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NETWORK GEOGRAPHIC INFORMATION SYSTEM FOR LANDFILL SITING

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A prototype network geographic information system (GIS) was developed to: (i) improve the effectiveness of a complex municipal solid waste landfill siting procedure; (ii) make siting-related information available to the general public; (iii) assist local environmental protection agencies in maintaining a GIS; and (iv) facilitate the central environmental protection agency in managing, instructing and evaluating the progress of a local siting. Siting analysis is performed with computerized mapping analysis to save time and effort of data processing. A multimedia network interface is provided for 24-hour local or remote access to the system from anywhere on the Internet. This networking capability allows a user without tools to utilize the system and to avoid the cost of system installation and training appropriate personnel to manage the system. Moreover, a case study for Miaoli is described. Environmental, social, economic and engineering feasibility issues are evaluated for the suitability of a candidate landfill site.

Key Words—Landfill, siting, Geographic information system, Municipal solid waste, Mapping analysis, Internet, Network, Multimedia, Hypermedia, Taiwan.

1. Introduction

Landfilling is an important part of waste management, even though waste reduction, recycling and incineration are now widely initiated to divert waste streams from landfills. The growing population, urbanization and limited land resources have not only decreased the lifetime of landfills, but also aggravated the difficulty of finding new landfills. The landfill capacity crisis has therefore become a critical environmental issue to be resolved in many local communities in Taiwan, R.O.C. A local landfill siting decision frequently becomes a controversial issue receiving national attention because of strong local opposition. Such a disputed situation typically derives from either an inappropriate or incomplete siting analysis or the public's misunderstanding of the siting procedure. The central environmental protection agency in Taiwan is therefore looking for a solution capable of opening the siting procedure to the general public, conveniently instructing local agencies to implement the siting procedure, and easily managing and monitoring the progress of local siting tasks. Landfill siting is a difficult, complex, tedious and protracted process (Allanch 1992). Many siting factors and criteria should be carefully analysed. An initially chosen candidate site may be later abandoned because opposition arises based on previously neglected but important factors; such a delay increases costs and postpones the final decision of a landfill site (Raba 1988). A landfill is generally prohibited from being located within an environmentally sensitive place such as a water resource or conservation district (Taiwan EPA 1993), flood plain or wetland (Repa 1992), or restrained by a buffer distance from a surface water body

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(B.C. Environment 1992). On the other hand, landfills should be near roads to reduce the cost of construction and operation (Lindquist 1991). Issues regarding impact on nature and society, the landfill's lifetime (Oliet 1993), the concession of land, and the protection of water resources (Raba 1988) should also be evaluated. As a general rule of thumb, Zyma (1990) suggested that a good landfill should have minimum impact on environment, society and economy, comply with regulations, and be accepted by the public. In light of the difficulties in attaining such goals, Ham (1993) pointed out that landfills have become fewer in number, located at a longer distance from the sources of waste, and interfered with by the "not in my backyard" syndrome.

Such a complex landfill siting analysis is generally multidisciplinary and requires extensive effort to evaluate numerous factors and environmental, economic and social constraints before an appropriate decision can be made. Spatial data should be collected, in addition to the overall condition, for environmental, social and economic factors to assess microscale impacts such as the exposure risk for adjacent areas. Implementing such a complicated procedure in a conventional information processing approach would be expensive and tedious. Moreover, such a process may be repeated several times as new factors are introduced or as siting constraints are altered. In many cases, a landfill is inappropriate because critical factors were not thoroughly analysed because of limited funds, coupled with poor handling of related siting information. This situation is particularly true for many local governments. This work was therefore initiated to explore a computerized tool to facilitate the siting procedure.

In this study, a prototype network-based system is developed to assist siting analysis using a geographical information system (GIS), a multimedia network information system and numerous computer programs to interface both systems. Landfill siting generally requires processing a variety of spatial data. Implementing such data processing according to a conventional approach using drawing and calculation tools is generally time consuming. GIS converts geo-referenced data into computerized maps and map analysis tools provided by the GIS make it easy to manipulate maps with a computer in a much more efficient way. Application of GIS and its advantages for landfill siting were demonstrated by Lindquist (1991). Michaels (1988) stated that with a GIS one can combine various demographic, geological, land use and census tract maps, apply landfill criteria and find suitable areas to place a landfill. In these previous experiences, although demonstrated as useful, costly commercial tools were utilized with many restrictive limitations to connect with an external computer program. The distribution of tools to many end users is generally unaffordable by a local government. Moreover, training appropriate computer experts to learn and maintain the tools is difficult for a local government because of a limited budget and manpower. The network GIS developed in this study is therefore based on a publicly accessible GIS, GRASS (USACERL 1993) and a multimedia information system, Httpd (NCSA 1995). Instead of distributing the developed tools to the computer of each end user, the tools are made available on the network for 24-hour local and remote access. A friendly multimedia network interface based on a publicly accessible World Wide Web (WWW) interface is provided to link the GIS. Another merit is that the user is not required to have previous knowledge of GRASS (USACERL 1993) to use the system. Consequently, a map of acceptable sites is presented via the network. This networking capability not only significantly decreases the cost of distributing tools to each end user, but also avoids trouble and difficulty that may be encountered when installing tools on each user's computer. The networking capability also allow siting-related information to be completely available to the public to reduce any misunderstanding of the procedure and to gain various inputs for recommendations and comments for a siting task. Furthermore, the central environmental agency can conveniently provide guidance via a network to assist local agencies in implementing a siting procedure. Local siting progress can therefore be easily managed and evaluated from the network by the central environmetal agency and the general public.

