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CUSTOMIZING ARCMAP INTERFACE TO GENERATE A USER-FRIENDLY LANDFILL SITE SELECTION GIS TOOL

by

Roozbeh Daneshvar

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Dec 20, 2003

ABSTRACT

One of the most difficult tasks faced by many communities in implementing a solid waste management program is the siting of new landfills. Typically, siting a landfill requires processing and evaluating a significant amount of spatial data with respect to various siting rules, regulations, factors and constraints. An appropriate landfill should have minimum impact on the environment, society and economy, comply with the regulations and be generally acceptable to the public. Implementing such a complex spatial analysis with drawing tools is certainly expensive and tedious.

The geographical information system (GIS) is capable of processing a large amount of spatial data, and thereby potentially saving time and money. The GIS is certainly the most appropriate tool for a preliminary screening, it will exclude areas where landfills are restricted by law or regulation and rank the remaining areas based on area attributes.

ArcGIS Desktop, one the most well known GIS packages, is designed as a scalable system that can be deployed in every organization, from an individual desktop to a globally distributed network of people. Since ArcGIS is built using Microsoft's component object model (COM) technology, it is customizable and possible to extend using any COM-compliant development language. In the present study, ArcMap v8.2, a component of ArcGIS Desktop, is customized using the built-in Microsoft Visual Basic for applications (VBA) language, to create a user-friendly toolbar, called landfill site selection (LSS) toolbar, specifically designed for preliminary landfill site selection.

Such a tailored ArcMap environment will enable engineers with different level of knowledge of GIS, to investigate and compare results of applying different criteria, constraints and scoring schemes on the final suitability map for a landfill site in an area.

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GLOSSARY/NOTATION

S = Slope

x = horizontal distance between two points in x direction, m

y = horizontal distance between two points in y direction, m

z = difference in height between two points, m

Z_{ij} = pixel value located in row 'i' and column "j" of the output map

$(C_{ij})_k$ = corresponding pixel value in row 'i' and column "j" of the k^{th} input scored map

W_k = weight of the k^{th} ranked input map

n = number of input map

Abbreviations

AHP – Analytic Hierarchy Process

API – Application-Programming Interface

CAD – Computer-Aided Drafting

CEAA – Canadian Environmental Assessment Agency

COM – Component Object Model

DEHNR – Department of Environment, Health, and Natural Resources

DEM – Digital Elevation Model

DLL – Dynamic Link Library

EAA – Environmental Assessment Act

EIA – Environmental Impact Assessment

EPA – Environmental Protection Act

ESRI – Environmental Systems Research Institute

EXE – Executable

GIS – Geographic Information Systems

GPS – Global Positioning System

GRASS –Geographic Resources Analysis Support System

GUID – Globally Unique Identifiers

IT – Information Technology

LSS – Landfill Site Selection

MSW – Municipal Solid Waste

MTM – Modified Transverse Mercator

NRC – Natural Resources Canada

OCX – Microsoft Object Linking and Embedding Custom Control

OEAA – Ontario Environmental Assessment Act

OESA – Ontario Endangered Species Act

OLB – AUTOGEN File

OWRA – Ontario Water Resources Act

RCRA – Resource Conservation and Recovery Act

SPANS –Spatial Analysis System

TIN – Triangulated Irregular Networks

TWFL – Trail Waste Facility Landfill

UID – Unique Identification number

USEPA – United States Environmental Protection Agency

UTM – Universal Transverse Mercator

VB – Visual Basic

VBA – Microsoft Visual Basic for Applications

VBE – Visual Basic Editor

CHAPTER 1
INTRODUCTION

Landfilling is one of the most important steps of municipal solid waste (MSW) management. Although integrated solid waste management is now widely practiced and aims at utilizing a variety of technologies such as reduction, recycling, recovery, composting and incineration, in order to divert solid waste from landfilling, technical and economic considerations limit the ultimate effectiveness of these alternatives. Hence, a significant fraction of solid waste still is hauled to the landfills. Even where incineration has been a means of reducing the volume of solid wastes, the landfill still plays a role in the disposal of ash, metals, glass and other materials that will not burn or might affect the public health or the environment if they were incinerated. Furthermore, sanitary landfilling is the conventional and most affordable method of disposing of municipal solid waste for many municipalities (Wichelns *et al.*, 1993).

