knowledge bases, but
also to add new information (knowledge) about the domain even during the consultation mode. This
ability contributes to the system's openness and ease of expansion without the need to repeat the
whole knowledge acquisition process from scratch.

This ease of expanding, updating and modifying the knowledge bases makes the system open for
rapid prototyping. In this process the user can construct the knowledge bases (PII checklist or even
the D/E Interaction Matrix) as initial prototype solution.   Expert can later improve the relevant
knowledge bases by running the system, examining its reasoning process and changing the
underlying assumptions. Another example is related to the process of inserting the project's impact
identification checklist in the relevant knowledge base. As mentioned earlier the user cannot anticipate
all development actions (projects) during the knowledge acquisition session. The knowledge
refinement tools make this unnecessary by providing the user with the abilities to add new and even
modify or delete the existing PII checklist during the system's consultation mode.

Figure 4.27 illustrates the knowledge refinement tools embedded into consultation mode interface in a
format of the easy-to-use interactive dialogue.

ECADSS-Development Implications Checklist Update

Development Action: HOUSING - HIGH DENSITY

Likely and Serious Implications: | **Project Involve/Generate:**

Likely and Serious Implications	Project Involve/Generate
Disturbance of Ecosystem	(1) site clearance, earth or underground works
Removal of Vegetation	(1) site clearance, earth or underground works
Grading-Leveling	(1) site clearance, earth or underground works
Reclamation: Land-Fill	(1) site clearance, earth or underground works
Provision of Access (Exposure)	(1) construction of roads,utilities and/or significant structures

Likely and Less Serious Implications	Project Involve/Generate
Erosion	(2) site clearance, earth or underground works
Air Pollution	(2) solid wastes disposal or waste water/effluent discharge
Creation of Barrier (Preemption)	(2) construction of roads,utilities and/or significant structures

Uncertain Implications:	Project Involve/Generate
Contaminated Run-off	(3) construction of roads,utilities and/or significant structures
Visual Impact	(3) site clearance, earth or underground works

Add Implication	Change Implication Significance	Done
Help	Remove Implication	

Figure 4.27   An example of the system's interactive dialogue designed to support the construction or modification of PII checklists