2. Landfill siting using a GIS

GIS is an information management system capable of providing spatial analysis tools to sort, retrieve, and manipulate geo-referenced computerized maps. Currently, GIS is widely used in various research fields, including landfill siting. Lindquist (1991) stated, from his experience in Illinois, U.S.A., four advantages of applying a GIS to assist landfill siting: (i) an objective zone exclusion process based solely on a set of provided screening criteria; (ii) capability of handling many complex geographic data; (iii) flexibility in performing "what-if" data analysis; and (iv) visualization of results and graphical presentation. In this work, GRASS (USACERL 1993), a publicly accessible GIS developed by Construction Engineering Research Laboratory of the U.S. Army Corps of Engineers, is used to establish the supporting landfill siting GIS. GRASS is primarily a raster-based GIS operated on a UNIX platform, although limited vector-type analyses are also available. In the raster mode, spatial data are divided into cellular geo-referenced objects. Attributes that describe the features of a geographical object are expressed with numbers and linked to the GIS cell that represents the object. A collection of connected GIS cells is called a "map layer", and each map layer stores a feature of an area. Various such raw map layers were collected for the Miaoli Prefecture in Taiwan, including:

(1) environmental factors: groundwater protection area, water resource conservation district, stream network, natural ecology conservation area, wetland, flood plain, fault area, soil, national parks, etc.;
(2) sociocultural factors: airport location, municipal development planning area, historic and important cultural sites, population, etc.; and
(3) engineering and economic factors: road network, land slope, digital elevation, land cost, etc.

Other than these map layers, numerous intermediate or analysis map layers are created with GIS map analysis approaches. Several major GIS map analysis approaches frequently used for this siting study are described as follows for reclassification, buffer zoning, neighboring computation, cost distance, and overlay by map calculation. USACERL (1993) provides further details of these and other functions.

2.1 Reclassification

Frequently, the attributes (or features) of a map layer must be re-assigned to other values for ease of manipulation or further analysis with other GIS functions. This function is therefore provided to alter the values of attributes to other desired values according to a reclassification list provided by the user.

2.2 Buffer zoning

A landfill is generally prohibited from being placed within a certain distance from some environmentally sensitive areas. For instance, a landfill should be located more than

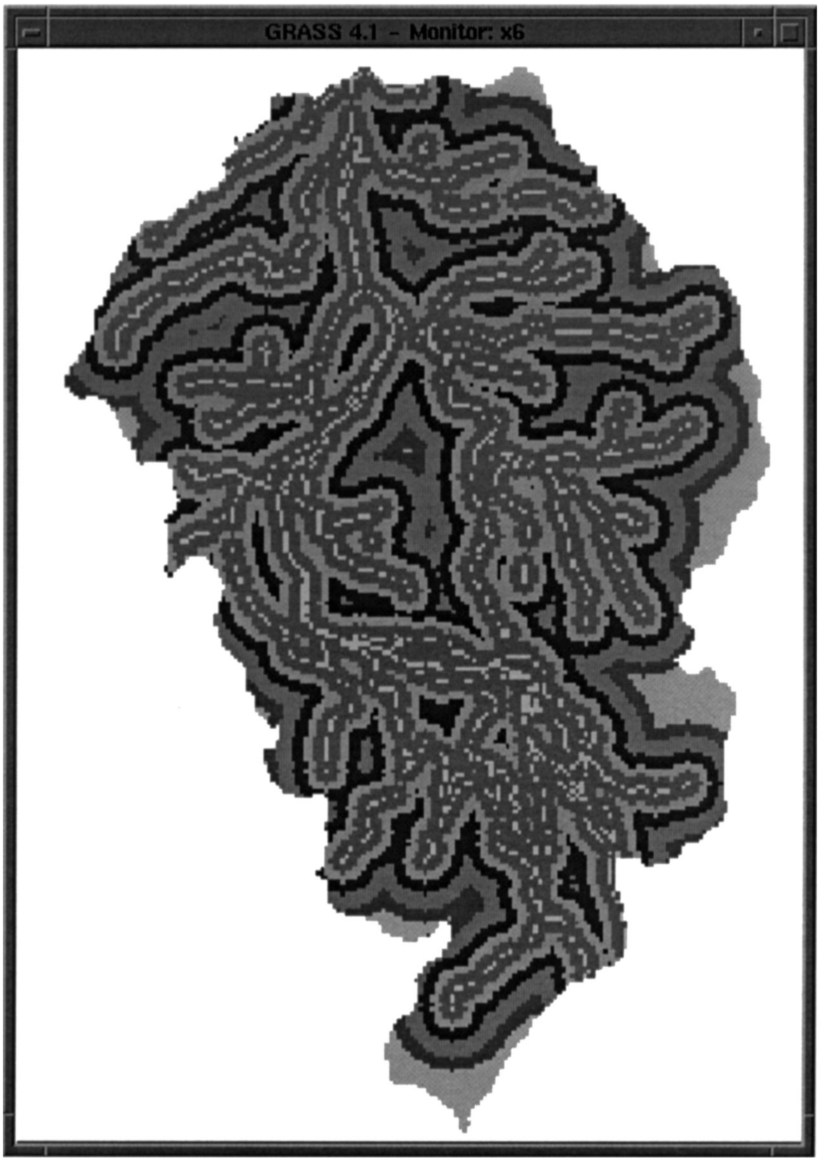

Fig. 1. Sample map layer with buffer strips.

