DEVELOPMENT OF A METHOD FOR THE SELECTION OF SUITABLE LANDFILL SITES, AND OF GUIDELINES FOR SANITARY LANDFILL IN MUNICIPAL AREAS

» EXTENDED EXECUTIVE SUMMARY «

Report to the
WATER RESEARCH COMMISSION
by the
GROUNDWATER PROGRAMME
DIVISION OF WATER TECHNOLOGY
CSIR, STELLENBOSCH

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NOTES ON THE DISTRIBUTION OF THE SOFTWARE AND USER'S GUIDE

The distribution of the software user guide and the software, MuLaSSAS, is being held in abeyance until DWAF's 'Minimum Requirements' guidelines are finalized.

The working prototype software may be viewed at the Water Research Commission's offices in Pretoria or at the CSIR's offices in Stellenbosch.

CURRENT STATUS AND FURTHER CHANGES

In this executive summary, landfill-siting information from draft reports up to the ninth draft report (Draft IX) of DWAF's 'Minumum Requirements' guidelines documents has been addressed, along with additional information from the literature and from experts.

Please note that this report and the current software serve to illustrate the potential of expert-systems based software for the applications addressed. The intention is that when the final version of the 'Minimum Requirements' guidelines is released, the landfill-siting aspects of the guidelines will be incorporated into the software, the software and user manual will be modified, and then made available for practical use.

DISCLAIMER

CONTENTS

LIST OF FIGURES, TABLES, DIAGRAMS AND TERMS

Term		Description applicable to this report
AquiRisk	:	Framework for **Aqui**fer **Risk** index-assessment
AHP	:	**A**nalytical **H**ierarchy **P**rocess
EOC	:	**E**nvironmental **O**verriding **C**ondition(s)
I & AP	:	**I**nterested and **A**ffected **P**arties
IEM	:	**I**ntegrated **E**nvironmental **M**anagement
MSW	:	**M**unicipal **S**olid **W**aste
MuLaSSAS	:	**Mu**nicipal **La**ndfill **S**ite-**S**election **A**dvisory **S**ystem
Fatal Flaw	:	An EOC which is explicitly covered by regulations
Critical Factor	:	A potentially important issue covered by regulations
Scoping	:	Framework for defining the extent and depth of study
DWAF	:	The Department of Water Affairs and Forestry.

FOREWORD

i) Acknowledgements

This report forms an executive summary of a project funded by the Water Research Commission entitled:

Development of a Method for the Selection of Suitable Landfill Sites, and of Guidelines for Sanitary Landfill in Municipal Areas.

The Steering Committee responsible for this project consists of the following persons:

Mr A.G. Reynders	Water Research Commission (Chairman)
Mr J.M. Ball	Institute of Waste Management
Professor G. Blight	University of the Witwatersrand
Mr L. Bredenhann	Department of Water Affairs and Forestry
Dr. O.O. Hart	Water Research Commission
Dr M. Levin	Atomic Energy Corporation of SA Ltd.
Dr G Tredoux	Division of Water Technology, CSIR

Grateful acknowledgements go to:

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The Research Manager, Mr. A.G. Reynders, for his support and sensitive guidance of the project.

Mr L. Bredenhann and Mr J. Ball for the extra time they gave and for their special commitment to the project.

Prof. G. Blight for landfill-siting information.

The members of the steering committee for their time and contributions.

Dr. G. Tredoux for his support and input to the document.

Mr. R. Parsons, Mr. J. Weaver and Miss L. Cave for editing and advisory inputs to the project.

Members of the Groundwater, Health Water, Waste & Effluent Treatment Programmes, Watertek, CSIR, for their advice.

Messrs. P. Engelbrecht, H. du Plessis and J. Conrad for compiling pictorial information.

Mr. H. du Plessis for developing bitmap viewer software.

ii) Objectives of the Study

a) To determine suitable municipal solid-waste landfill site-selection and site-evaluation methodologies for South African conditions.

b) To draw up guidelines for landfill site-selection and evaluation, which will help determine suitable management alternatives and regulatory requirements for the establishment of landfill, taking into account integrated environmental management principles and pollution-prevention measures.

c) To determine to what extent expert systems (special computer programs) can be used to:
- help model a suitable framework for a landfill-site-selection decision-support system,
- form the final, working, computer-based decision-support system.

iii) Objective of the Report

This extended executive summary, along with the software user guide, completes the reporting requirements of the project. The intention of this executive summary is threefold:

a) to report on those parts of the study which are not addressed by the expert-systems software

b) to describe the modelling concepts behind the expert-systems applications

c) to describe what each expert system does.

The introduction presents an approach to a site-selection strategy and a preamble on the use of expert systems for modelling purposes as well as for software applications. The landfill site-selection strategy, and the modelling and application aspects of the individual expert systems, are addressed in detail in later sections.

iv) Background to Study

The project involved:

* investigation of existing landfill site-selection and evaluation methodologies suitable for environmental-impact assessment purposes;

* the derivation of a suitable 'environmental scoping' framework for landfill-siting in South Africa;

* the collation of information from which landfill-siting guidelines for South Africa may be derived;

* the incorporation of selected methodologies, guidelines and supporting information into expert-systems based computer software for application purposes;

* investigation into the feasibility of using expert-systems for accessing waste disposal statistics on a computer database.

Although the project objectives were not changed during the course of the project, the content of originally-defined tasks have been. The need for changes became evident during the course of the project, which was mainly due to the work being done by a group of consultants for the Department of Water Affairs and Forestry, on proposed new landfill-permitting regulations, termed 'Minimum Requirements for the Permitting, Operation, and Closure of General and Hazardous Waste Landfills' (referred to as ' Minimum Requirements' in this report). In order to derive maximum benefit from the project, some tasks were re-defined so as to accommodate the draft forms of the proposed new regulations, and to address possible needs relating to the Department's Waste Base computer database. As a result, the project was extended for a further year. The current regulations are still in draft form, and once the final draft is produced, the software could be modified to reflect the latest changes. Several versions of the draft regulations are referred to in the report.

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1 INTRODUCTION

1.1 Environmental impact of sanitary landfills

For many countries, prime land available for development in urban areas is becoming scarce. This has resulted in increasing pressure for the location of sanitary (municipal solid waste) landfill sites in zones considered unsuitable or uneconomical for other kinds of development. Many such zones, however, are highly unsuitable for landfill sites. Further, even if an area is itself determined to be suitable for a landfill site, its proximity to land with an incompatible landuse or zoning may render the site unsuitable.

Landfill site selection and evaluation needs to be dependent on the type of landfill as well as the geographical, ecological, and socio-political environment. Such landfill studies typically are multidisciplinary and complex, involving decisions which are often subjective and are based on incomplete information. It is therefore considered important to identify and evaluate potentially suitable landfill sites, and to determine effective options and constraints for landfill on those sites, using scientifically-acceptable approaches.

In order to help regulatory bodies and consultants to determine types and depths of studies required, and to guide them through the decision-making process, there is a need for decision support. This may be in the form of direct access to expertise, computer software, documented guidelines, and others. A decision support system, which consists of a suite of expert systems tied together with hypertext/graphics systems, and which attempts to provide such decision support, is described in this document. The overall system is called MuLaSSAS: **Mu**nicipal **La**ndfill **S**ite-**S**election **A**dvisory **S**ystem. An outline of MuLaSSAS, showing what each component does, is depicted in tabular format (Table 1) on the next page.

1.2 Landfill Site-Selection Strategy

Scoping

Scoping is a strategy used to determine the extent and approach to an impact assessment investigation (Preston et al, 1992). The key concepts are:

* involvement of relevant parties
* identification and selection of alternatives
* identification of significant issues to be addressed
* identification of appropriate mitigating measures
* determination of guidelines and terms of reference for an impact assessment.

(Integrated Environmental Management Scoping Guidelines, Department of Environment Affairs, 1992).

(3.1)
SELECTION-CONTROL EXPERT SYSTEM: Calls up other expert systems and the hypertext/ graphics system {See columns numbered (3.2) to (3.7), below}.

(3.2) Hypertext/ graphics information systems.	(3.3) Landfill site-selection advisory expert systems.	(3.4) Aquifer and surface-water vulnerability index-assessment expert systems.	(3.5) Annual waste load and waste volume estimation aid.	(3.6) Landfill site-cost comparison aid:	(3.7) On-site soils-suitability advisor:
These provide supporting information. Aspects addressed include: * Landfill-siting minimum requirements. * Important definitions. * Display of diagrams * Aquifer vulnerability indexing * IEM Scoping 'procedure'.	These two systems use a 'checklist' approach in the selection of candidate landfill sites. For a site, they help to identify: * 'Fatal Flaws'. * 'Critical Factors'. * Other important issues. * Applicable 'Minimum Requirements'. * Relevant advice.	* DRASTIC: A standardized system for evaluating groundwater pollution potential, used by EPA (USA). * AquiRisk: A framework for modelling surface and ground water pollution-potential, using a source-pathway-sink component-based modelling approach.	This expert system uses current waste/population statistics and a given growth rate to estimate future annual waste loads transported to a landfill site, as well as the volume of landfill taken up by the accumulated, compacted waste. This information is presented as a table. Assuming available soil cover reserves are not a limiting factor at a site, the total air space taken up by landfill may be estimated.	An expert system which estimates comparative costs for a site regarding soil transport, refuse transport, other annual site running costs, and distributed capital costs, from data input by the user.	This expert system advises on the suitability of different types of soils for use at a landfill site, based on a sand-clay-silt content classification. The humus content and cation-exchange-capacity of soils are not addressed in this system.
These systems are used to present textual and pictorial information for back-up and educational purposes Besides the standalone information systems, Hypertext/ graphics information support forms part of every expert system.	These expert systems are designed to form the core of the total system, MuLaSSAS	These expert systems are designed to help in the assessment of relative impact weightings for surface water and groundwater resources for sites with similar geographic settings. Impact weightings are often used when ranking alternative sites.	Expert system may be used for determining the size-category of a landfill in (3.3), assuming on-site soil reserves are not a limiting factor. It may also be used prior to estimating annual refuse transport costs in (3.6).	Designed to be used to help in environmental benefit/cost studies, prior to ranking sites, in conjunction with expert systems in (3.4) and (3.5).	Designed to be used when estimating quantities of on-site soils which are suitable for landfill cover. Available soil reserves put a constraint on the maximum allowable volume of a landfill. This expert system is designed to be used alongside those in (3.3), (3.5) and (3.6).

Table 1: Tabulated outline of the software system, MuLaSSAS. (The numbers refer to subsections in Section 3: EXPERT-SYSTEMS APPLICATIONS.)

In this study, only the involvement of relevant parties is not addressed in any detail, although it is recognised as being important. Part of the reason for this has been the difficulty of deriving detailed guidelines suitable for software implementation, where these are not likely to change markedly in the immediate future. The other items are addressed in some detail, and the related guidelines are not expected to change much in the near future. The latter concepts, taken together, have been used to form a basic strategy for identifying and selecting landfill sites for permitting purposes.

Environmental impact assessment is by nature subjective, and the approach suggested in this document attempts to ensure that an optimum solution is sought, taking into account an impact assessment's subjective nature. It is believed that comparing a single site *with* a potential impact-producing activity to that same site *without* the activity is generally not as effective as comparing the *relative* impacts of alternative sites and options regarding that activity. Put another way, comparing relative impacts between two or more proposed sites and/or development options is generally more effective than comparing impacts for one site with, and then without, a proposed development. The following statement seems relevant "the comparison of multiple alternatives facilitates the derivation of an optimum solution".

A phased approach

A phased approach is considered suitable for incorporation into the site-selection strategy. The aim of this approach is to improve the efficiency of an investigation by narrowing the focus of attention at each successive step, onto an area most likely to produce viable solutions. At the first level a broad, shallow study is done. At the last level, at least one narrow, in-depth study is undertaken. If new information is revealed at any level, the option to return to a previous level should be made available.

Task-description categories

The following task-description categories for landfill siting are considered compatible with the above requirements. In **Diagram I** and **Diagram II** (Landfill Site-Scoping Flow-Chart) on the following pages, the colours green, blue and yellow refer to phases; red indicates exclusion from further study.

(i) Delimitation of search area

A desktop study is undertaken where existing information is utilized to identify possible areas or sites on a map. (This forms part of a feasibility study used to determine the breadth and depth of the next stage of the investigation.)

(ii) Identification and ranking of possible sites

Field visits and discussions with experts are carried out in order to identify suitable sites. The environmental costs and benefits of each site are then assessed. The sites are ranked and the most suitable ones selected as alternative sites for further study.