Due to growing human population, urbanization and shrinking land availability, landfill siting has become a controversial and critical environmental issue. Moreover, many existing landfills are either reaching their maximum capacity or will be abandoned because of public health concerns, extreme public and political resistance, and also because they cannot meet the increasingly strict environmental regulations.

Currently, engineering improvements and new technology make it physically feasible to site landfills almost anywhere. However, this alone is not enough for proposed sites to gain public and regulatory acceptance. In view of this situation, it is becoming increasingly critical to find suitable locations for new landfills that have minimum impact on environment, society and economy, comply with regulations and be accepted by the public. This is hardly possible, particularly when numerous criteria and constraints must be taken into consideration and consequently large amount of spatial data need to be evaluated. Implementing such a complex procedure using manual approaches would be tedious, time consuming and generally impossible without an aid of a systematic and computerized tool.

Geographic information system (GIS) is a powerful tool to work on all pertinent spatial data. GIS is capable of providing spatial analysis, retrieving the required information, manipulating and combining maps with respect to landfill criteria and eventually presenting the results in a transparent and understandable form to the public (Dorhofer and Siebert, 1998).

The practicability and efficiency of using GIS for landfill siting were demonstrated in different studies; however, in those studies, a broad knowledge of GIS was essential for the users to carry out the project. Due to insufficient experts and limited funds to train new users, an inappropriate site may be selected as a result. In this study, a user-friendly GIS tool is developed to overcome the above limitations.

1.1. OBJECTIVES

The main objective of this study is to develop a new tool within one of the most recent and well-known versions of GIS software, i.e. ArcMap v8.2, in order to improve the effectiveness and systematize the complex landfill site selection procedure. This new tool will assist engineers and planners with different level of GIS knowledge to accomplish an actual preliminary landfill site selection problem, potentially save time and avoid cost of training personnel that is generally costly and unaffordable.

The new tool, designed in the form of a toolbar named *landfill site selection (LSS) toolbar* pursues two major tasks: (1) Customizing and categorizing the existing built-in ArcMap tools required for landfill siting, (2) Developing two new interfaces for map integration process that enable the users to perform two common map-overlay models, called *Boolean Logic* model and *Index Overlay* model. This task can be done using the Visual Basic for application (VBA) language.

The steps of how this tool, its components and the new designed interfaces work are presented for a hypothetical case study for the city of Ottawa, Canada, and at the same time, the capability of the tool is verified.

1.2. THESIS ORGNAZATION

From the project perspective and in order to meet the ultimate objective, this study falls into five steps: (1) Reviewing the general landfill site procedures and criteria as well as introducing GIS and its role in preliminary landfill site selection studies, (2) Reviewing ArcObject programming fundamentals and procedures to develop specifically designed GIS tool for landfill siting, (3) Exploring the components of the developed tool, (4) Testing the developed tool and applying it to a case study in Ottawa, Canada, and finally (5) Presenting the conclusions and recommendations.

Each of these steps is briefly described in the following paragraphs.

1.2.1. LANDFILL SITING PROCEDURE & REGULATIONS, GIS IN LANDFILLING

Various environmental, engineering and socio-economic criteria must be taken into consideration when prospective sites for landfills are being studied. Although these criteria vary from location to location, there are common standards and rules, which can be applied to most cases. Most of those criteria are available in the form of the digital maps. GIS is capable of analyzing and processing a variety of spatial maps involved in landfill siting procedure. Creating suitability maps for a landfill site can be efficiently carried out using GIS software. Among various commercial GIS software, ArcMap, as a component of ArcGIS Desktop, is selected for implementing this task.

Chapter 2 discusses general landfill site procedure and the most common location criteria for the new waste disposal facilities as well as an introduction to GIS.

1.2.2. DEVELOPING THE LSS TOOLBAR

ArcMap is built based on Component Object Model (COM) technology. Hence, its interface can be customized according to the user preferences and a particular project needs. In this study, the LSS toolbar is developed using VBA language. Chapter 3 discusses the steps of developing this toolbar.