200 m from a stream bank. The GIS buffer-zoning function is suitable to apply such rules that would exclude desired buffer areas. Figure 1 presents an example of a buffer map layer with buffer strips for <200 m, <320 m, <480 m, and <600 m away from a stream is shown (Note: the originals of this and most following figures are in colour). This function can also be applied to other factors. For example, exposure risk to a populated city is generally a function of the distance between the landfill and the city. According to a similar process, buffer strips for varied risk levels can be created with this function.

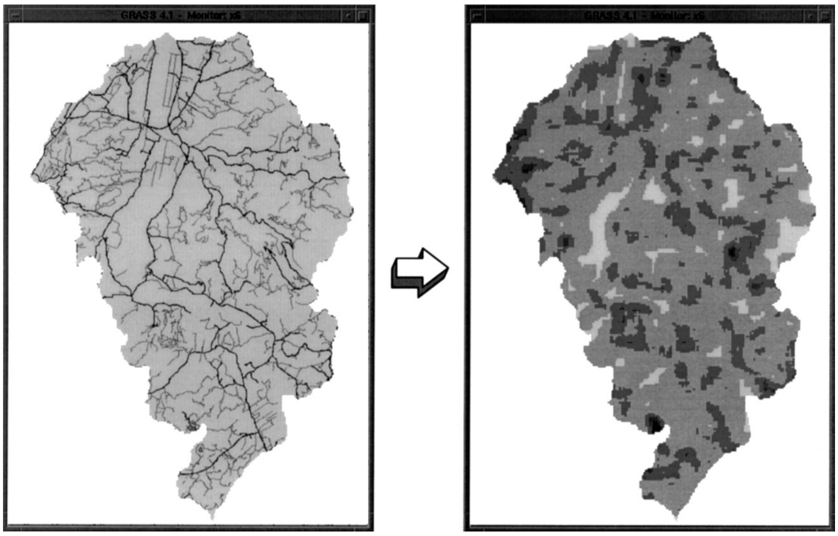

Fig. 2. Sample map layer produced with neighboring computation.

2.3 Neighbouring computation

Neighbouring computation re-assigns the value of a GIS cell with a user-specified (e.g. average, median, mode, minimum, and maximum) function based on values of a window of the current and adjacent GIS cells. The result of using this function for a road network map layer for a window size equal to 3×3 is shown in Fig. 2. Such an analysis map layer can be used to estimate the transportation cost, human activity or land cost.

2.4 Cumulative cost

This function produces a map layer for the cumulative cost between one (or more) pre-specified cell(s) and all other cells from a provided map layer. The value of a cell in the raw map layer is regarded as the cost of moving across the cell; the cumulative cost is determined by the least-cost path. This function is particularly useful to determine the impact of a site on all other cells or the efficiency of a site evaluated based on a factor. Figure 3 presents an example of the resulting map layer when applying this function for a road network. In this figure, the light areas indicate low transportation costs and dark areas represent high transportation costs due to inaccessibility to a good road or a long distance to the site.

2.5 Overlay by map calculation

Overlay by the map calculator provided by GRASS is the most commonly used GIS function in this work. Values of cell features are expressed with numbers in various geo-referenced map layers. With logical or arithmetical operations, this overlay function performs arithmetical expressions on existing map layers to create a new map layer. Of these expressions each map layer is treated as a single variable, and a new value of