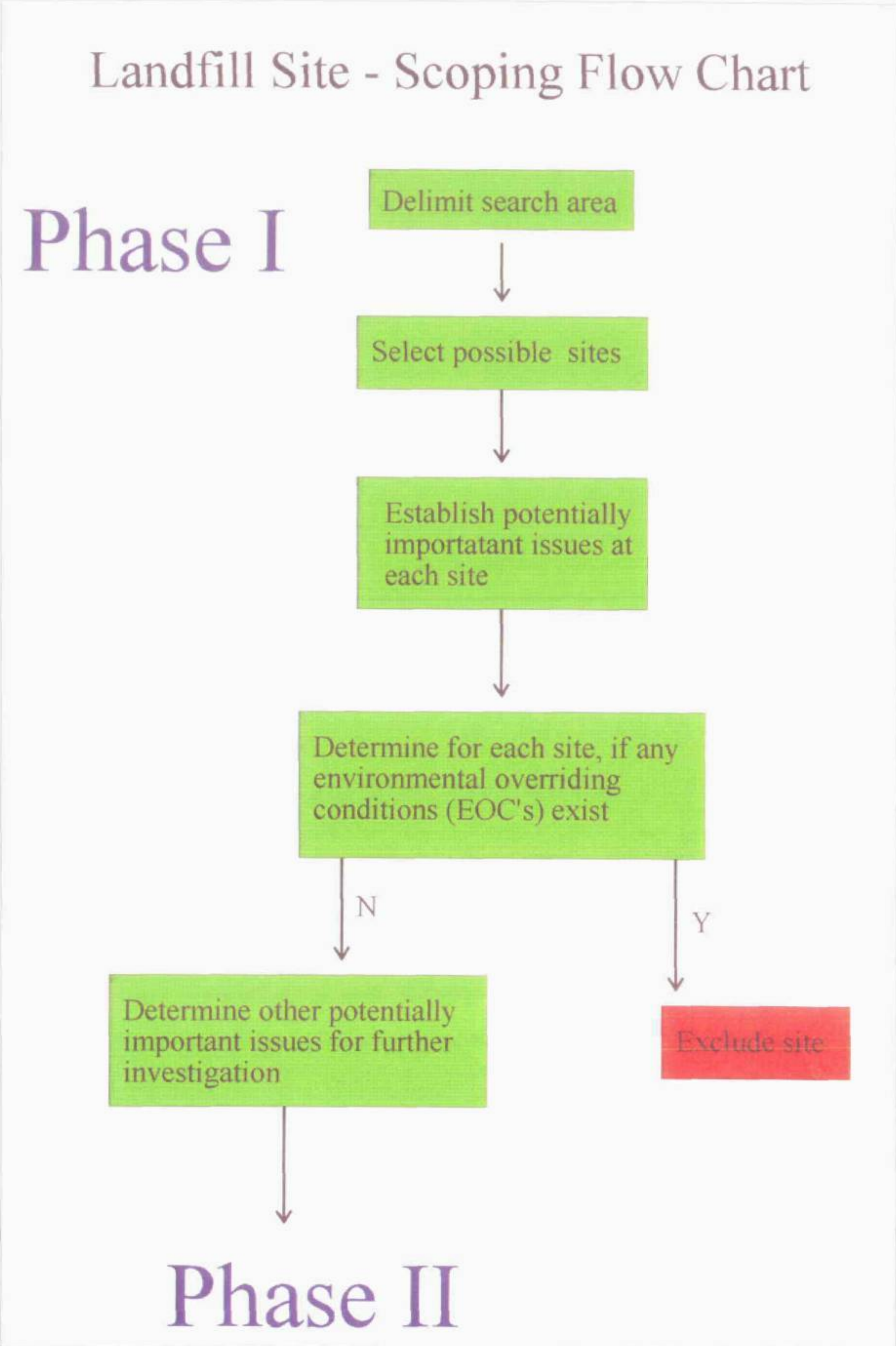


Diagram I Phase I : Landfill Site-Scoping Flow Chart

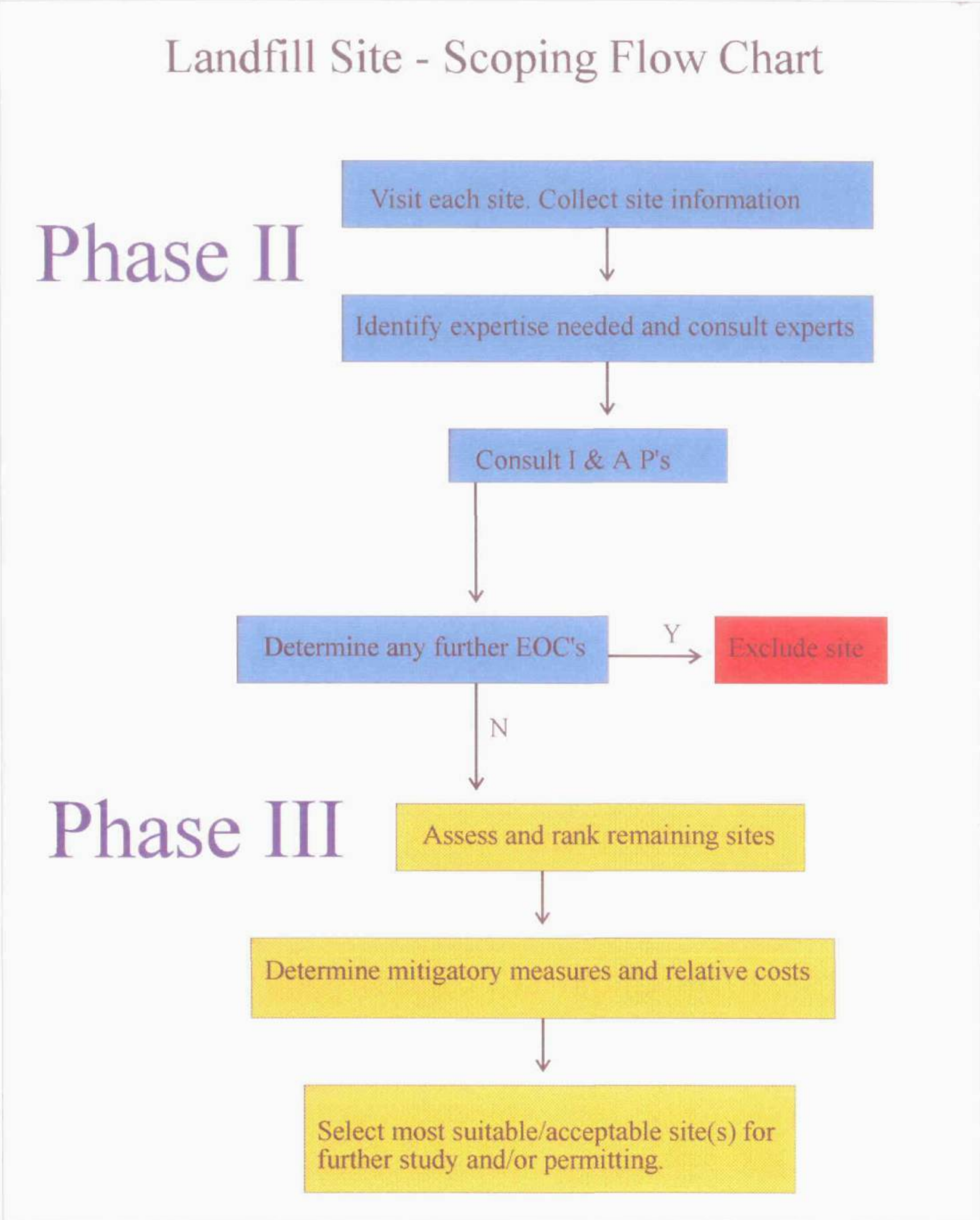


Diagram II Phases II & III : Landfill Site-Scoping Flow Chart

(iii) Determination of site-specific options and the selection of final candidate sites

Options for site-specific protective measures and landfill design are identified for the alternative sites. In conjunction with the client and affected parties, one or two final candidate sites are selected, together with their design/plan configurations and recommended protective measures, for a preliminary permit application study.

(iv) Preparation of a preliminary permit application

If problems with a selected site are revealed when a preliminary permit is being prepared or submitted, further options for that site could be considered, another candidate site may be selected, or guidelines for further investigation and/or reporting may be defined.

The above categories are expanded on and described in more detail later in the text.

1.3 Expert Systems

Expert systems are computer programs which are designed to utilize routine expertise for decision-support purposes. The aim of using expert systems in this project is twofold. First, to model the required expertise. Second, to make expertise of a routine nature readily available on computers, at reasonable cost, and to make it comprehensive yet concise. The project has demonstrated that expert systems facilitate the derivation and presentation of practical solutions to multi-disciplinary problems, where these involve both multiple criteria and multiple objectives. The development of effective computer-based decision-support-systems is expedited by the availability of different programming tools which are designed to be utilised together, within one software-development environment.

Expert systems have been developed as part of this project to :

- perform as modelling aids
- form a basis for computer-based decision support for decision-makers involved with identifying and selecting landfill sites.

Expert systems applications have been developed for the following tasks:

* To display context-sensitive text and some diagrams for information support purposes.
* To help identify a candidate site for a proposed landfill and to list the criteria, regulatory requirements and recommendations applicable to that site.

* To calculate comparative risk indices for an aquifer, based on the well-known DRASTIC method and on a derived, component-based framework named AQUIRISK.

* To help estimate landfill site capacity, assess comparative site costs and determine the suitability of site soils for a landfill.

In the following sections, the landfill site-selection strategy developed for this project, is discussed first. The expert-systems applications are considered next.

2 SITE IDENTIFICATION AND SELECTION.

Both the scoping guidelines and the phased investigatory approach are considered in the following detailed description of an approach for identifying and selecting potential landfill sites. The task-description categories described earlier are now explained in detail:

(i) Delimitation of search area

Given a delimited geographic area within which to select possible sites, identify 'no-go' sites or areas:

A general search-area is at first defined by socio-economic constraints. The type of landfill and its approximate design-size are determined. Within the search-area and with the aid of maps, orthophotos and reports, setback distances and land slope limits are used to define 'no-go' areas. Some of these constraints depend on the type and size of landfill in question. For the remaining areas, those topocadastral, geological and land-use features which represent 'Environmental Overriding Criteria' (EOC) are identified on the maps, on photographs and in reports. These are also used to define further 'no-go' areas. The scope of the search is now narrowed down to smaller, discrete areas suitable for site visits. (Note: sometimes it is preferable to consider proposed sites instead of areas within the general search-area.)

(ii)(a) Removing from consideration those sites with 'Environmental Overriding Criteria'.

Discussions are held with experts. The remaining sites/areas are visited and further information is gathered. Candidate sites are identified and checked against geohydrological, hydrological, soils, environmental, economic, zoning, land-use and site-access constraints. Some constraints take the form of measurable limits and some take the form of 'environmental overriding criteria' (EOC). Sites or areas which satisfy the required limits and for which no overriding criteria apply are selected for further assessment. If no sites/areas pass the tests then either more sites/areas must be considered or else in certain cases (in consultation with experts, the permitting authorities and third parties), set-back limits or overriding criteria could be relaxed with the idea that special investigations and protective measures will be required.

(ii)(b) Identification of other significant issues which do not have 'overriding criteria' status.

From the discussions with experts and during the field visits, potential problems are identified at the remaining sites. These are used to formulate the significant issues which need to be addressed in further study. Important criteria are then defined from these issues, both for assessment purposes and for identification of regulatory requirements and suitable protective measures.

(ii)(c) Comparative site assessment

Several methods are available for use in comparative site assessment. Amongst these are 'weighting-and-rating' index assessments (*), environmental benefit/cost or benefit/risk analyses (**) and impact-assessment matrices (***). These are discussed in further detail in what follows:

(*) Important criteria (see ii(b)) are weighted in terms of their importance in a regional or wider perspective. They are then rated according to their applicability at each site, on a comparative basis. For each criterion, the weighting is multiplied by its rated value. Then for each site, comparative indices are calculated as the sum of the products of the individual weights and ratings. The sites are ranked according to these indices.

(**) For each site, a checklist aid is used to identify applicable criteria. These criteria are then assessed comparatively in terms of their (relative) positive and negative aspects. Sites are then compared, in terms of overall comparative costs (including costs of any special investigations required), environmental risk and/or potential impact. Sites are then ranked according to the comparative assessments.

(***) Impact matrices may be used to help assess the comparative impact potential of sites. Matrices are presented as tables which are used to help identify and assess the impact potential of landfill components (design, pollution type and quantity, related activity, etc.) on environmental components (aquifer, birds, municipal water-supply, vegetation, adjacent residents, etc.). Sites are ranked in terms of overall comparative impact.

For these assessments, there exist useful comparative-evaluation techniques which utilize numeric matrix computational methods. One example is the Analytical Hierarchy Process (Saaty 1988), a weighting technique which uses pairwise comparisons between components. Details on the application of this process in the project are included in the appendix.

(ii)(d) At this stage, further key criteria and EOCs may become evident, and suitable mitigatory measures may be identified (see next section). Sites with EOCs are excluded from further consideration. Highly ranked sites are selected for further study.

(iii)(a) Incorporating protective measures.

Suitable protective (mitigatory) measures, design options and aspects requiring special investigation are identified for the highly-ranked sites. These sites, along with recommended protective measures and design options (keeping in mind the required special investigations), are now considered as alternatives. Further assessment of these alternatives may then be carried out.

(iii)(b) Site selection

One or two of the most suitable sites together with their design options and mitigatory measures are selected for a preliminary permit application study. The selection is done in consultation with the client, the permitting authorities and other affected parties.

(iv) Preliminary permit application and specifications for further investigation.

This involves the drawing up of a report with current input and results, a preliminary environmental impact control report (EICR), geohydrological report, engineering plan, a permit application document, etc. Recommendations for further impact investigations are defined at this stage, in consultation with the permitting authority.

3 EXPERT-SYSTEMS APPLICATIONS

Proper landfill site-selection, incorporating environmental principles, can be complex. Part of the complexity may be attributed to the fact that decisions required for wise environmental management and planning must be based on qualitative and quantitative data as well as experts' accumulated experience (Richey, 1985).
Expert systems provide a framework for modelling both qualitative and quantitative data as well as expertise and hence may be used to provide decision-support for environmental managers and planners. Expert systems are potentially useful tools for modelling and providing much-needed decision-support for those involved in site-selection studies, for the following reasons:

* They help to make the reasoning behind decision-making explicit and make the resulting decisions replicable (Armoni,1988);
* Besides modelling expertise, they may be used to model partial or conflicting information (Hayes-Roth, 1985);
* They can be used for numerical modelling, provided the tasks are not too large, and are able to integrate qualitative aspects into such models (Rykiel, 1989);
* They can address issues specifically relevant to a current context or goal, so helping to simplify complex tasks (Winston, 1984; Starfield and Bleloch, 1983);
* As modelling tools, expert systems help to formalise existing knowledge, thus capturing data for more efficient use (Armoni, 1988);
* They can reveal important gaps in current knowledge and also, loopholes in regulations (Murphy, 1989; Barr, 1990);
* They may be used as a basis for incremental development of larger, working, systems.

Of the nine expert-systems applications developed for this project, one is used to select and run seven others, two have links to electronic text-reference systems, one uses weighting-and-rating methods for aquifer risk assessment purposes, two perform as computational tools, three use list-processing for regulatory interpretation and advisory purposes, and one accesses a computer database file. These are addressed in a bit more detail in the text. Other comparative environmental-impact assessment methodologies suitable for landfill sites, such as pair-wise weighting-and-rating, environmental cost-benefit analyses and various types of matrix assessment, are not incorporated into any expert systems (although they are potentially suitable).

The expert-systems applications are described as follows:

3.1 The Selection-Control Expert System

This expert system is designed to call up the other expert systems, and has links to an electronic text system with some pictorial displays. The first screen displayed is used to present a general introduction to the software system. The Task-Selection screen, which follows next, displays a menu of task items from which one may be selected (See **Figure 1**). Access to a description of a recommended approach to site-selection is enabled here. **Figure 1** shows the typical format of a screen used to request data. The top half is used to present background information on the question, the question itself is presented in red text along the line at centre, and the bottom part of the screen is used for the answer(s). In **Figure 1**, the menu item information is highlighted, and adjacent to it, on the right, appears explanatory text on the type of information that may be accessed. The following sections (except for the last) address the list of menu items shown in **Figure 1**.