1.2.3. EXPLORING THE LSS TOOLBAR

The LSS toolbar is comprised of a collection of existing built-in tools required for landfilling as well as new interfaces designed for the map integration process. The LSS toolbar is designed according to the step by step procedure and a rational order in which the result of each tool is a prerequisite for another. In order to implement these tools efficiently and obtain the appropriate final result, they must be clearly identified. Chapter 4 explores these tools and their functions.

1.2.4. APPLYING THE LSS TOOLBAR TO A THEORETICAL CASE STUDY

The main objective of this step is to test and illustrate the capability of the LSS toolbar by conducting a hypothetical case study for the city of Ottawa, Canada. Chapter 5 describes how to apply LSS toolbar components to this case study and obtain the results in the form of a user-manual.

1.2.5. CONCLUSIONS AND RECOMMENDATIONS

Chapter 6 of this thesis presents the conclusions and makes suggestions for further research.

CHAPTER 2

LITERATURE REVIEW

Landfill siting requires an extensive assessment procedure in order to identify the most suitable areas that comply with location criteria and regulations established by the government or local zoning-by laws and have minimum impacts on the environment, public health, economy and social costs. The landfill site selection procedure is presented in detail in the following section.

2.1. LANDFILL SITE SELECTION PROCEDURE

In general, landfill site selection procedure involves identifying the locations for landfills that can meet strict siting, design, construction, operation, monitoring, performance and financial responsibility requirements to maximize the protection of public health and the environment (Wisconsin, 2003). This procedure can be divided into five main steps as follows:

a) Defining project goals and gather supports
b) Identifying facility design basis and requirements
c) Identifying candidate sites for new landfill sites by preliminary screening
d) Selecting the most suitable sites by performing detailed study
e) Obtaining regulatory site approval

Each of these steps is described in the following sections.

2.1.1. DEFINING NEW FACILITY GOALS AND GATHER SUPPORTS

As an initial part of landfill site selection, project goals must be clearly defined by the person or company that is developing the landfill. Objectives can vary based on each individual case and project specifications, however, the following goals must be generally taken into consideration: (a) Means to protect the public health and the environment, (b) Type of wastes accepted or rejected by the new landfill, (c) Maximum haul distance to the new landfill, (d) Target tip fee or cost of operation, (e) Minimum and maximum site operating life, and (f) Means for harmonizing with recycling and resource recovery projects.

Presenting comprehensive and understandable objectives of the proposed plan will not only ensure that the new facility can compete economically with alternative sites, but also will encourage citizens and political officials to support the project and facilitate the next steps towards obtaining the final approval.

2.1.2. IDENTIFYING FACILITY DESIGN BASIS AND REQUIREMENTS

Collecting information in regard to current population, solid waste generation rates as well as waste quantities that the new landfill will receive during its operating life are vital for the design process and determining the space requirement for a new landfill prior to construction. An estimation of future population growth and industrial development should be considered in the analysis as well as the effect of other solid waste management technologies such as recycling or resource recovery of available waste.

For example, the developers may estimate a tip fee for the new facility. Failure to make a correct calculation may result in increasing the tip fee during the operation. As such, the waste quantity received by the new facility may be less than initially anticipated and consequently uneconomical to operate.

2.1.3. IDENTIFYING CANDIDATE SITES FOR A NEW LANDFILL SITE BY PRELIMINARY SCREENING

Once the basic requirements for handling the solid waste during a certain number of years are established, the geographical and physical search for potential sites begins. The first step of this search, known as a preliminary screening, is to eliminate clearly unsuitable areas and rank the remaining areas according to their relative importance. This is certainly beneficial to direct the sparse and limited funds for further investigation into only highly favorable areas that might be worth studying. Criteria and methodologies used for the preliminary screening should be practical so that areas of social and environmental significance are eliminated without removing large numbers of technically valuable sites from consideration (Charnpratheep *et al.*, 1997).

Criteria and constraints for preliminary screening are simple but they are fundamental for the initial identification of suitable landfill sites prior to undertaking further analyses or field investigations. Hence, they must be clearly identified. Thus, landfill location criteria and regulations are described in detail below.

2.1.4. LANDFILL SITING CRITERIA AND REGULATIONS

Due to the growing list of constraints and factors, decision-makers need to be as thorough and inclusive as possible when making choices for the location of landfills. It is critical to effectively and carefully choose which rules to include in site selection and which ones should be left out for a particular case.