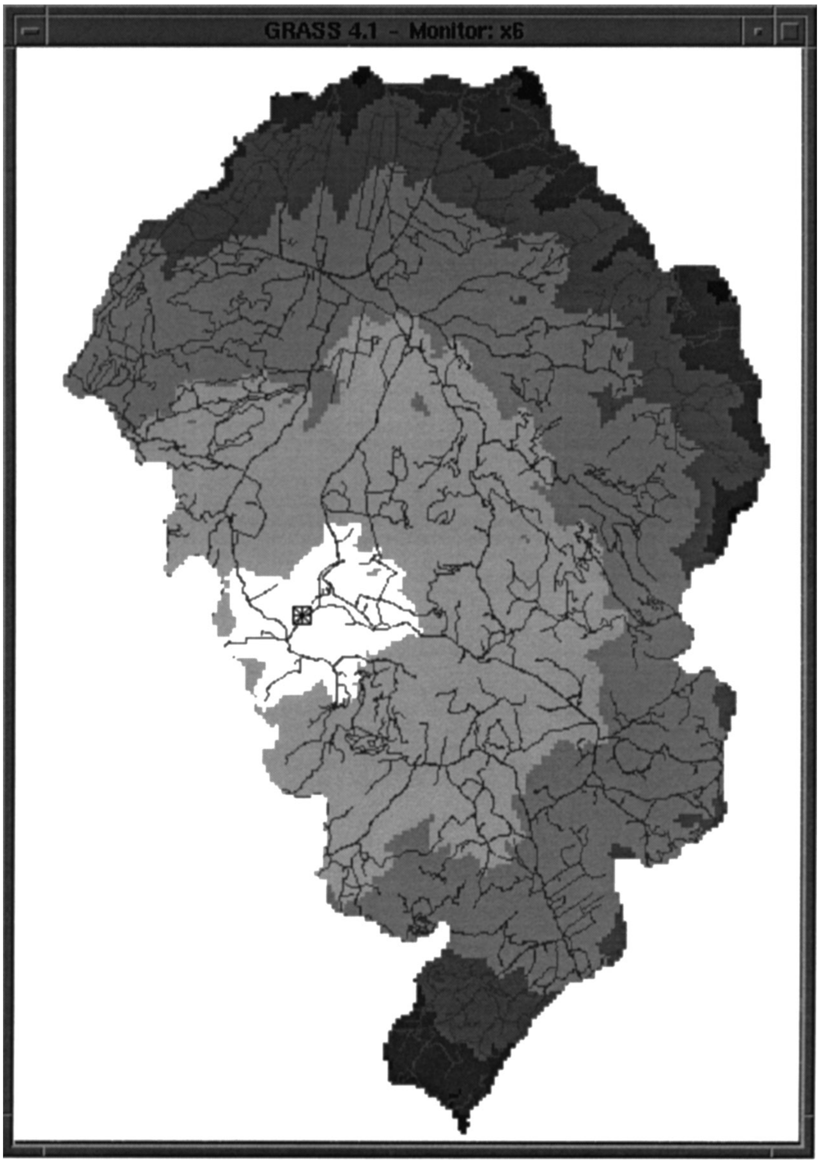

Fig. 3. Sample cumulative cost map layer.

each cell is computed based on the expressions from values of the cell at the same geo-referenced location of map layers included in the computation.

Figure 4 illustrates a typical procedure to apply the GIS with these functions. The user may first select a desired area to site a landfill by reviewing various available map layers and to define siting criteria by the user. Appropriate GIS map analyses are then implemented according to these criteria to create intermediate or analysis map layers. Further analysis is performed with other GIS map analysis functions to produce specific map layers for various factors and criteria. Finally, with the map calculator, the map

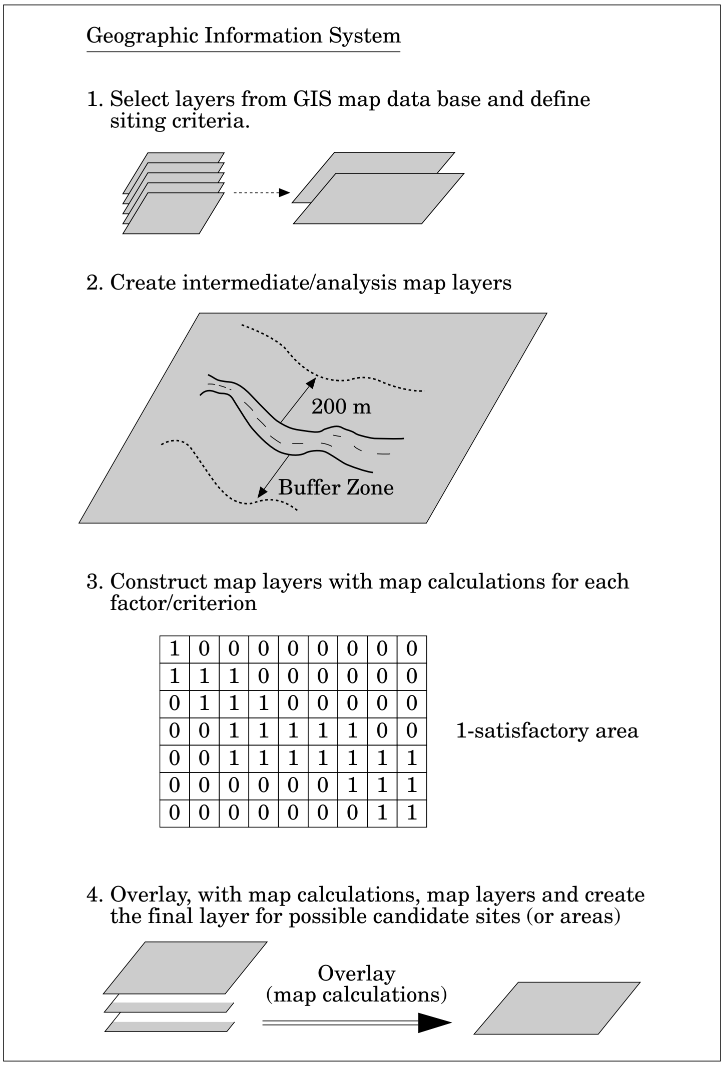

Fig. 4. A typical procedure to apply a GIS for landfill siting.

layer for possible candidate sites is created by overlaying these intermediate and analysis map layers.

3. Multimedia network information system

Multimedia combines various media of text, image, graphics, audio and video to provide a friendly environment to access complex computer systems. Maher (1994) applied such a multimedia approach to facilitate a case-based structural design and stated, in his conclusion, that multimedia technology provided tremendous flexibility to represent design information. This prototype GIS, although powerful, may not be widely accepted by a general user because difficulty arises in manipulating the system without experience of using GRASS and a UNIX workstation. A multimedia WWW