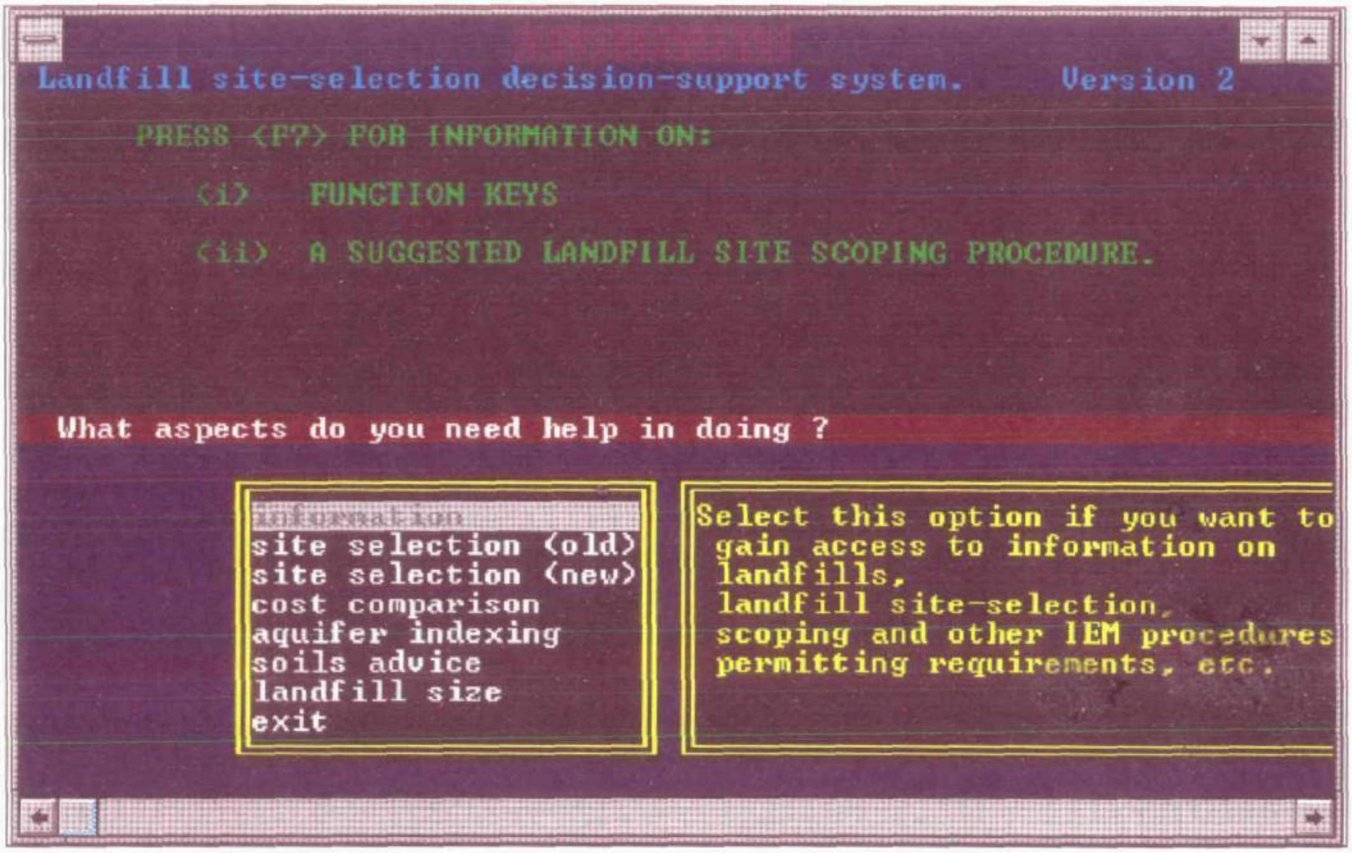


Figure 1 Selection of a menu item from the list of programs.

3.2 Hypertext Information Systems

The expert-systems software include electronic text-reference (hypertext) systems. Some pictorial information is also available. There are two stand-alone information systems. One is accessed by selecting 'Information' at the task-selection screen, and the other is accessed via the introductory screen for the aquifer-index evaluation expert system. The former is now discussed.

Two options are presented on selecting 'Information':

1) Access some of the textual information in this user guidelines document.

2) Access a hypertext system containing textual and graphics information relating to landfill siting in the 'Draft X Minimum Requirements' report.

As all the hypertext user support in the suite of expert-systems software is accessed in ways similar to that of the 'Draft X' report, the latter system will now be described in some detail.

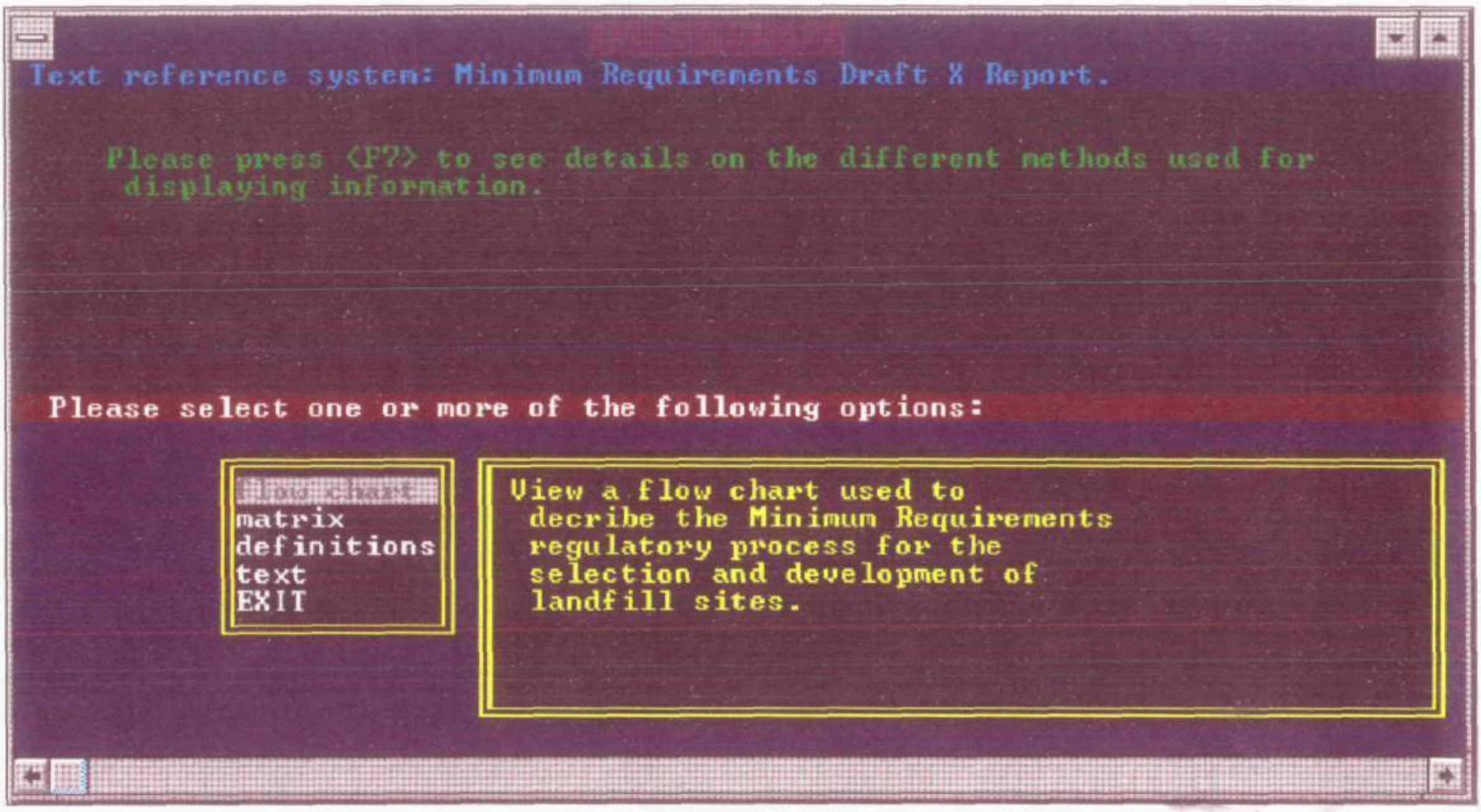


Figure 2 Text reference system: Minimum Requirements Draft X report.

Text reference system: Minimum Requirements Draft X Report.

Referring to **Figure 2**, we now discuss the list of menu options:

The first two options call up a graphics file viewer to display diagrams. If flow chart is selected then the landfill site permit-application procedure is displayed as a flow-chart. If matrix is selected, an example of an Environmental Impact Assessment matrix is displayed.

The third option reveals a screen with words and phrases organised into two columns. Each word or phrase is linked to a description or definition of the word or phrase which can be viewed in a 'pop-up' window by pressing a function key (See **Figure 3** on the next page). The text is encoded in the system and so cannot be changed by third parties.

Figure 3 A list of important words and phrases.

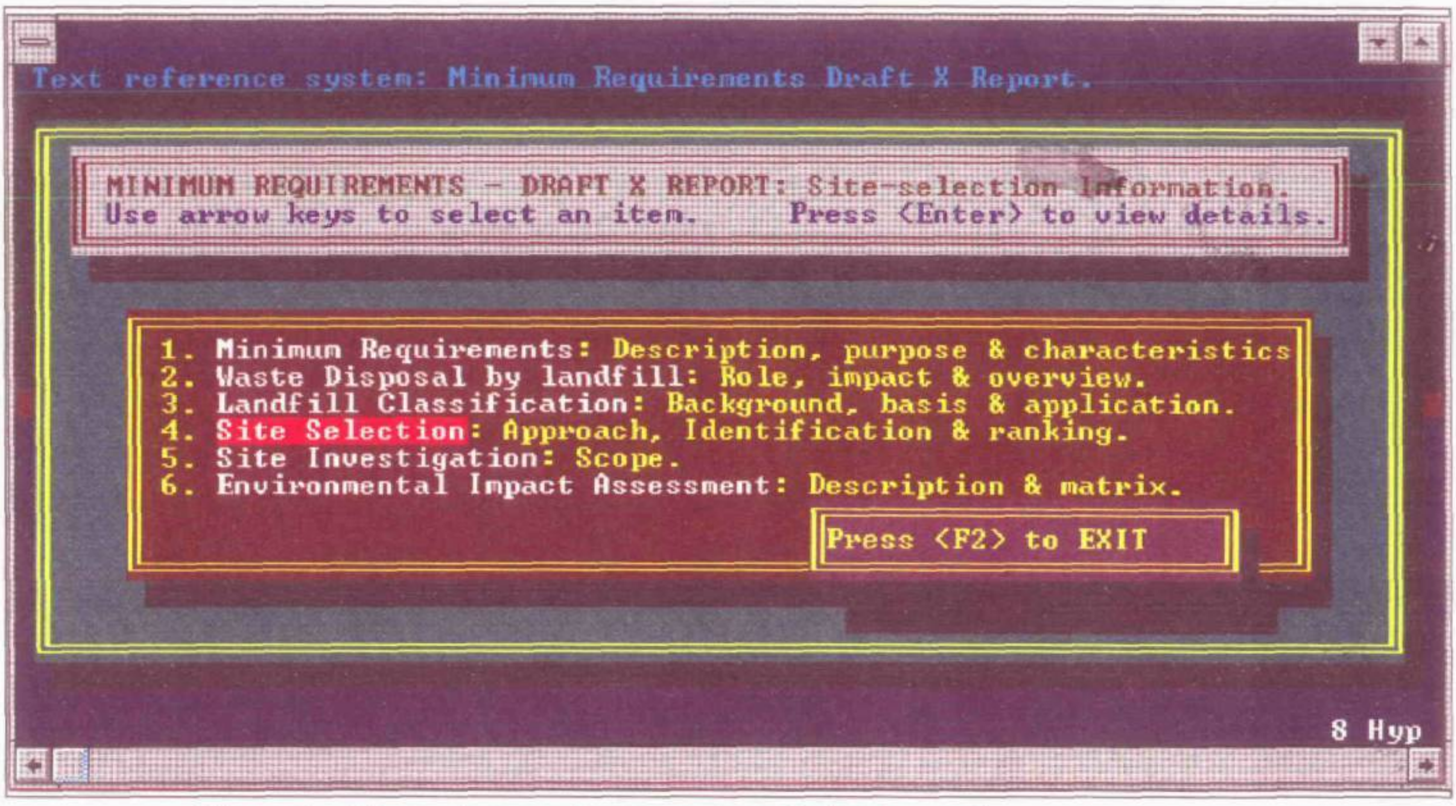


Figure 4 Electronic text reference system: 1st level menu items.

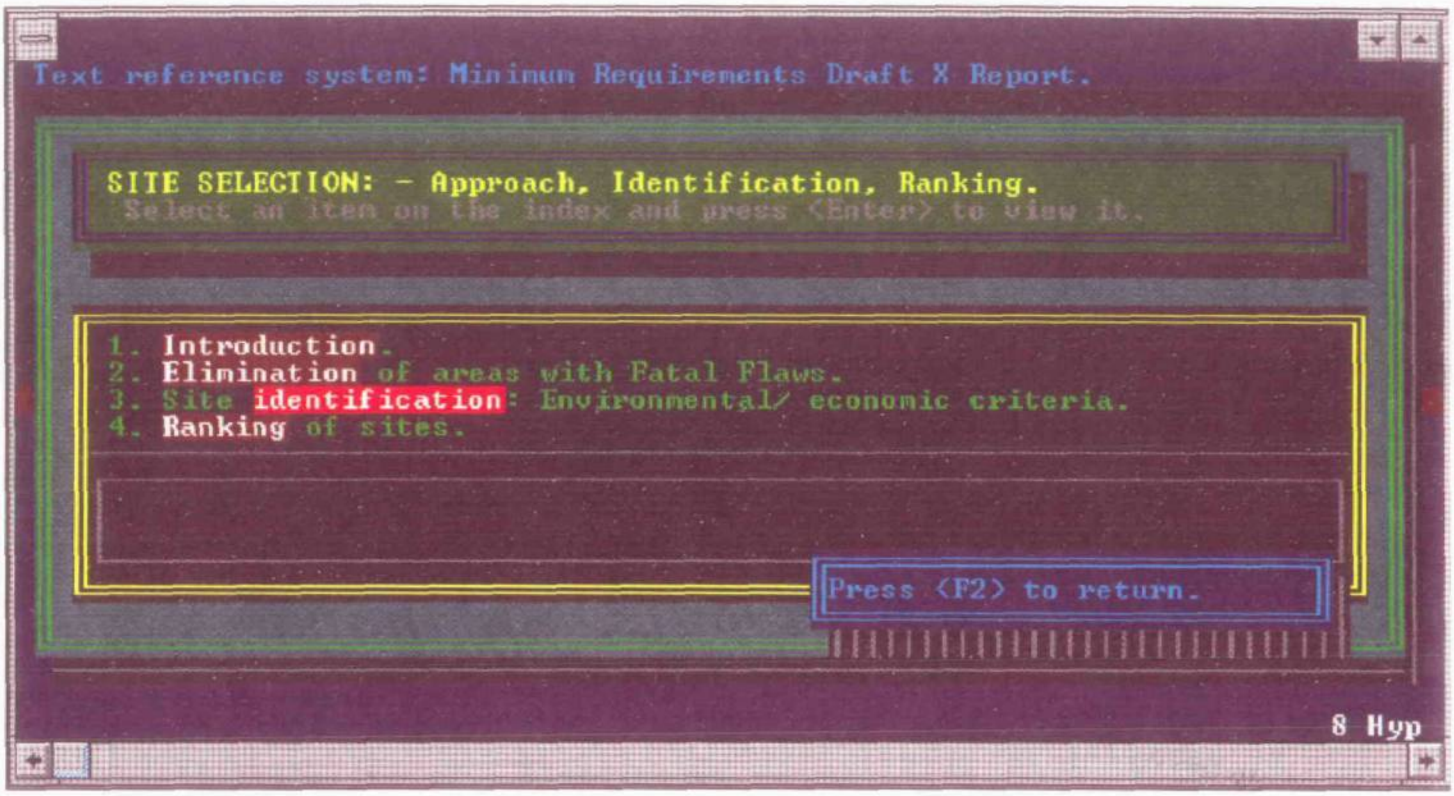


Figure 5 Electronic text reference system: 2nd-level menu items.

The fourth option reveals a screen which is linked to other screens, forming a tree-hierarchy network. The lowest level screens are linked to text files stored on the computer hard drive, which are displayed when the screens are accessed. **Figure 4** (previous page) shows the highest-level screen with menu items. When a menu item is selected (e.g. site-selection), a screen is displayed with another list of items for selection (see **Figure 5**, above). On selecting one of these items (e.g. site identification) an associated text file is then displayed which can be viewed one section at a time.

3.3 Landfill Site-Selection Expert Systems

The site-selection expert systems are designed to identify 'environmental overriding criteria' (EOC) and other important criteria, and to present mitigatory measures, regulatory requirements and recommendations for further investigations. **Diagram III**, entitled 'Landfill Site-Selection Advisor Decision Flow Chart' depicts the decision process used to select possible landfill sites (see next page). The colours green, red, orange, yellow and brown are used to represent aspects relating to the input procedure (green), 'Fatal Flaws' (red), 'Critical Factors' (orange), important criteria not covered by regulations (yellow) and the output (brown).