Landfill criteria and regulations can be divided into four main groups: (1) essential, (2) secondary, (3) recommended, and (4) particular rules.

Essential rules are mostly the regulations to which landfill must comply. Secondary rules are also regulations but not clearly defined or not directly proposed for landfill siting. Recommended rules are conditional or heuristic rules suggested by some researchers or experts but not yet regulated. Particular rules apply to a specific site or are extracted from previous case study experiences and cannot be included in the previous three categories.

Ioannis (1993) suggested subdividing the essential rules into three classes, (a) environmental, (b) engineering-economic and (c) social-cultural factors. This classification is vital and can prevent the possibility of duplication during the assessment.

Environmental factors describe issues that are of vital concern when referring to a landfill. They include impacts that the landfill may have on the nearby biophysical environment and may also affect the ecology of the area. For example, landfill sites should be restricted from being placed within geologically and hydro-geologically sensitive areas. The required information to determine the degree of sensitivity and vulnerability may include type of aquifer, geologic formations, groundwater depth, hydraulic gradient, flow directions and drainage pattern (Dorhofer and Siebert, 1998).

Additionally, in order to avoid groundwater pollution, sites should be located on an impermeable formation or soil types that have low permeability, which can impede or retard the natural movement of contaminants and consequently protect groundwater resources. According to the USEPA (1991a), it is also recommended to restrain sties from being placed within the 100-year flood plain of rivers to avoid drinking water resources pollution. Climatic factors such as high temperature and an area with heavy rainfall can also dictate the method of operation of a landfill site with the aim of avoiding odor production and leachate generation and hydraulic loading, which will affect wastewater plant operation.

Moreover, landfill sites should also be restrained from being located within national parks and natural ecology conservation districts to avoid destroying perfected landscapes and ecosystems respectively.

Engineering factors consist of those criteria that correspond to the engineering aspects that make the operation of the site possible and practical. For example, landfill sites must be constrained from being placed within steeply sloping area to avoid difficulties for construction, operation and maintenance. To avoid damage to the structure of a landfill, it is also restricted from being located in areas with active faults and unstable or prone to land sliding areas. Additionally, it is recommended to place landfill sites near existing roads to reduce the construction and transportation costs (Bader, 2001).

Economic factors are relevant to the costs associated with acquisition, development, operation and running of the site. For instance, it is preferred to locate landfills in relatively inexpensive land. In addition, development, operational and maintenance costs should be estimated carefully and minimized as much as possible. For example, all site development costs drawn from the engineering stage of the site selection and the infrastructure must be considered against the amount of capital investment put into the landfill; otherwise the development will not be successful.

Social and cultural factors comprised of those criteria that may have potential for disruption to residents, community, recreation features or impact on existing or undiscovered historic, cultural and archaeology sites. For example, to reduce the impact on human activities, landfills should not be located close to urban planning areas. Furthermore, landfills must be constrained from being placed within a certain distance from residential areas with high-density population, schools, hospitals and also military areas to minimize the social and political opposition.

Public and political opposition in fact represents as the single greatest obstacle to the siting of waste disposal facilities. A site may be technically practical and meet the environmental and engineering criteria discussed earlier, nevertheless may have to be abandoned due to serious public opposition. Therefore, one of the most important questions to answer when developing procedures to search for a landfill site is whether the public will accept it.

In order to speed the process, planners and engineers should have a clear understanding of public opinion. Public involvement is a series that starts by creating awareness and interest. It is a two-way exchange that involves both presenting the information to the public and receiving ideas, issues and concerns from the public. This process is not trouble free and it can be time-consuming and difficult, however, by constructing better relationships with communities, potential misunderstanding and disagreement will significantly be reduced.

Experience from successful cases such as Wisconsin's landfill siting process (Wisconsin, 2003) shows that involving the public is as important to success as performing good technical studies. The search process can also be used to educate the public about the difficulties and obstacles when siting a new landfill and about the degree of effort and expertise that developers apply when making landfill decisions. This can help to encourage the public to participate in choosing a site from among the available alternatives. Kao *et al.* (1997) proposed a prototype network computerized system, available to the public to understand the siting system. Feedback, comments and suggestions at each siting step can be provided via this system.