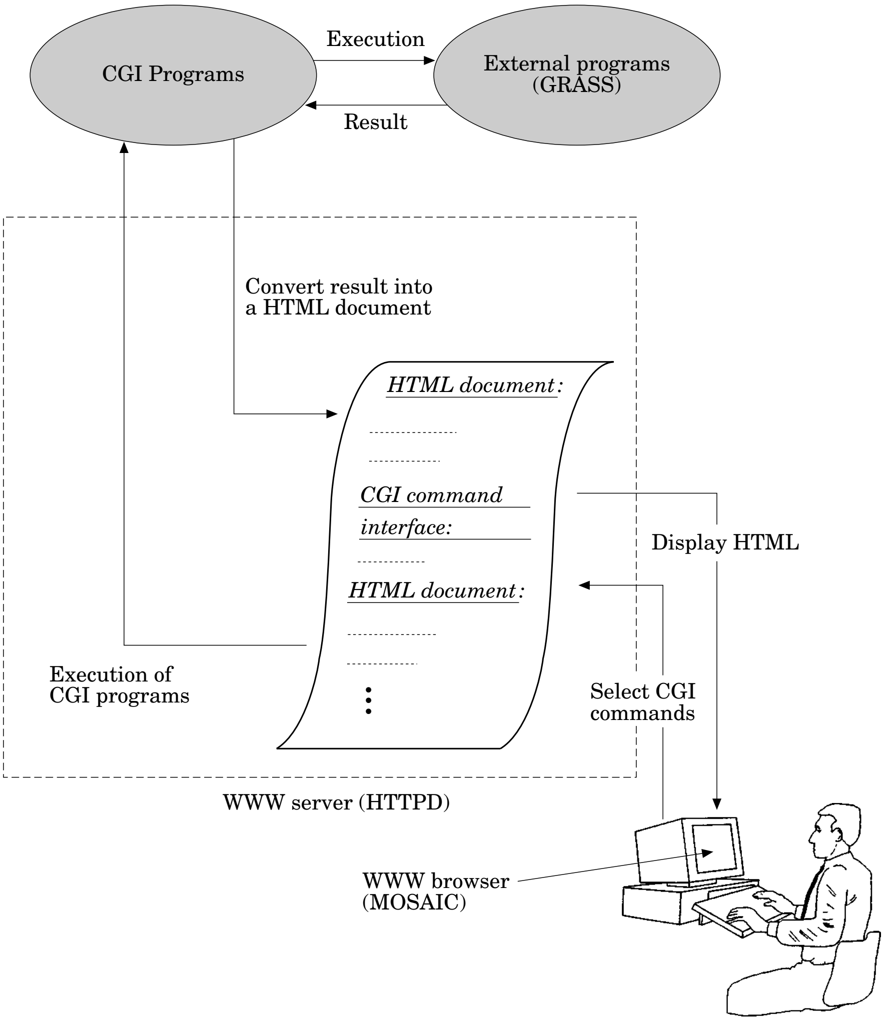

Fig. 5. Multimedia network interface implementation.

information system with interface was therefore designed with Httpd (NCSA 1995). HyperText Markup Language (HTML; Berners-Lee, 1993), and script programs based on the common gateway interface (CGI) protocol to provide a friendly siting analysis environment. With the interface, a general user does not require previous knowledge of GRASS to use the system. The prototype can be remotely accessed via a network without installing the GRASS and analysis tools on the local computer. The WWW interface can transfer not only textural but also audio and graphical data. Video data are currently unavailable, although the interface also has the capability to transfer such data.

Many CGI UNIX shell and PERL (Wall & Schwartz 1992) script programs were developed to link the systems and to make it possible to evaluate various criteria of landfill siting locally or remotely from a computer attached to Internet. Figure 5 illustrates the process in which the multimedia network interface is implemented. The

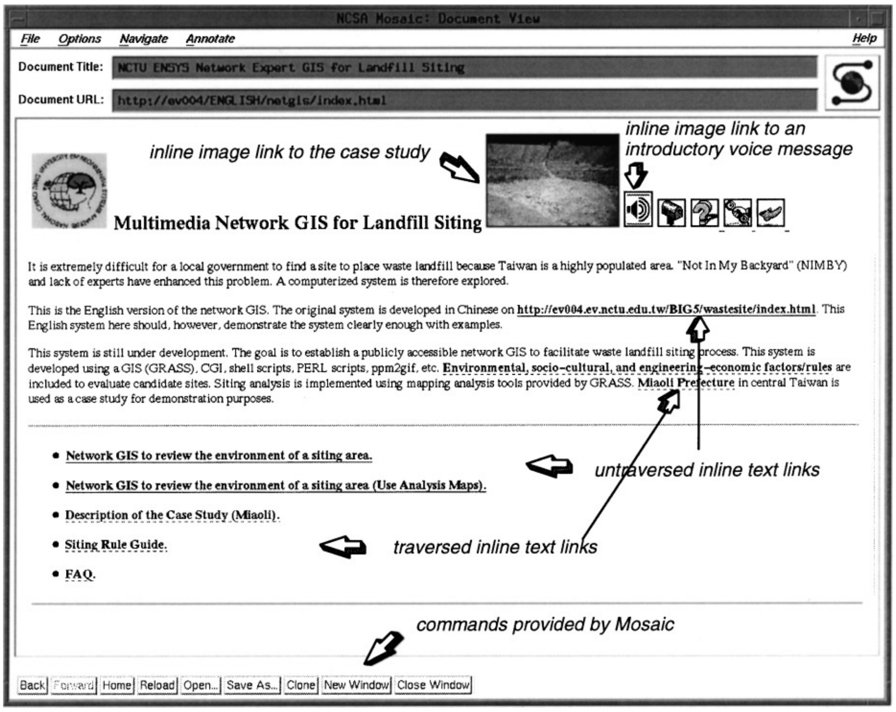

Fig. 6. Initial screen of the system.

user uses a WWW browser [e.g. Mosaic (Andreessen 1993)] to access the multimedia interface and to select command options from the interface to perform map analysis according to the GIS. User-provided commands are fed into a CGI program that executes the network GIS based on the commands. Results, including associated texts and graphical map layers, are then converted into HTML format and sent back to the user via the network. Candidate sites can be evaluated simply by clicking a computer mouse on desired sites of the graphical map layer displayed within the multimedia interface. The prototype system is made available for remote public access, even from an international user, in order to decrease the cost of tool distribution and analysis. Although the system is constructed on a UNIX platform, a personal computer with a WWW browser and connected to Internet can access the system. This advantage minimizes the distribution cost and maximizes the accessibility of the system. Furthermore, the proposed system alllows the general public to easily access the siting system.