The expert systems are designed to be used for steps (i), (ii)(a), (ii)(b), and (iii)(a) in the site-selection strategy. For step (ii)(c), site evaluation, they can be used to help identify "pros" and "cons". Where mention is made of a draft version of the 'Minimum Requirements', it is because the later documents were significantly different, thus recessitating modified software. Also, there was a need to have the software behave differently. The two software applications are examples which help illustrate the usefulness of expert systems. The two expert systems are designed to:

* identify a possible landfill site for a municipal-solid-waste landfill

* identify important criteria for a given site and present regulatory requirements, mitigatory measures and recommendations for further investigation

a) *Site Selection (old)*: Selection of candidate landfill sites using the 'checklist' approach

'Old' refers to an expert system which utilizes a simple 'checklist' of set-back distances and other criteria defined for landfill categories in the 'Minimum Requirements Draft VII' guidelines report. The expert system also addresses important criteria derived from other literature.

The program is designed to ask questions relating to minimum landfill separation distances from residential, commercial and industrial areas, public utilities, transport routes, airports, nature reserves, water bodies, boreholes, municipal water supplies and beaches. Questions include those needed to determine relevant issues relating to steepness of slope, insufficient and unsuitable soil-cover and high rainfall, amongst others.

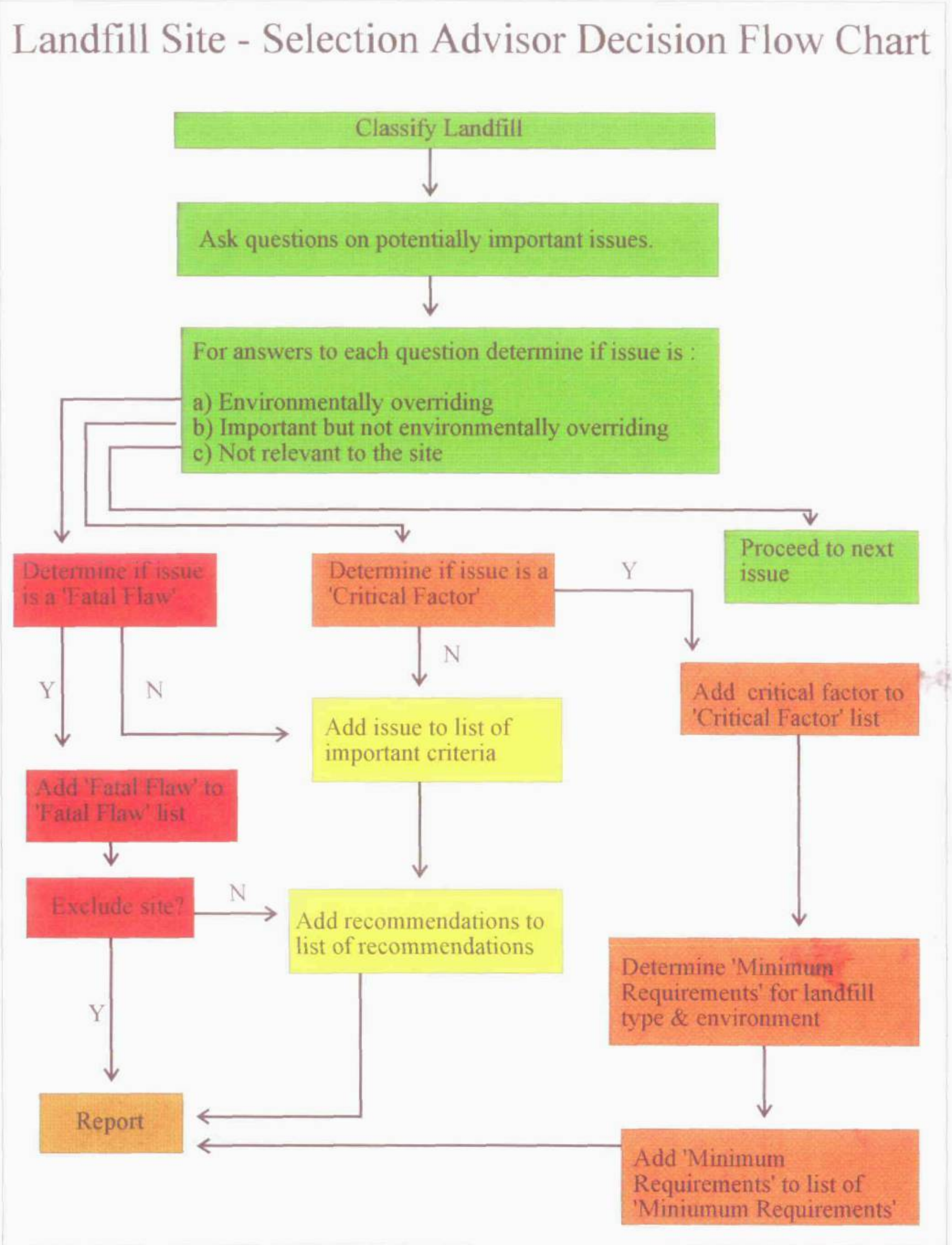


Diagram III Landfill Site-Selection Decision Flow Chart

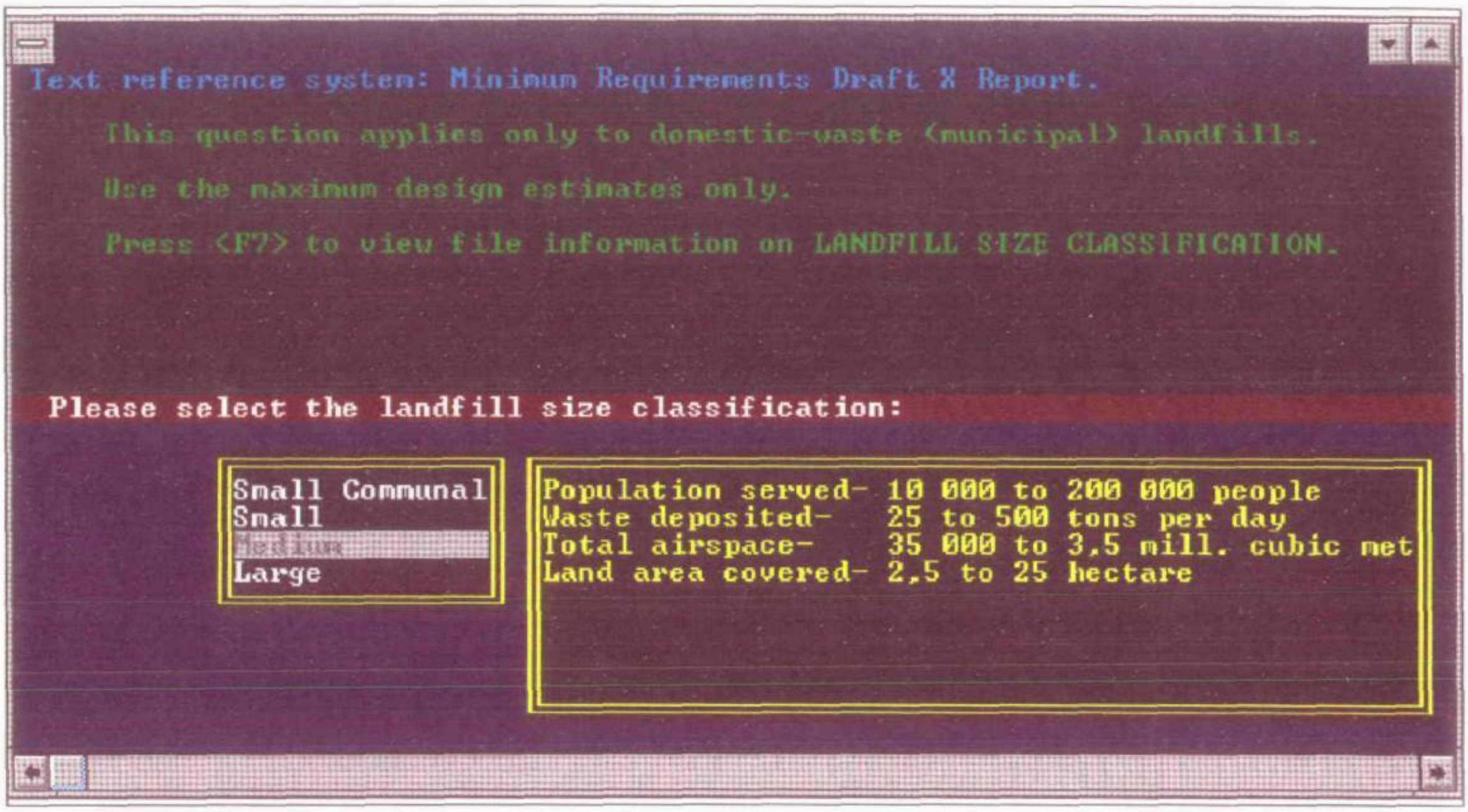


Figure 6 Screen showing menu-selection items for the landfill-size category.

Questions are first asked in order to establish the relevant landfill category (see **Figure 6**, above) and the host environment in line with the 'Draft VII Minimum Requirements' report (Department of Water Affairs and Forestry, 1992). The landfill category is used to determine what 'Minimum-Requirements' constraints are applicable to the landfill category in question. In order to facilitate use of the system, most of the ensuing questions are presented in a way that requires the selection of either 'yes' or 'no' items from a menu.

Answers to questions are used to determine what important criteria are applicable at a proposed site, and whether any of these represent 'environmental overriding criteria' (EOC). EOCs are criteria which are of such significance that the occurrence of one EOC at a site will cause the site to be excluded from further consideration. Other important criteria are used to determine the measures required for the design, planning and management of a site, as well as the need for specific investigations

Answers to questions will cause the expert system to ask other related questions, to present supporting information, and to identify applicable criteria, requirements and advice. If an EOC is identified, it gives the site an 'exclusion status' and at the end of the consultation it presents reasons for that status. At the end of a consultation the expert system does the following:

* It validates certain input items and provides warning messages to the screen.

* It shows whether the site is excluded or not.

* It lists the 'Draft Minimum Requirements' (from the 'Draft VII' report) for a landfill category in its surrounding environment, as well as some regulatory requirements applicable to the USA.

* It lists mitigatory measures applicable to each problem revealed.

* Finally it lists some recommendations, and asks if a printed report is required.

Although a landfill site may be excluded from further consideration, appropriate mitigatory measures and recommendations are still displayed. Decision aids for estimating landfill dimensions and lifespan are incorporated into the expert system. The user can access background information relating to a question by using function keys. Such information also includes pictures on landfill design.

If a printed report is required, the following will be printed out:

* Answers to the questions (user input).

* Exclusion list parameters (if any).

* List of Minimum Requirements .

* List of possible mitigatory measures/ recommendations.

b) *Site Selection (new)*: Selection of Candidate Landfill Sites Using The 'Categorized Checklist' Approach

'New' refers to an expert system which is a modification of the one described above. It incorporates changes which appear in the 'Draft IX' and the 'Draft X' 'Minimum Requirements' reports (Department of Water Affairs and Forestry, 1992/ 1993). Some of the simple yes/no answers of the earlier checklist program have been replaced with three or more choice options (a multiple choice question on slope steepness is presented in **Figure 7**, following page). In this program, criteria are categorized into aquifer, geology, hydrology, soils, natural environment, zoning, social, agricultural potential and (simple) topography. The order of the categories is dependent on the importance and number of important criteria in each. In this way, an attempt is made to address the more important issues at the outset of a consultation. This version is designed to address 'Fatal Flaws' as EOCs and 'Critical Factors' as other important criteria. 'Fatal Flaws' and 'Critical Factors' are EOCs and important criteria, respectively, which appear in the 'Draft IX' and 'Draft X' ' Minimum Requirements' reports (Department of Water Affairs and Forestry, 1992/ 1993).

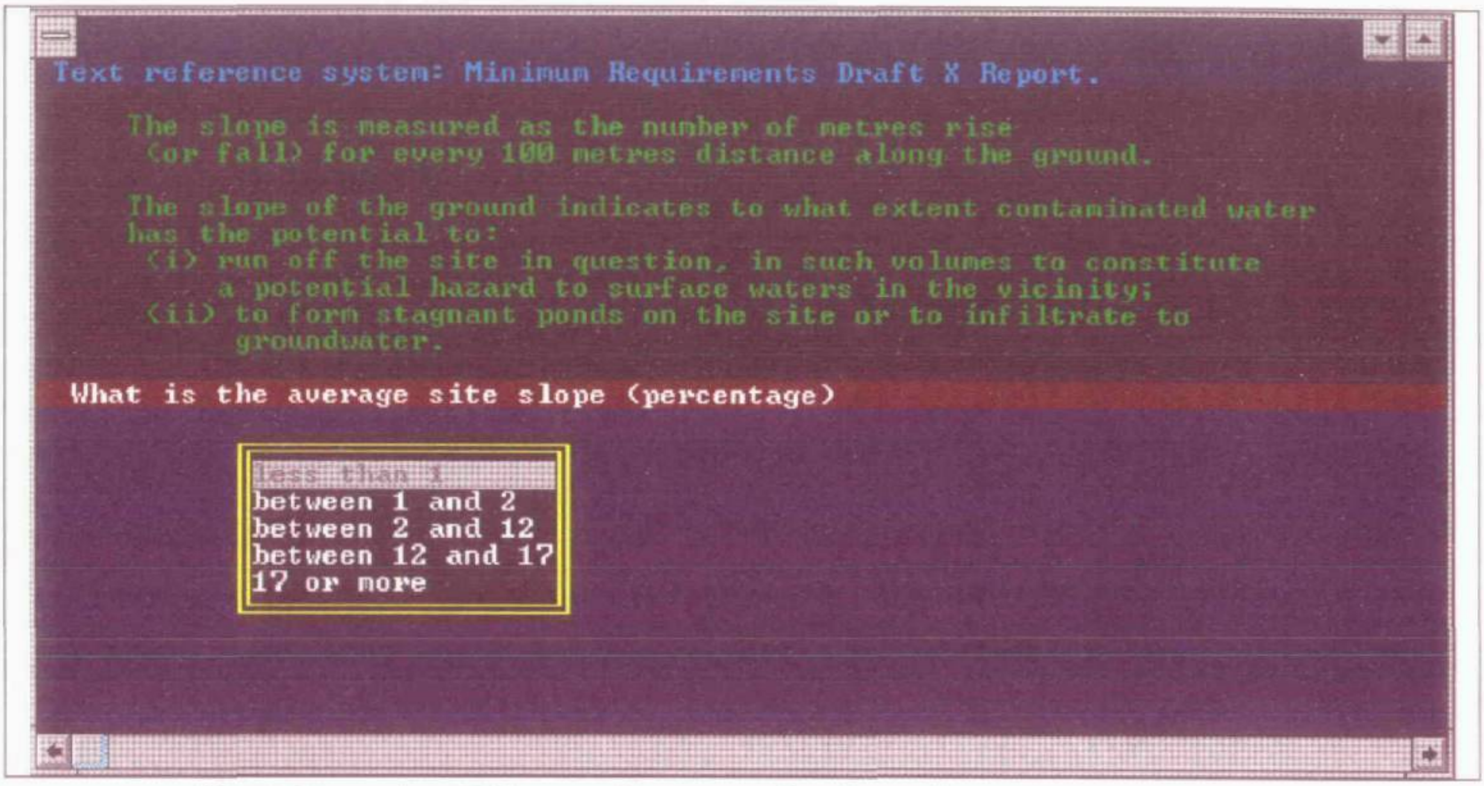


Figure 7 A multiple menu-item screen for slope value.
The first and last values relate to important criteria.