Many developers, however, try to keep their decisions secret until a final choice is made because they worry that if the plan officially announced, price of the land is being studied, will go up.

Public involvement is mandated by some federal, state or local regulations. For instance, the U.S. Environmental Protection Agency (USEPA) recommends early involvement of the public and it requires a developer notify the public and hold a public hearing prior to applying for a facility construction permit. USEPA also developed the

Resource Conservation and Recovery Act (RCRA) "Public Participation Rule", to empower communities to become more actively involved in local waste management (USEPA, 1996).

Although socio-cultural factors are important, they are not always easily available and are too expensive to collect for use in a preliminary analysis and should be limited to sites with the most promising characteristics.

Preliminary screening process involves evaluating the criteria and regulations outlined in the abovementioned factors when prospective sites for landfills are studied. Although the majority of the requirements are presented by those criteria, yet they are not constant and may vary from case to case and location to location. Moreover, their details and specifications can be interpreted differently according to the characteristics and nature of each individual case. Therefore, it is not possible to establish a comprehensive list that contains all the landfill-siting criteria and regulations. It is in fact up to engineers and planners to obtain and determine the final necessary criteria and regulations for a particular case.

Landfill siting factors are generally established by main regulators, mandate federal, state or local regulation and are compulsory in the landfill siting analysis. For example, the following are the major regulators in Canada and US: (1) Resource Conservation Recovery Act (RCRA, 1976), (2) US Environmental Protection Agency (USEPA, 1991b), (3) Canadian Environmental Assessment Agency (CEAA, 1992a), and (4) Environment Protection Act (EPA, 1990b).

A complete discussion of the abovementioned sources is beyond the scope of this study, however, as an example, landfill-siting criteria as outlined in USEPA is briefly described below.

The federal RCRA (1976) established general standards for landfill siting including controls for detecting site impacts on water quality, siting in flood plains and effects on endangered species. The USEPA is one of the most comprehensive and well-known regulatory agencies and its mission is to protect human health and to safeguard the natural environment, air, water, and land.

USEPA published new landfill regulations, known as Subtitle D, which contains a guide for owners and operators of municipal solid waste landfills and provides basic requirement information (USEPA, 1991b).

As required by Subtitle D, the USEPA has published regulations on the siting of all municipal solid waste landfills. New location criteria have been elaborated under subpart B, of MSW landfill criteria technical manual (USEPA, 1993). According to this manual, landfill development is restricted in areas including wetlands, unstable soils such as Karst terrain or landslide susceptible areas, fault areas, seismic impact zones, and land in the 100-year flood plain, or in proximity to an airport. Location requirements apply to all new municipal solid waste landfills and existing landfill expansions.

The following are brief descriptions of location criteria for municipal solid waste landfills according to USEPA (1993).

- Because landfills can attract birds that can interfere with aircraft operation, owners/operators of sites near airports must keep a certain distance from airports and show that birds are not a danger to aircraft.
- Landfills may not be located in areas that are prone to flooding.
- Since wetlands are important ecological resources, new landfills and laterally expanding ones may not be built in wetlands.
- To prevent pollution that could be caused by earthquakes or other kind of earth movement, new and laterally expanding landfills may not be built in areas prone to faulting and seismically active zones.
- Landfills cannot be located in areas that are subject to landslides, mudslides, or sinkholes.

Provincial or local government by-laws and other regulations can also affect site acceptability. For example, in Canada the Ministry of the Environment has issued basic legislative framework for waste management facilities under part V of the Environmental Protection Act (EPA, 1990b). Moreover, in Ontario, regulation 232/98 has been established for new landfilling sites and it includes requirements for site design, operation, closure and financial assurance (EPA, 1990a).

There are numerous rules and criteria from different regulators involved in siting a new landfill. For example, some of the location criteria and their sources are presented in the following list.