4. The system

The current system consists of three major sub-systems: the network GIS, a siting rule guide, and a case study demonstration. Figure 6 shows the initial multimedia screen of the system with links to the sub-systems. For ease of explanation, explanatory messages are provided with arrows pointing to hypermedia objects shown in the figure. These messages are not part of the interface. The interface is designed according to a hypermedia approach in which discrete data pieces of texts, graphics and audio are

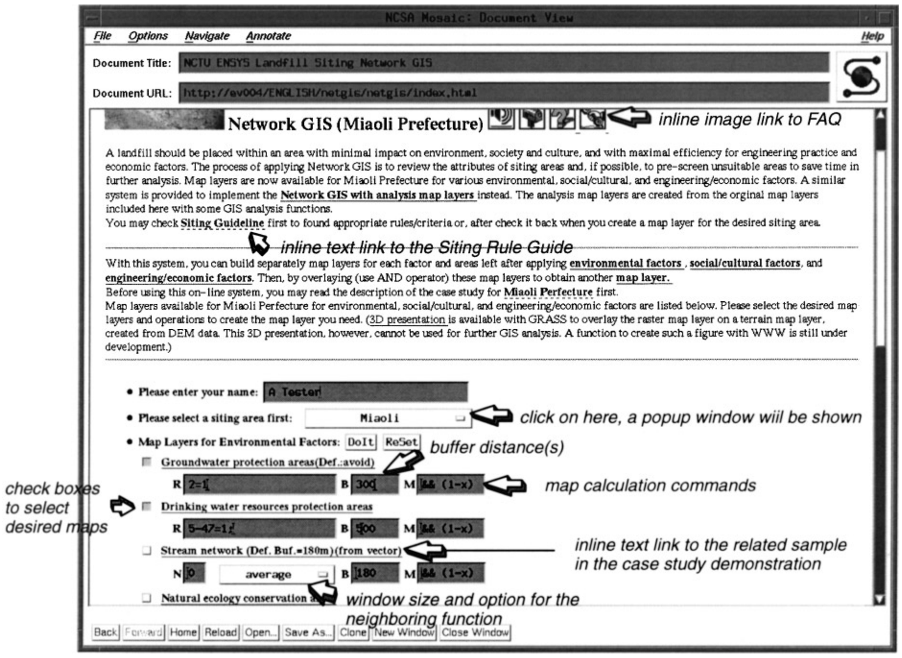

Fig. 7. Initial screen of the Network GIS sub-system.

interlinked by in-line texts or images. The user can traverse between data of different types via in-line links, by clicking a computer mouse on them, or commands provided by a browser, e.g. Mosaic, as the one shown in the figure.

The network GIS provides real GIS map analysis functions that can be applied to the desired map layers. On-line response with graphics is provided to the user not only to review results, but also to implement further siting analysis. Siting rules are collected from various literature to assist the user in reviewing various constraints. Finally, applying the system to a local area, Miaoli Prefecture, is demonstrated. A more detailed description of the three sub-systems is presented below with sample screens from the system.

4.1 Network GIS

Figure 7 illustrates a portion of the initial interface of this sub-system. Although the interface is used primarily for the network GIS sub-system, other sub-systems can be navigated with embedded in-line text and graphic links. Such interlinks are also available in other sub-systems. Currently, GIS data for Miaoli Prefecture are available with the system. In applying the sub-system, the user should initially select a siting area, e.g. a county or the whole Prefecture. Desired map layers are then selected by checking the boxes displayed before map names. If any GIS map analysis function is applicable to the selected map layers, text areas are provided for the user to input desired commands or options. For instance, as shown in Fig. 7, the map layer of groundwater protection areas can be reclassified (R), buffered (B) or recalculated (M). Map layers are grouped into three categories, i.e. environmental, sociocultural and engineering-economical factors, which correspond to those categories used to classify rules described in the