Other important criteria are considered separately in the program. The categories are ordered so that 'Fatal Flaws' are more likely to arise towards the beginning of a consultation than towards the end of it. When a 'Fatal Flaw' is relevant for a site in a category, an option is presented to the user allowing him/her to see a display of the currently-applicable 'Fatal Flaws' and 'Critical Factors'. At this point, the user can stop the consultation and proceed immediately to the screens containing the results (see as examples, **Figure 8** and **Figure 9** on the next page).

In this program, only 'Fatal Flaws' are to be seen as exclusionary conditions for site-selection purposes. The option is left to the user to exit when a 'Fatal Flaw' is revealed. 'Critical Factors' include potential 'Fatal Flaws' which do not cause a site to be excluded as a candidate site. 'Critical Factors', EOCs other than 'Fatal Flaws', and other important criteria are associated both with requirements for further investigation and with relevant mitigatory measures. Those that appear in the 'Draft IX' and 'Draft X' reports are listed as 'Site-specific Minimum Requirements' (see **Figure 8**). Other criteria, which do not appear in the draft reports, are listed in the screen entitled 'Other key issues/criteria' (see **Figure 9**), and the associated recommendations for further investigations and mitigatory measures appear in a screen entitled 'Advice applicable to other key issues/criteria'.

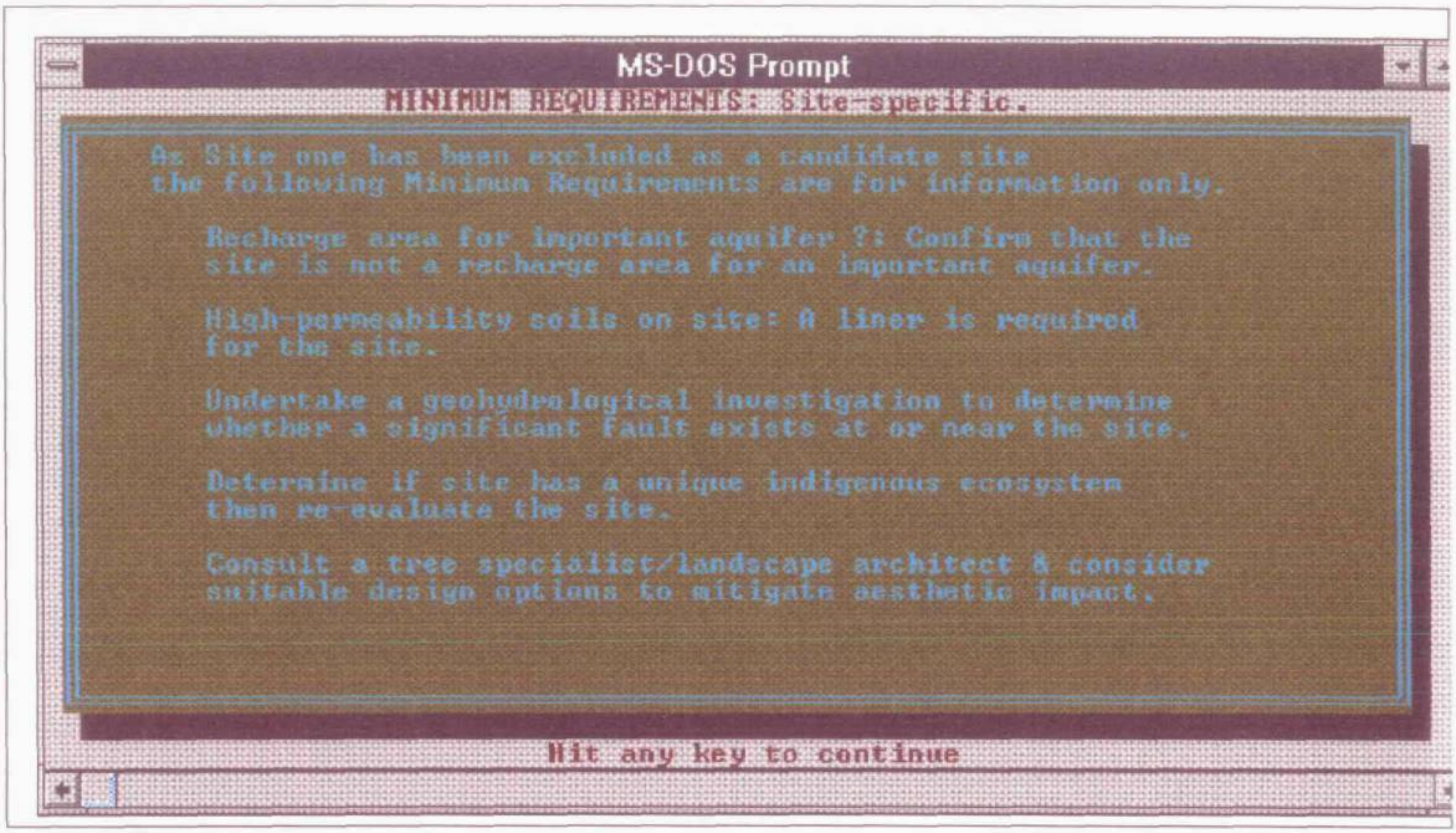


Figure 8 Site-specific Minimum Requirements.

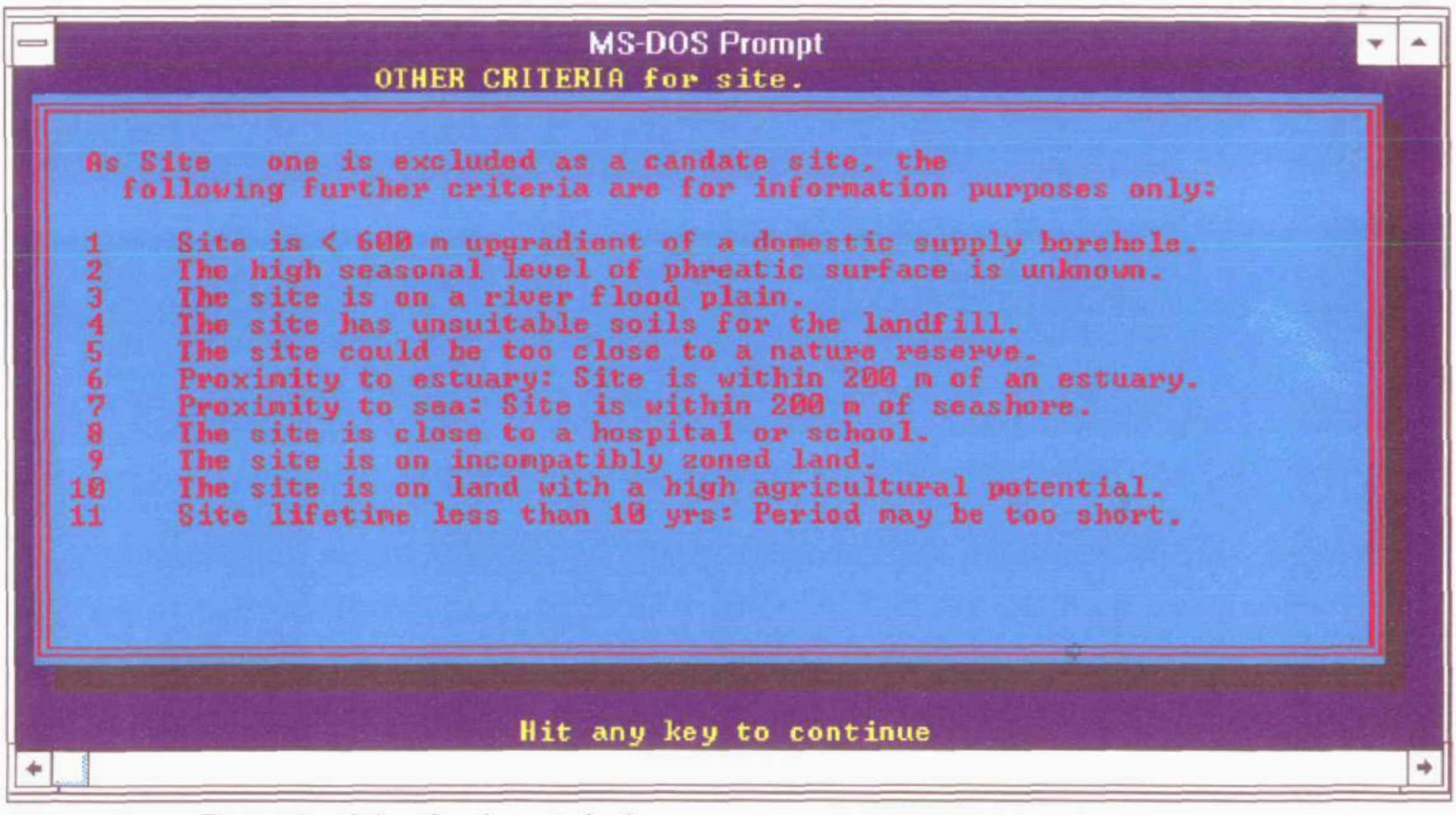


Figure 9 Other key issues/criteria

3.4 Aquifer and Surface Water Vulnerability Index Assessment

Weighting and rating techniques

Several weighting and rating methodologies for aquifer hazard assessment exist in the literature, each with slightly different objectives and different levels of precision. Most use summation formulae of the type:

$$\text{Impact Index} = A1*B1 + A2*B2 + A3*B3 + \ldots + An*Bn$$

Where A1, A2, etc. are importance weightings assigned by the experts who were involved in developing the formula, and B1, B2,etc. are ratings assigned for a site by the specialist involved in assessing different sites. Although such formulae are aimed at removing personal bias in evaluating sites, they are usually developed for specific situations or settings. If they are applied outside these boundaries, then the investigator needs to be aware of the errors or bias that could result. These formulae are usually intended to be used for site comparison purposes, and are especially suited for sites within similar geographic, meteorologic, socio-economic, geohydrologic and other contexts. An example of a such a system developed for aquifer sensitivity studies is DRASTIC (Aller et al, 1987) .

In order to model impact weight-assessment problems effectively, methods that combine factor weights and ratings into a composite value need to take into account the interactions between components represented by the factors. This is especially relevant if these methods are to be applied outside the domain for which they were originally developed. Summation formulae of the kind above often do not take into account the interaction between the components represented by factors in the formula. If the components are mutually independent of one another, then each one's contribution to a potential-impact weight is independent of the others, and the resultant weight may effectively be estimated using a summation formula (including 'absolute-value' vector summation: i.e: the square root of the sum of the squares of values). On the other hand, if any component is totally dependent on another, then the contribution of the representative factor of the latter to a potential-impact weight should be in proportion to that of the former. For these two factors, a product formula is more relevant than a summation formula.

The following example illustrates the effect of linearly dependent components on an overall pollution-potential index:

> Assume the problem is considered as having four components: source, vadose-zone, aquifer and the affected environment. The impact of the source will be passed through the vadose zone and aquifer to the affected environment. If the vadose-zone media is changed so that its rated value is reduced by 50 %, then the effect of the reduction will be passed through the aquifer resulting in about a 50 % reduction in the pollution-potential index relating to the affected environment. Also, if the rating of the source

input is increased by 20 %, then there will be a similar increase in the pollution-potential index. Using this approach, the effect of an environmental overriding condition such as a significant fault at a site will be to increase the overall pollution-potential index in proportion to the rated effect of that overriding condition.

A method has been derived which is based on DRASTIC's weightings and ratings, but unlike DRASTIC, attempts to account for inter-dependence between components. The method, named AquiRisk, consists of composite summation and product formulae made up of components. The components are defined so as to model a 'source-pathway-sink' approach to impact-index assessment. For index-assessment purposes, the source is considered as one component, the pathway can be made up of one or more sequential components (eg. soil/vadose-zone, aquifer) and the sink is usually considered as one component (aquifer OR user, etc.). A component consists of a group of factors whose weight-and-rating products are combined together using a single operation, to give a component index. Component indices may be utilised as they are, or else may themselves be combined together to give an overall index (ie an index which describes the vulnerability of the sink component to a specific pollution source). For AquiRisk, component-based extensions have been developed to give an aquifer end-use pollution potential index and a surface-water pollution potential index .

DRASTIC

DRASTIC is designed to be used as a planning tool for assessing the relative vulnerability of aquifers to contamination from various sources of pollution located at the ground surface (Aller *et al* , 1987). The equation for determining the DRASTIC index is:

$$DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw = A.P.P.I.$$

where: A.P.P. I. is Aquifer Pollution Potential Index
r = rating
w = weight

A team of experts in the United States has evaluated the relative importance of DRASTIC factors with respect to each other. These are weights which range from 1 (least important) to 5 (most important):

Acronym	Feature	Weight
(D):	Depth to Water Table	5
(R):	Net Recharge	4
(A):	Aquifer Media	3
(S):	Soil Media	2
(T):	Topography	1
(I):	Impact of the Vadose Zone	5
(C):	Hydraulic Conductivity of the Aquifer	3

Each DRASTIC factor has a range, either of numeric categories, or else of significant media types in terms of the effect each has on the potential for pollution impact. Each category in a range is assigned a rating. A rating is a number between 1 and 10 . The factors D, R, S, T, and C have been assigned one unique value per category. Categories in A and in I have been assigned both a range of possible values per category and also a unique, 'typical' value. This allows the user to choose either the typical value or to choose from the range of possible values based on more specific knowledge.

AquiRisk

The expertise of many knowledgeable professional hydrogeologists in the United States has been incorporated into the DRASTIC system (Aller *et al*, 1987). A new rating framework, AquiRisk, has been designed to utilise the DRASTIC parameters and their weights by incorporating five of them directly into components in AquiRisk. For pollution potential index assessment purposes, AquiRisk parameters are grouped into source, pathway (ie vadose zone + soils) and sink components. Indices are calculated for each component.

For aquifer index assessment purposes, AquiRisk factors are designed to be comparable to those of DRASTIC. However AquiRisk contains two more factors than DRASTIC, namely, Soil Depth and Precipitation. (These factors attempt to account for climatic effects on aquifer recharge and for soil depth.) In an effort to make the other five factors in DRASTIC comparable to their counterparts in AquiRisk, the weight of Net Recharge in DRASTIC has been divided between Net Recharge and Precipitation in AquiRisk, and the weight of Depth to Water-table in DRASTIC was divided between Soil Depth and Vadose-zone depth in AquiRisk.

The factor Net Recharge in DRASTIC is included in both the source and the pathway components of AquiRisk. To accommodate for this, Net Recharge is re-defined to be only in the pathway component. The DRASTIC weighting has been split and re-allocated to new factors in the source component, as well as to the redefined factor Net Recharge. Further, the Depth to Aquifer factor weight has been split between newly defined 'soil-depth' and 'vadose-zone-depth' factors. Both these factors are in the pathway component. Except for Net Recharge and the new AquiRisk factors, all other parameter values are directly comparable to those of the original DRASTIC formula.