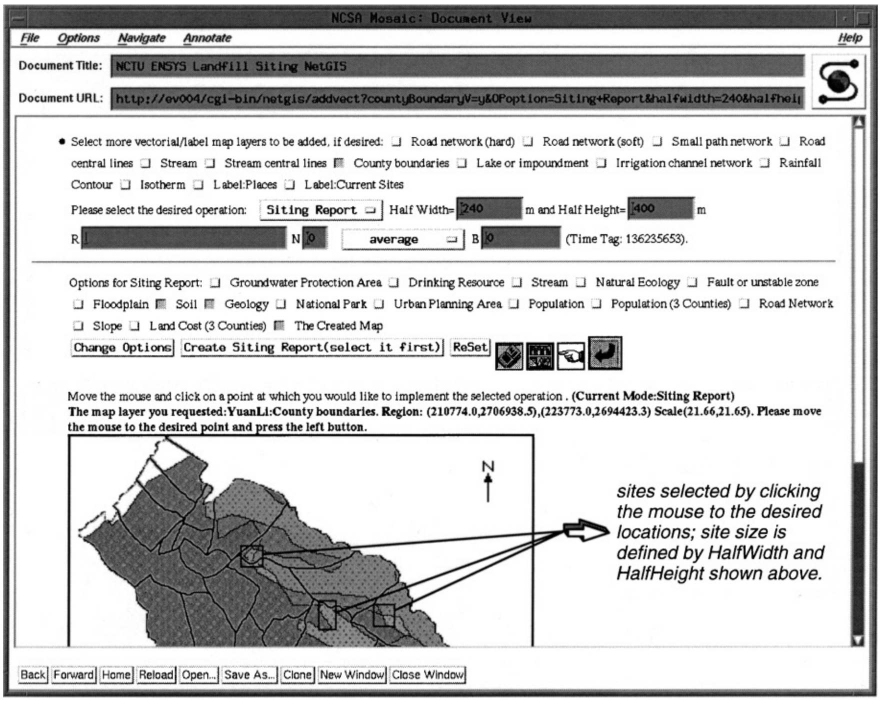

Fig. 8. Screen with clickable image for the Network GIS sub-system.

next section for Siting rule guide. After selecting a siting area and map layers and input of desired GIS functions, another screen (Fig. 8) with a graphic result is prompted. The upper portion of this new screen shows available vectorial map layers and label files. These map layers and label files are used as visual aids to assist the user in reviewing the resulting map layer, although they are not used for GIS analysis. Below the vectorial map layer and label list, the user must select the operation to be used for the current screen. Currently, operations are available for zooming, siting, siting reporting, implementing cost distance function, and reviewing current sites. The zooming operation allows the user to zoom a specified area. The siting operation allows the user to select a desired site on the graphic display shown in the lower portion of Fig. 8. Figure 8 shows three sites selected after clicking the mouse on desired locations. The siting reporting operation is used to report information on selected sites.

4.2 Siting rule guide

Rules related to landfill siting have been collected from various sources, including local and foreign regulations, case studies, reports and other literature that provides siting guidance. The rules are divided into four groups: essential, secondary, recommended and particular rules. Essential rules are primarily regulations which a landfill must comply with. Secondary rules are also regulations, but either not directly proposed for landfill siting or not clearly defined. Recommended rules are conditional or heuristic rules suggested by some researchers or engineers, but not yet included in a formal regulation. Particular rules apply to a specific site or are extracted from previous case

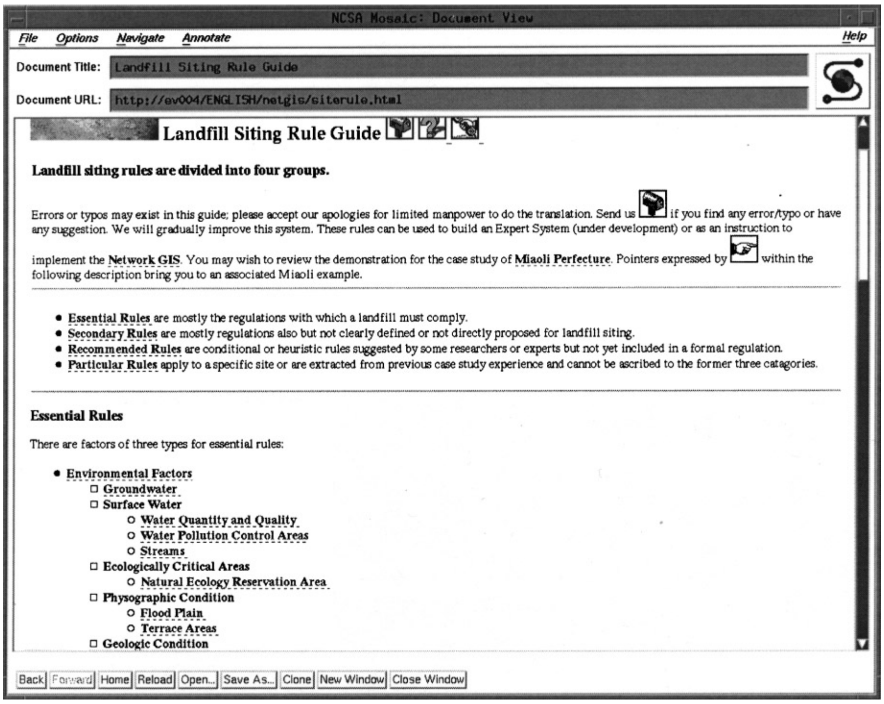

Fig. 9. Initial screen for the Siting Rule Guide sub-system.

study experiences and cannot be ascribed to the former three categories. All rules are converted into a hypermedia document with links to appropriate examples to the case study described in the next section. Figure 9 illustrates the interface of this hypermedia guide. Rules of each group are further classified into environmental, sociocultural, and engineering-economic factors. Only a portion of the essential rules were translated into English for demonstration purposes.

4.3 A case study

The system is originally designed for local governments in Taiwan to perform preliminary siting analysis and is in Chinese. An English interface was added to gain international feedback of the system and to gain foreign experience in improving local siting processes. In this sub-system, the siting analysis of related factors with the network GIS for the Miaoli area is demonstrated. For demonstration purposes, many static pre-processed map layers were prepared, when an on-line dynamic alternation of the map-layers could be made using the Network GIS sub-system. A hypermedia document in HTML format was created for each siting factor with an appropriate map layer attached to the document. The initial multimedia interface of this sub-system is presented in Fig. 10.

The case study primarily involves Miaoli Prefecture located in central Taiwan. The size of the area is about 1820 km^2, of which one-half is a mountainous area. Annual average temperature is around 20°C. Population of the area is about 560 000 and population density is roughly 310 km^{-2}. Solid waste generation is around 500 metric

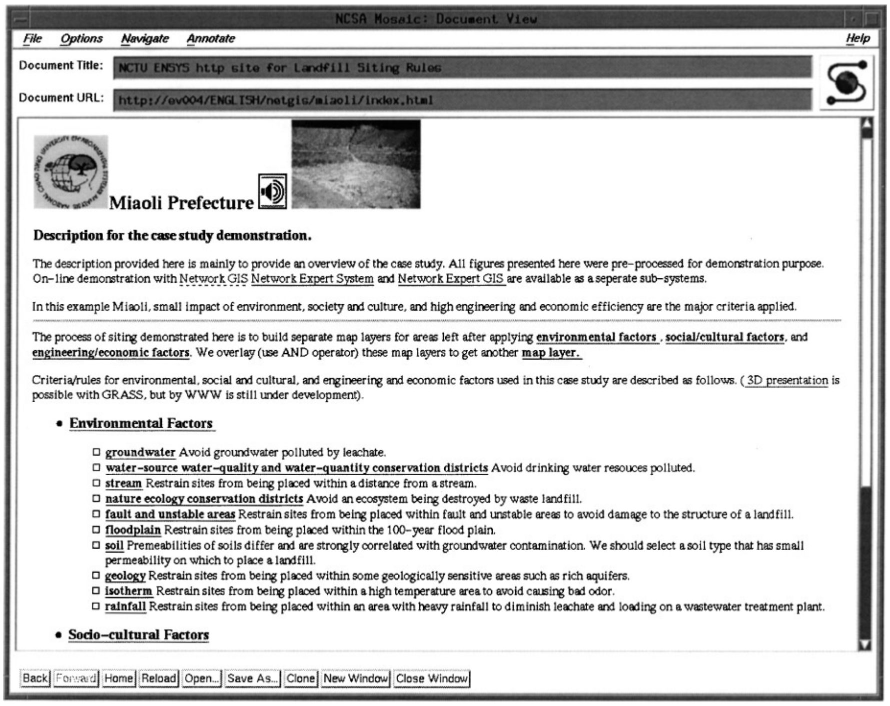

Fig. 10. Initial screen of the case study demonstration.

tonnes per day. Currently, there are seventeen landfill sites, of which two are closed, eight are to be closed this or next year, and two are under construction.

Various map layers are collected for the area and grouped into three categories: environmental, sociocultural, engineering-economical factors. Each map layer is constructed into a multimedia document and interlinked to this and other sub-systems. For instance, the in-line text pointer of "Groundwater protection areas (Def.:avoid)" shown in Fig. 7 can be used to retrieve the groundwater-related map layers for the study area to review the example and siting instructions for this factor. After all factors of each category are evaluated, unsuitable areas that fail to satisfy siting criteria of factors can be easily excluded by GIS map analysis functions. Finally, a map layer with areas left after applying various siting criteria can be obtained.

5. Conclusion

A landfill siting process generally requires evaluating many factors and criteria and processing much spatial information. This condition is particularly true for a highly populated area such as Taiwan, R.O.C. in which siting criteria must be carefully evaluated to avoid a health hazard to ecological wildlife and humans. Local governments generally lack sufficient funds and experts to implement a complete siting process; thus an inappropriate site may unfortunately be selected and subsequently cause significant damage to the environment. In this study, a low-cost computerized tool has been developed to overcome the above limitations. With the developed prototype multimedia network GIS system, siting rules gathered from various regulations, reports and case studies, are provided. Candidate sites are selected simply by clicking on the map layer displayed on the multimedia network interface; information is then presented to the user for various siting factors. All information is transferred via a network, and the user can access the system remotely any time from Internet without having the developed analysis tools installed on a local computer. No previous knowledge is required for GRASS to use the system. In addition, the interface requires minimal learning time. The prototype provides a siting analyst with not only appropriate information but also a good environment to analyse a siting problem. Although the system is designed primarily for landfill siting, many other site selection problems for transfer stations, incinerators, recycling facilities etc. (Nobel 1992) can be implemented with a similar system.

The network interface also allows for the general public to access the siting system. Feedback, comments, and suggestions for any siting task or issue can be provided via the network. Such a siting environment is expected to reduce potential misunderstanding by the public regarding a siting procedure, thereby making a siting decision more acceptable. The network environment, in addition to being an effective communication tool, is also an economically feasible approach for the central environmental protection not only to provide guidance to local agencies, but also to manage, evaluate and monitor the progress of local siting tasks.

Improving the prototype is currently underway at NCTU to add an expert system, a fuzzy expert system, a fuzzy GIS, a mixed-integer linear optimization based subsystem to implement multiobjective analysis similar to that described by Koo *et al.* (1991), and a directional risk analysis tool using an air pollution model. All programs developed in this work are available for public access. Information for obtaining them can be requested by sending an electronic mail to environ@ev004.ev.nctu.edu.tw.

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