The primary purpose for categorising the original DRASTIC parameters is to establish the extent that the source, pathway and sink components contribute to the overall DRASTIC pollution index. This is an attempt to help identify in which components a major problem might lie.

Other components have been defined for AquiRisk:

* In place of the 'aquifer-as-a-sink' component, another one is designed to model the 'aquifer-as-a-pathway' to the user. The sink component is not the aquifer any more, but is now the end-user. Factors for end-user sensitivity in this component are currently not defined, but could be defined in the future. Factors in the new pathway component include distance-to-user, hydraulic gradient and aquifer media.

* A further component assigns an index to surface water pollution potential, based on meteorologic, slope and vegetation-cover factors. This component is independent of the others and, although it uses the precipitation and slope parameters of AquiRisk, it could be considered a stand-alone method. The parameter weights in this method need validation: for example, what importance weighting should slope have when compared to percentage vegetation cover regarding pollution transport to a river ?

Whereas DRASTIC assigns weights to aquifer depth, ground slope, net recharge, soil-media type, vadose-zone type, aquifer-media type and aquifer hydraulic-conductivity, AquiRisk assigns weights as follows:

* Aquifer pollution potential index: Besides the above factors (excluding aquifer depth) it also assigns weights for soil-depth, vadose-zone depth, rainfall and rainfall season.

* End-use pollution potential index: It assigns further weights for user-distance and aquifer hydraulic-gradient (needs validation).

* Surface water pollution potential index: As well as rainfall, it assigns weights to slope and vegetation cover (needs validation).

Points to bear in mind

When using DRASTIC or AquiRisk, the following should be remembered:

- the assumption is made of a landfill as a time-invariant pollution source

- the size and type of landfill does not vary between alternative sites

- the quality and importance of the aquifer is not considered

- the distance-to-user parameter weights in AquiRisk have not been evaluated

- the surface water parameter weights in AquiRisk have not been evaluated

- the division of the nett-recharge weighting parameter in DRASTIC in order to allocate part of it to the pollution source parameters in the AquiRisk formulations needs validation. The important parameter aquifer recharge is very difficult to estimate, as it is dependent on both climatic and geologic conditions.

- methods based on weighting-and-rating and similar 'lumped-parameter' models usually cannot be used to account for overriding conditions at a site.

- DRASTIC does not specifically take into account the depth of soil to the underlying consolidated material. The partitioning of the depth-to-water weighting in DRASTIC so as to give a weight to soil depth in AquiRisk therefore needs validation.

The aim of modifying DRASTIC components and adding new ones is not to establish a new weighting and rating method for immediate use, but to provide a framework so that current weightings and ratings can be easily replaced or modified to account for South African conditions. AquiRisk is not designed to be used alone, but rather in conjunction with DRASTIC. Also, neither DRASTIC or AquiRisk is intended to replace the need for expert investigation, but rather to act as tools to help experts in their decision-making.

The index-evaluation expert system

An expert system has been developed to model the DRASTIC and AQUIRISK index-evaluation methods.

Input data for DRASTIC and AQUIRISK consists of quantitative data (e.g. aquifer hydraulic conductivity) as well as qualitative data (e.g. aquifer media type). These are interpreted using sets of rules to give individual (numeric) ratings. Each rating is multiplied by a weighting. Summation and product formulae are used to combine the weighting-and-rating products to produce the DRASTIC and AquiRisk indices.

The consultation process

At the start of the consultation an introductory screen is used to allow the user to access an electronic text (hypertext) system (see **Figure 10**).

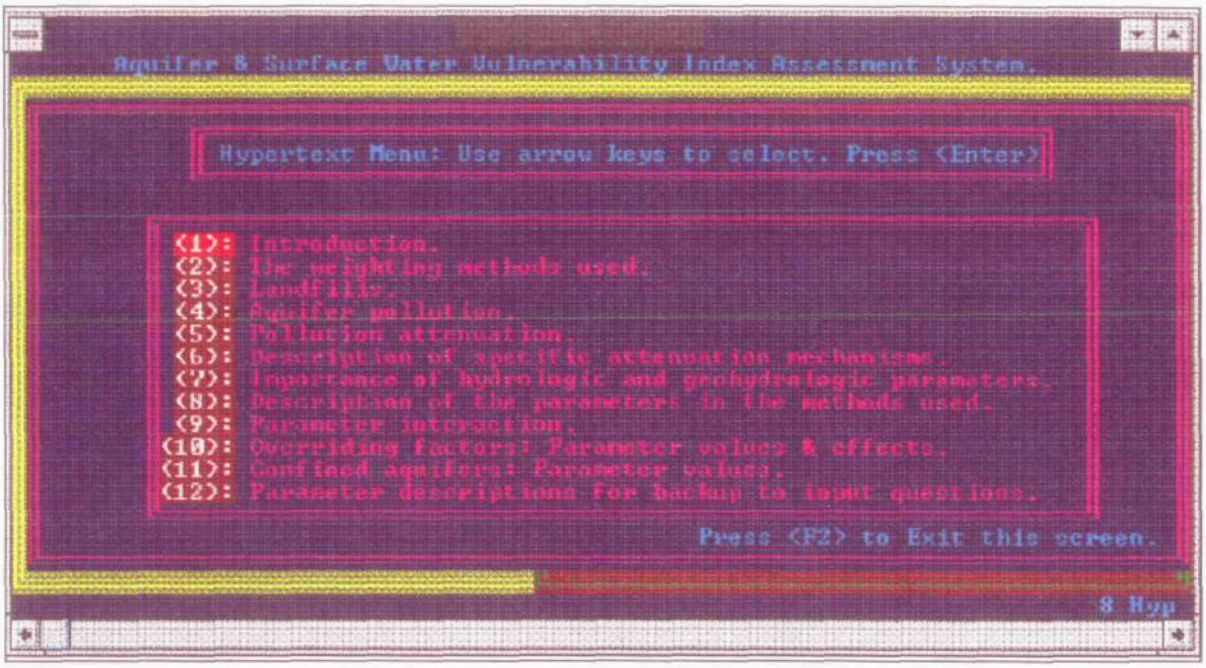


Figure 10 The introductory menu screen to the text-reference system

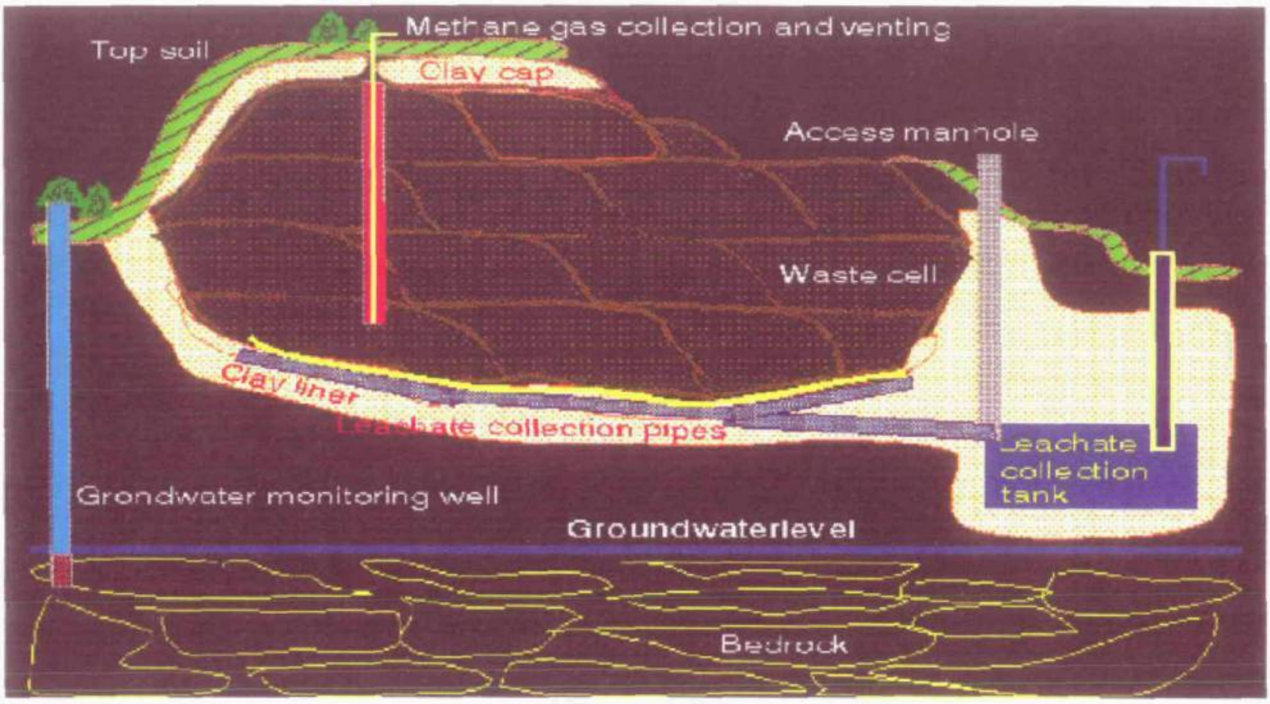


Figure 11 A diagram depicting a cross-section of a landfill.

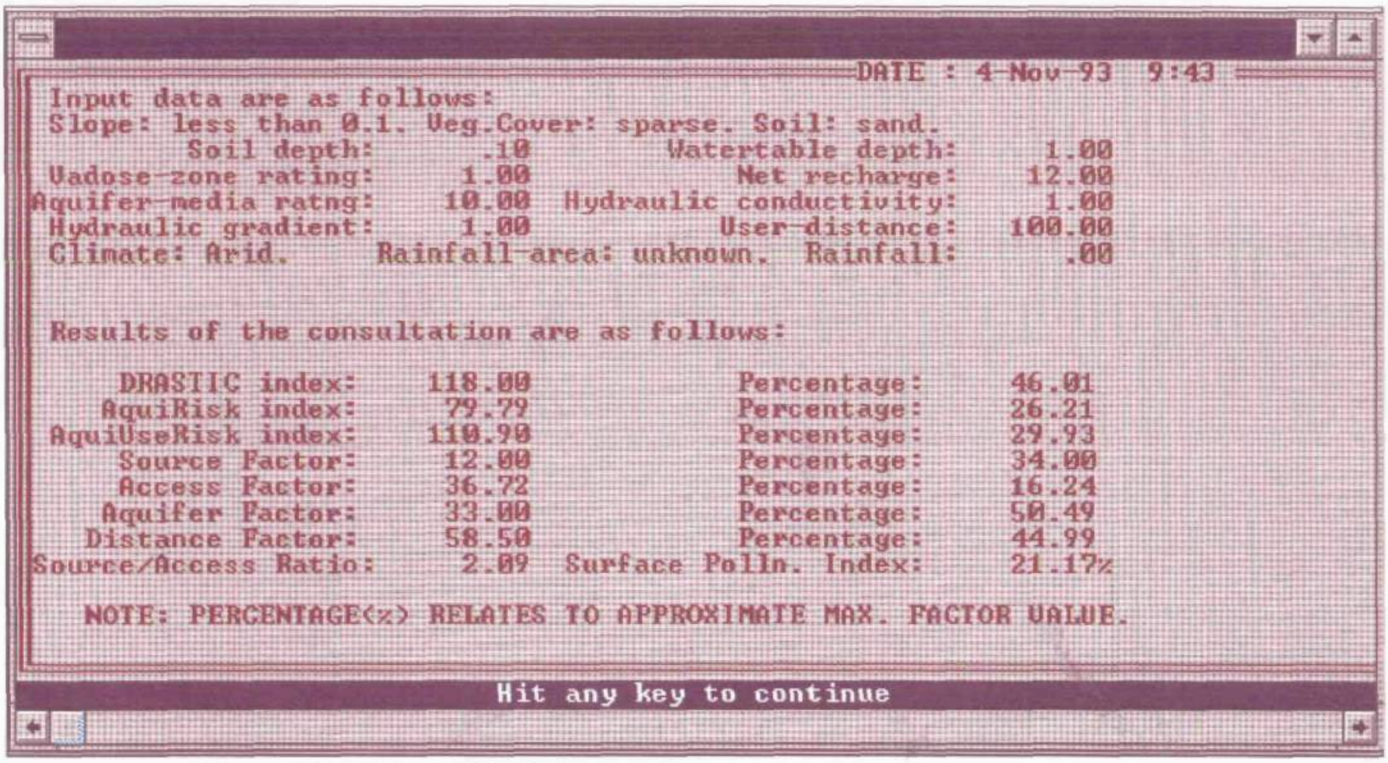


Figure 12 Vulnerability index summary screen.

Questions are presented to the user on consecutive screensduring the consultation. For each screen, back-up text for the question asked and for menu items is presented. Access to further backup text, to hypertext and, for some questions, to pictures is available (see **Figure 11** for an example).For very high or very low index values, the DRASTIC and AquiRisk indices are similar. For At the end of the consultation, the DRASTIC and AquiRisk indices and their percentage values are displayed (percentages shown are in terms of the maximum index value) (see **Figure 12**). intermediate values, the AquiRisk index is smaller than the DRASTIC index because of the use of products instead of sums for AquiRisk's pathway components. The 'end-user distance factor' and surface pollution index have not been validated and should not be used. The Source, Access and Aquifer 'factors' are displayed so that the user can see which components represent the greatest contribution to the potential pollution index.

3.5 Annual Waste Load and Landfill Volume Estimation Aid

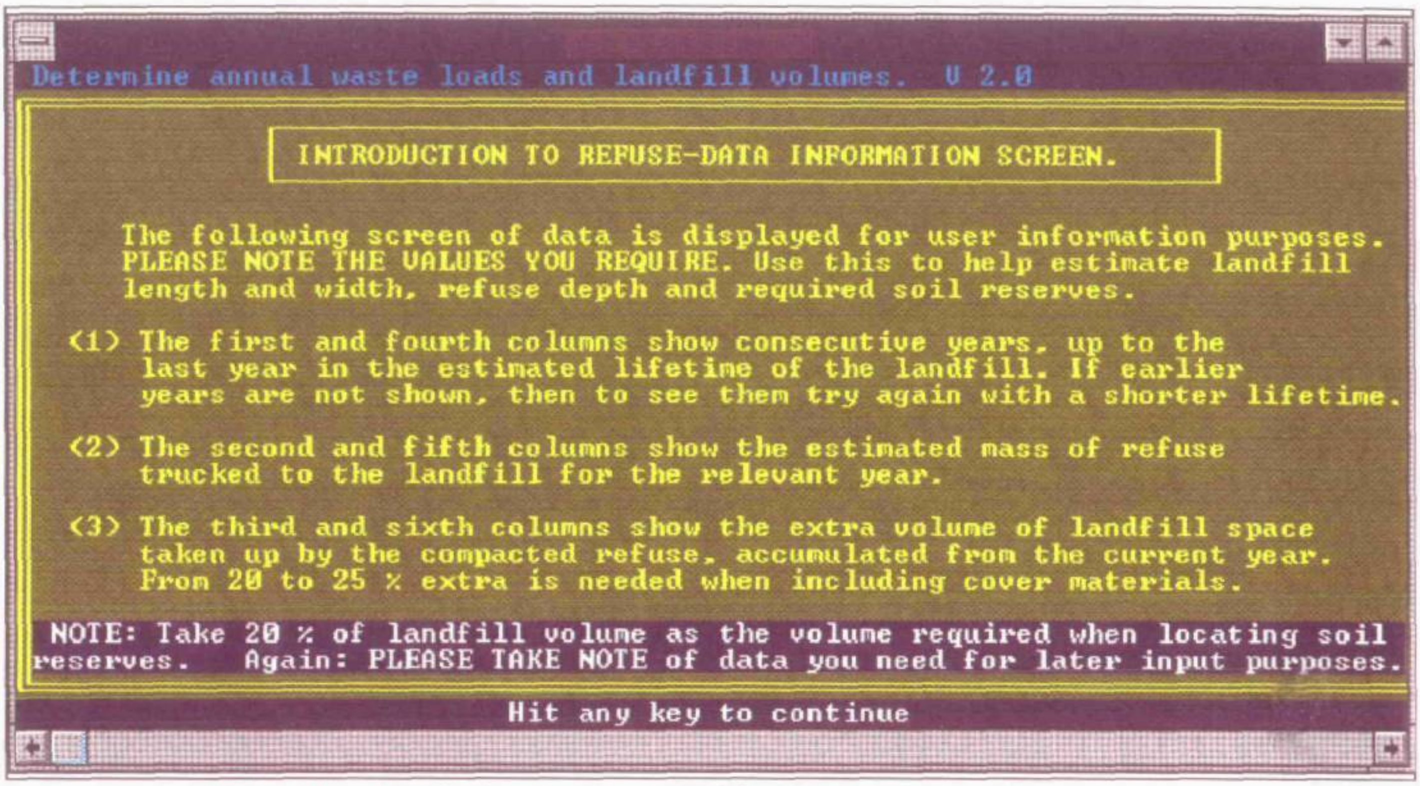
An expert system has been developed to form a decision-support tool which presents tabulated annual waste loads and accumulated volumes of compacted waste in a landfill, starting from the end of the current year as year 1. Results are presented in a table, showing the amount of solid waste transported to the site and the accumulated volume of compacted waste in the landfill for each year over a 36-year period in a landfill's operational life. Annual growth in waste volumes is estimated using a compound growth formula, given an estimated annual growth rate which is input by the user.

The consultation process

In order to calculate the required statistics, the expert system first asks for the density of the landfilled refuse. Next it asks whether mass, volume or population figures are available. If volume is selected, further questions on the type of trucks used are asked so as to estimate mass figures. Further questions asked relate to the expected percentage increase in waste and the expected landfill lifetime.

The penultimate screen is displayed for user information purposes. This reminds the user what data to take note of in the concluding refuse-quantification summary screen, and how to estimate the capacity of the site, in order to estimate the site's operational lifetime (see **Figure 13**). The final screen presents the tabulated data (see **Figure 14**).

(**Figure 13** and **Figure 14** appear on the next page.)



Determine annual waste loads and landfill volumes. V 2.0

INTRODUCTION TO REFUSE-DATA INFORMATION SCREEN.

The following screen of data is displayed for user information purposes. PLEASE NOTE THE VALUES YOU REQUIRE. Use this to help estimate landfill length and width, refuse depth and required soil reserves.

(1) The first and fourth columns show consecutive years, up to the last year in the estimated lifetime of the landfill. If earlier years are not shown, then to see them try again with a shorter lifetime.

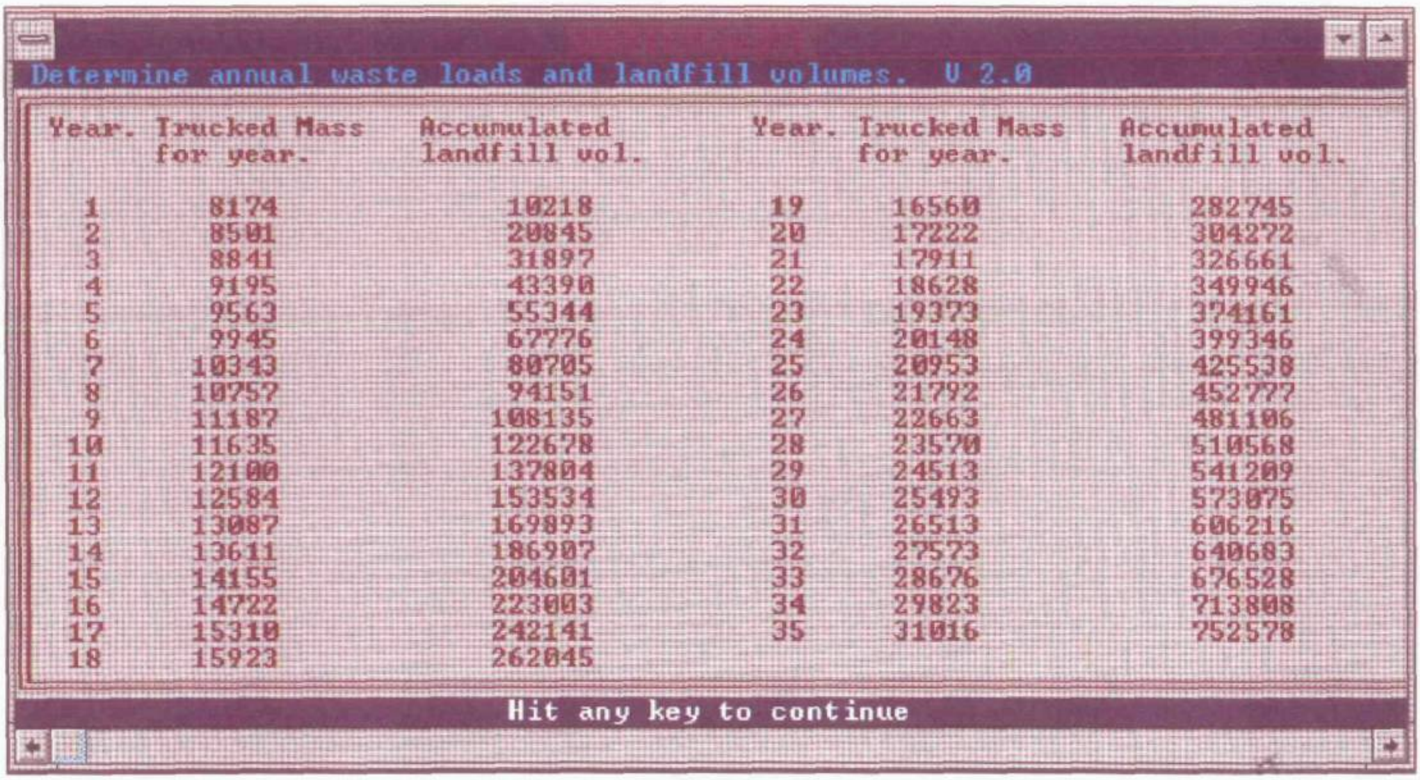
(2) The second and fifth columns show the estimated mass of refuse trucked to the landfill for the relevant year.

(3) The third and sixth columns show the extra volume of landfill space taken up by the compacted refuse, accumulated from the current year. From 20 to 25 % extra is needed when including cover materials.

NOTE: Take 20 % of landfill volume as the volume required when locating soil reserves. Again: PLEASE TAKE NOTE of data you need for later input purposes.

Hit any key to continue

Figure 13 Introduction to refuse-quantification summary screen.



Determine annual waste loads and landfill volumes. V 2.0

Year.	Trucked Mass for year.	Accumulated landfill vol.	Year.	Trucked Mass for year.	Accumulated landfill vol.
1	8174	10218	19	16560	282745
2	8501	20845	20	17222	304272
3	8841	31897	21	17911	326661
4	9195	43390	22	18628	349946
5	9563	55344	23	19373	374161
6	9945	67776	24	20148	399346
7	10343	80705	25	20953	425538
8	10757	94151	26	21792	452777
9	11187	108135	27	22663	481106
10	11635	122678	28	23570	510568
11	12100	137804	29	24513	541209
12	12584	153534	30	25493	573075
13	13087	169893	31	26513	606216
14	13611	186907	32	27573	640683
15	14155	204601	33	28676	676528
16	14722	223003	34	29823	713808
17	15310	242141	35	31016	752578
18	15923	262045			

Hit any key to continue

Figure 14 Refuse statistics summary.

3.6 Landfill Site-Cost Comparison Aid

In order to compare the relative costs of candidate landfill sites, it is often useful to select only those running costs and capital costs which differ significantly between sites. In the landfill site-cost comparison expert system, capital costs are distributed over the number of years of an item's useful life. These annual capital costs and the annual running costs are then summed over the different items for each site. Cost comparisons are then able to be made for different sites. The expert system developed as a comparative landfill-cost estimation tool is a simple prototype version only. Although it can be used to help estimate costs, it should be used from a feasibility-study perspective only. The following is a description of the program:

> Capital costs, running costs, the refuse transport volume, cover-soil haulage distance and landfill life-length at a site are required as input data. Capital costs are divided by the landfill life-length in years, and combined with annual costs. Site-comparative annual costs (based on 1991 rand values) are calculated for a site, and displayed.

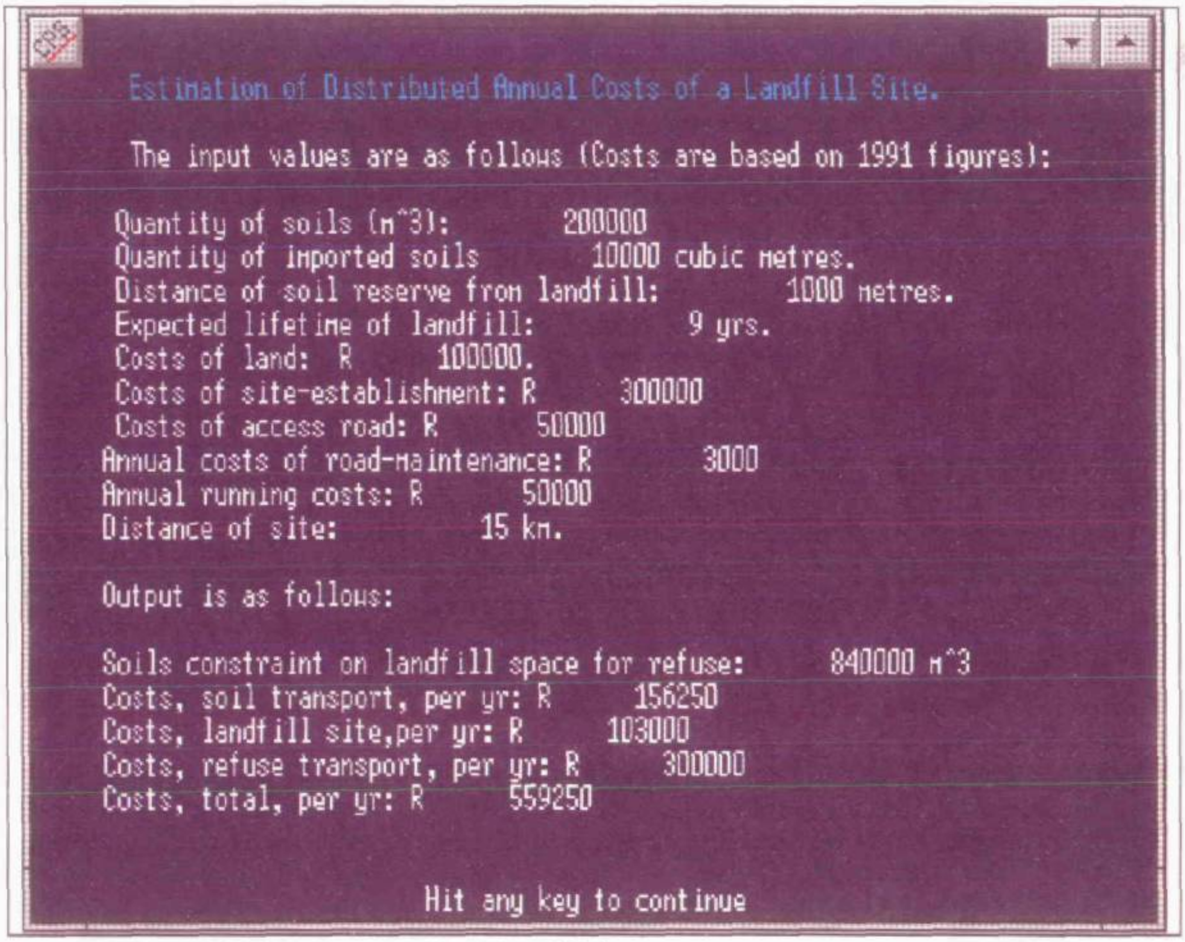


Figure 15 Relative costs for a landfill site.

The quantity of cover soils available for landfill cover purposes is used as a basis for estimating the maximum size of a landfill. Refuse generation figures and the expected annual increase in refuse production rates may be used to determine the number of years it takes to reach the maximum landfill size. The life-length of the landfill site is assumed to be not greater than this number. Other than the volume of available cover-soil reserves, a further constraint on maximum landfill size is the space available for a landfill (sufficient space must be allowed for a buffer-zone).

Sites may then be compared directly on a cost basis, where costs take into account site life-length, average distance of soil reserves from the landfill, cover-soil haulage costs, average distance that refuse has to be transported to the site, and refuse transport costs (using rands/cubic metre/km rates). The summarised data are shown on a screen. (see **Figure 15** on the previous for a typical layout)

The results shown in the lower part of **Figure 15** are:

* The maximum volume occupied by refuse in the landfill.

* The annual soil transport costs.

* Other costs, excluding refuse transport costs, on an annual basis.

* The annual refuse transport costs.

* The total annual costs.

3.7 On-Site Soils Suitability Advisor

The On-site Soils Suitability Advisor is an expert system which gives simple advice on the suitability of different types of soil for use on a landfill site. Soils are considered to be topsoils and subsoils, consisting of the O, A and B or G soil horizons according to the S.A. Binomial Soil Classification System (MacVicar et al, Dept. of Agricultural and Technical Services, 1977) but are not limited to 1,2 metres in depth. A soil's ability to attenuate landfill leachate is dependent in part on the type of clay present, the shrink/swell characteristics of that clay, and the soil's grain size, amongst others. Generally, the less the clay shrinks and swells and the smaller the grain size, the less the groundwater pollution potential is for such in-situ soils underlying landfill. The humus, calcium and iron content of the soils, as well as other aspects, are not addressed in the expert system.

The following categories are utilized:

* Weathered rock

* Non-shrinking clays which have a textural classification typified as: 15-55% silt, 27-40% clay, and 20-45% sand.

* Shrinking aggregated clays (montmorillonitic clays or smectites), which have similar content to non-shrinking clays, but which shrink or swell on drying or wetting.

* Clay loam has a textural classification typified as: 50-85% silt, 12-27% clay, and 0-50% sand.

* Silty loam is texturally classified as being : 25-50% silt, 7-27% clay, and 0-50% sand.

* Loam contains 0-50% silt, 0-20% clay, and 15-50% sand.

* Sands range in particle size from 0,06 mm to 2 mm. They are typically free of silts and clays.

* Gravel consists of particles greater than 2mm in size. Gravels typically contain mixtures of gravel, sand, silt and clay, large-sized particles being in preponderance.

Figure 16 and **Figure 17** on the next page show screens relating to on-site soils advice.

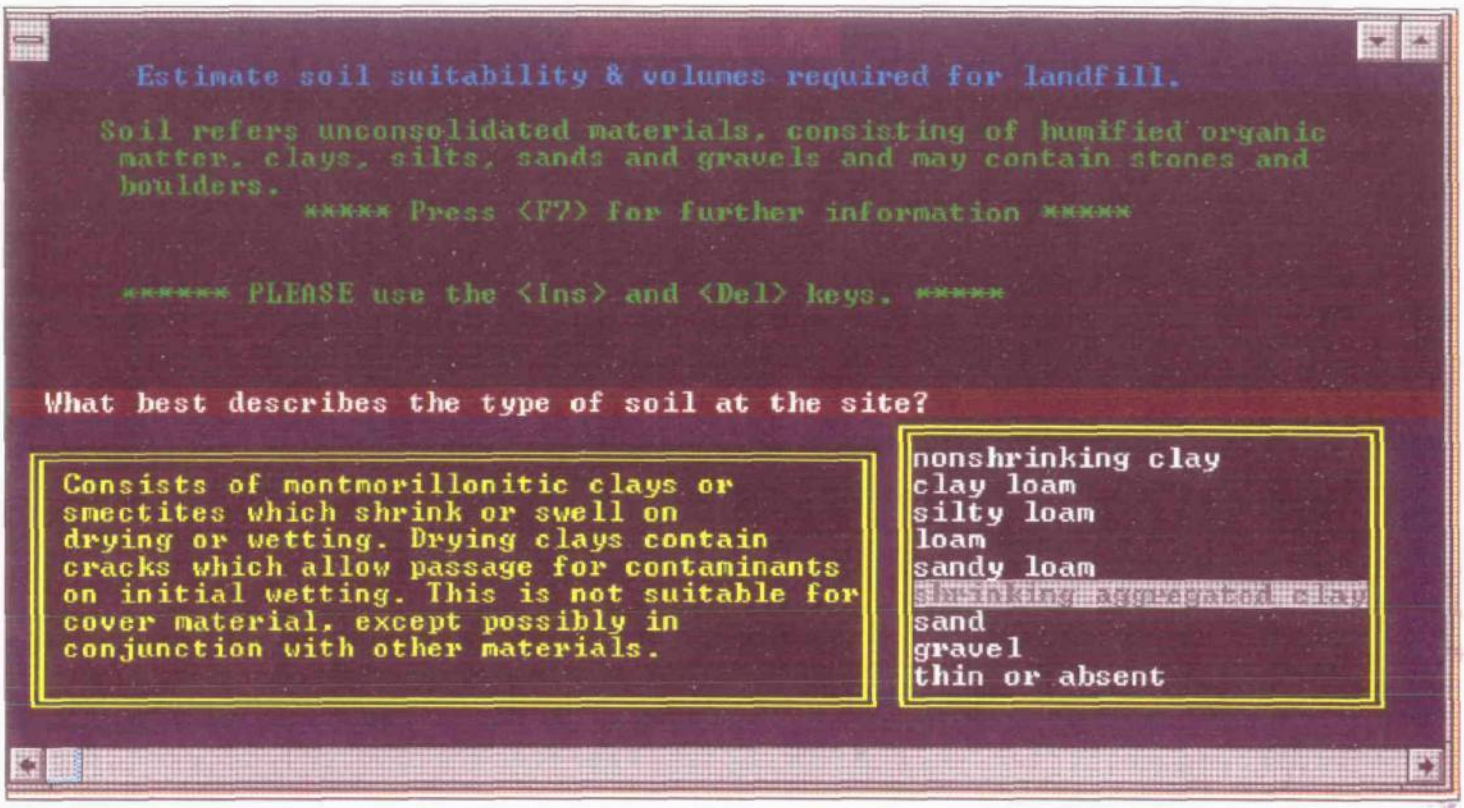


Figure 16 Multiple-item soil-type selection screen for on-site soils

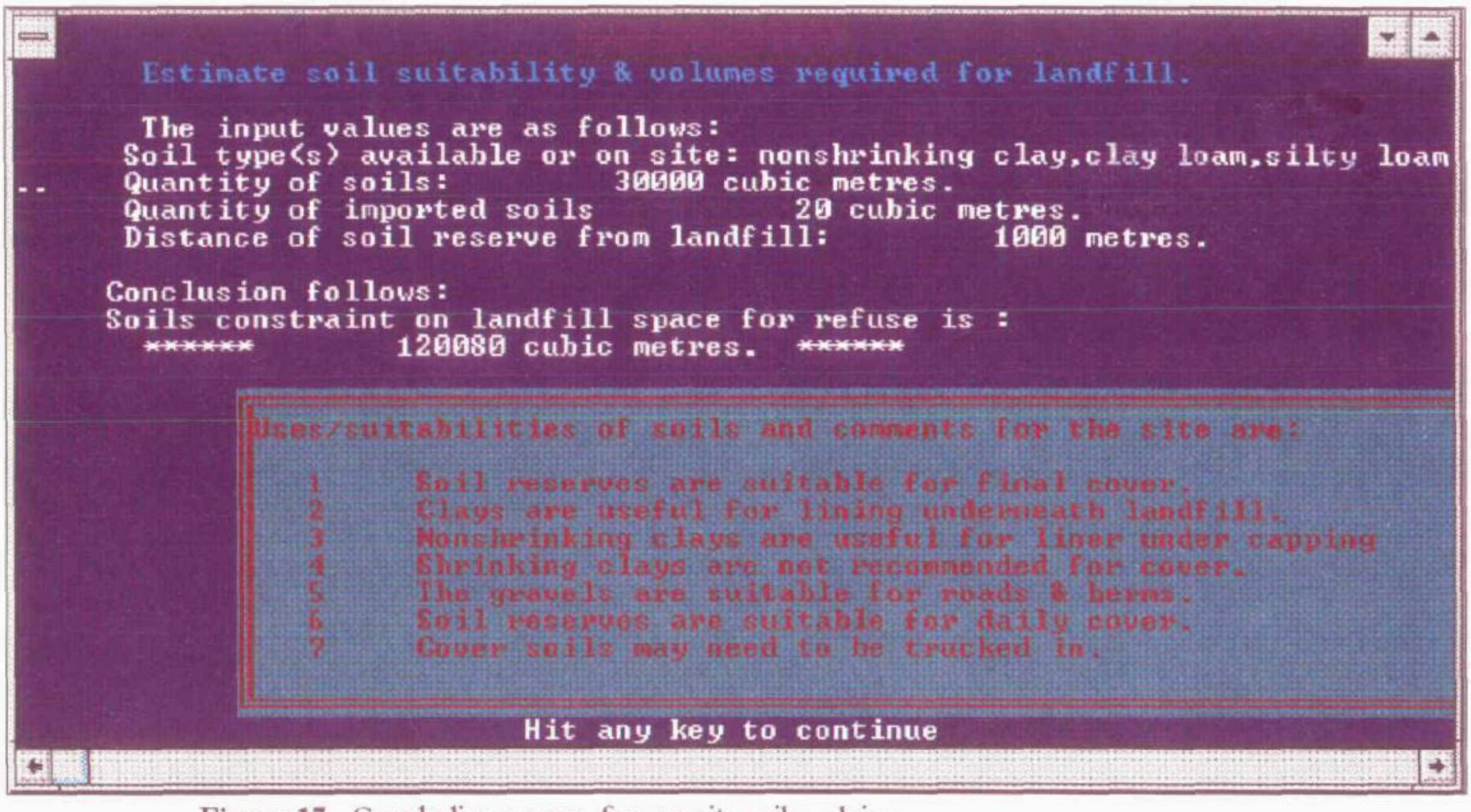


Figure 17 Concluding screen for on-site soils advice

3.8 Waste Database Access: Interpretation and Validation.

One of the tasks of this project was to develop a prototype expert system to establish the feasibility of accessing waste statistics from a database file similar to one in use at the Department of Water Affairs and Forestry for storing landfill-permit data. The aim was to determine what information could be accessed for interpretation and error checking by an expert system, and what useful new information could be passed from an expert system to a database file. The expert system, in its simple prototype form, currently retrieves items of information from a database file and presents the information on a screen shown as follows:

The following data has been read directly from the database file, WASTDISP.DBF:

YEAR is	1990	SITE_LIFE is	25
HOUSEH_QTY is	60000	GARDEN_QTY is	30768
RUBBLE_QTY is	79464	HOSPIT_QTY is	-1
INDUST_QTY is	8304	SLIMES_QTY is	-1
OREDIS_QTY is	-1	ROCDIS_QTY is	-1
POWASH_QTY is	-1	SEWAGE_QTY is	190
HAZARD_TOT is	80	CLAS03_QTY is	-1
CLAS04_QTY is	-1	CLAS05_QTY is	- 1
CLAS06_QTY is	-1	CLAS08_QTY is	-1
CLAS09_QTY is	-1	CLAS010_QTY is	-1
CLAS011_QTY is	-1	ALL_TOTAL is	184144

The expert system then asks if any data should be changed. If the user elects to change a specific data item, he/she can change the value, and the expert system then presents the modified list to the user and asks if these should be stored to the database file. If the user selects 'yes', the original record is overwritten with the latest values.

4 SUMMARY AND CONCLUSION

4.1 Objectives of the Study: The extent to which they were fulfilled:

The objectives are repeated here in italics, and the relevant comments follow:

a) *To determine suitable municipal solid-waste landfill site-selection and site-evaluation methodologies for South African conditions.*

This objective was addressed by considering available methodologies and approaches from the literature and using expert systems to model them. The Analytical Hierarchy Process (AHP) was assessed using a computer program (Expert Choice). Expertise and data gained from three landfill site-selection projects (at Upington, Grabouw and Kleinmond) helped to provide a basis to test the AHP, and to identify suitable methodologies and approaches for landfill site selection for use in terms of the impending 'Minimum Requirements' regulations and the recently published IEM scoping guidelines.
Most impact-assessment methodologies use a weighting and rating index-assessment approach, either through the use of simple summation formulae, or else through matrix-evaluation techniques. A widely-used pollution-vulnerability index-assessment method for aquifers, DRASTIC, was selected for investigation into the applicability of such an approach. As a result, a modified component-based procedure was developed which can be used together with DRASTIC.

b) *To draw up guidelines for landfill site-selection and evaluation, which will help determine suitable management alternatives and regulatory requirements for the establishment of landfill, taking into account integrated environmental management principles and pollution-prevention measures.*

Guidelines, derived from overseas literature and including the proposed draft 'Minimum Requirements' regulations have been incorporated into an expert system. These guidelines address both site selection and site valuation A suitable IEM-Scoping approach, compatible with these guidelines, has been drawn up.

c) *To determine to what extent expert systems (special computer programs) can be used to:*

- *help model a suitable framework for a landfill-site-selection decision-support system,*

- *form the final, working, computer-based decision-support system.*

Expert systems have been shown to be highly suitable to model typical decision-making processes, including those which incorporate functional aspects, which relate to landfill site-selection. These models often form a suitable base for the development of full-scale decision-support tools.

The goals defined for the study are considered to have been achieved.

4.2 Summary of Task-Goals and Related Findings

Task-goal summary and related findings follow:

i) A landfill-site identification, selection and evaluation strategy for municipal landfill sites has been developed. The strategy uses the IEM scoping procedure as a basis, and incorporates a phased investigative approach.

ii)(a) Site-evaluation methods developed during the course of this study consist of:

- a framework for aquifer and surface water pollution-risk assessment based on a derived component-based, weighting-and-rating index-assessment approach.
- a simple comparative site cost-evaluation method
- a 'checklist-method' for landfill site selection for permitting purposes.

ii)(b) Site-evaluation methodologies assessed during the course of this study include DRASTIC and the AHP process. DRASTIC is considered suitable for expert-systems applications. The AHP process in its current form in the program 'Expert Choice' appears to contain serious flaws regarding the conversion of value judgement (text) values to numeric values. Further, the problem of categorizing data before using the AHP process needs to be addressed. The use of an appropriate clustering method *together* with the AHP process appears suitable for an expert system application (This task is considered beyond the scope of the current project, due to its size.). Finally, the problem of comparing financial costs with environmental impact likelihood is a difficult one to address, and the task is not considered amenable to a solution within the confines of the current project.

iii) Expert systems were found to be suitable tools for modelling decision-support processes and are considered suitable for use in deriving guidelines relating to landfill site-selection. They are also useful for producing functional computer-based decision-support software. However, it is important that the expert-systems development software does more than just allow rule-based programming. The development software should preferably :

- facilitate the integration of high-level procedural programming
- facilitate the integration of graphics-user interfaces
- facilitate external software calls and access to files and database systems
- incorporate hypertext and hypergraphics facilities.
- be component-based / object-oriented

Expert systems have been developed with the aim of helping consultants and permitting authorities to identify and select landfill sites, based on draft regulations and overseas standards. The following expert-systems based software has been developed:

- a site-selection 'Checklist Aid'
- a modified site-selection checklist-type of aid following the 'Draft IX' and 'Draft X' 'Minimum Requirements' reports for permitting landfill sites
- a landfill site-cost comparison aid
- a groundwater and surface water pollution index-evaluation system
- a landfill-site soils suitability assessor
- a waste database access demonstration tool
- two hypertext information systems

5 RECOMMENDATIONS

It is recommended that the expert systems software be used by one or two consultant groups and/or by government departments for evaluation purposes over a period of a year or two. When the draft landfill-siting regulations are in their final form, the expert-systems software can be modified to tie in with, and support, these regulations.

It is also recommended that technology transfer workshops be held, during which the software is demonstrated, the supporting theory discussed, and recommendations for further improvements sought .

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APPENDIX: Discussion on the Application of the Analytical Hierarchy Process for Site-Ranking Purposes.

The Analytical Hierarchy Process (AHP), a weighted pair-wise comparison method, has been investigated for suitability in ranking of possible sites, in this project. The AHP approach involves the formation of a tree hierarchical structure, where the top level represents the goal, the second level is split into sub-goals, the third and further levels are split again and again into components (each group of components having as sub-goal above it a component at a higher level) until the bottom level is reached. At each level and for each component group, components are compared pairwise and assigned weightings, with regard to the sub-goal just above. The weights are then proportionately modified so that their sum equals the weight assigned to the sub-goal above.

For this study, the goal is that of selecting the most suitable landfill site. The next level consists of three components: costs, environment, and planning. The following describes how these components are subdivided, for the next two levels down the tree:

* Costs are split into capital costs and running costs, which are in turn split into site cost, access cost, transport costs and landfill operation costs.
* Environment is split into hydrology and "other environmental aspects", which are in turn split up into aquifer, surface water, ecology, social "resistance", nuisance and aesthetics.
* Planning is divided into site lifespan, transport, and adjacent landuse. The next level is split into soil reserves, area size, site access, landuse type and future zoning.

There appear to be problems associated with using the analytical hierarchy process, especially when using the value-judgement scale, as supplied in the program "Expert Choice". The following examples relate to using this scale in the program:

- With regard to the goal of selecting the most suitable site, assuming costs are moderately more important than environment and environment moderately more important than planning, weights are assigned by Expert Choice according to a normalised summation formula to give the values .692,.251 and .077 (to give a zero consistency index). From these values it can be seen that costs are ten times as important as planning, which appears unrealistic. The problem is that a small change in value-description reflects a great difference in numeric rating. For example, when one component is moderately more important than another, it is assigned a value which is three times greater than the other. Yet "moderately more important" could mean (say) only 50 % more important. In order to avoid this problem, a numeric rating could be assigned as input for each component. This latter aspect was not addressed further in the project.

- When two components are compared at the same level of the tree, and these