- The location must be where the underlying bedrock is not a fractured limestone or sandstone quarry (Ohio EPA, 1996).
- Landfills must not be located in floodplains (USEPA, 1991a).
- Landfills should be kept more than 180 meters away from rivers (Wisconsin, 1998).
- Landfills should be kept more than 500 meters away from water bodies (Ontario, 1998a)
- No landfill should be constructed in a wetland (USEPA, 1991a).
- To avoid groundwater contamination, landfill must be located in low permeability geology formations. This means that sites with naturally attenuating soils, such as sites in clayey areas, are preferred. In addition, site should be kept away from high-level water table areas (Australia, 2001).
- Landfills should not be constructed on unstable soils or bedrock (Ontario, 1998b).
- In general, it is stated that new landfills should not be located within 60 meters of faults (USEPA, 1991a).
- Landfills may not be sited within 800 meters of a well or spring used for a community water supply (Pennsylvania, 2001).
- Disposal facilities shall not be located in seismic impact zones (Tennessee, 2003).
- To avoid difficulties of constructing a landfill, and increasing cost, landfills should not be constructed in the steep slope area (City of Cheyenne, 2001).
- Local cover material availability for the lining and capping is one the most important criteria for landfill site suitability (Ontario, 1998b).
- No landfill should be constructed near an airport in order to reduce bird hazard. An airport requires an extensive area. (i.e. 3048 meters from runways used by turbojet and 1524 meters from runways used by piston-type aircraft) (Oklahoma, 2001).
- To avoid increasing the transportation, construction and development cost, the site should be easily reached by trucks and via streets or highways (Bader, 2001).

- Landfills should be away from developed areas to reduce impact on living environment. Also no construction including waste disposal facilities can be built in the first level military control area (City of Phoenix, 2003).
- Landfills should not be placed within 1600 meters of any threatened or endangered species or plant (Oklahoma, 2001).
- Landfills must be kept away from historical sites and national parks (Pennsylvania, 2001).
- Landfill sites must be away from hospitals, schools and other institutions (EPA Publication, 1991).

2.1.5. SELECTING THE MOST SUITABLIE SITES BY DETAILED STUDY

The fourth step in the site selection process is to conduct a detailed investigation of the sites designated most suitable. Detail investigation is also compulsory as a necessary part of the Environment Impact Assessment (EIA). The EIA is defined as an integral part of the administrative procedures and includes the investigation, description and assessment of the impact of the potential landfill on the environment, water, soil and air in that particular area.

Further detailed studies usually concern hydrogeological characteristics of the potential sites. In order to find out those characteristics, subsurface investigations are necessary. Subsurface investigations consist of drilling boreholes to obtain information about the geology and hydrology of the region (Dorhofer and Siebert, 1998).

Hydrological studies include gathering information in regard to the groundwater hydraulic system, groundwater recharge, chemical composition of the groundwater, drainage patterns, and groundwater depth, flow and directions. Geological studies involve determining geologic formations, geotechnical parameters, natural quality and construction characteristics of the site soil. These studies are relatively expensive and they are usually conducted by consulting companies, therefore, they should be limited to sites with the most promising and desirable characteristics.

Additionally, data about existing land use, surrounding land development, visibility, available utilities, political jurisdiction, exposure to the prevailing wind direction and land cost are also tabulated. As such, more areas are subtracted and the list of suitable sites is further narrowed down. The ultimate selection of the site is made from a list of remaining sites.

The preliminary feasibility report, subsequently, should contain all of the relevant information needed during the process to find the selected site. The report may select a preferred site or may leave this decision to the government's governing board or other group that will be operating the landfill.

2.1.6. OBTAINING REGULATORY SITE APPROVAL

Once a site has been selected, a final feasibility report can be prepared for submittal to the appropriate approval agencies. The final report may include final engineering design, design calculations, details on the phases of construction, proposed construction documentation, sequencing of operations, daily operations, monitoring, closure design, long-term care of the proposed landfill after closure, and a detailed estimate of the costs for construction, operation, closure and long-term care of the landfill. Sometime, this step is subject for local approval as well. Although local approvals need only be obtained prior to the construction of a landfill, as a practical matter, many applicants do not proceed to develop a feasibility report until the issue of local approvals is resolved.

In Canada, Ontario, for example, in order to obtain approval for a new landfill site, a detailed assessment of the site must be carried out, to identify and potential effects on the environment and to show how these possible effects can be adequately addressed. The basis of this assessment and the requirements for site design are presented in regulation 232/98 under part V of the EPA (1990a).

Landfill siting may also be subject to approval under the Canadian Environmental Assessment Agency (CEAA, 1992b) and the Ontario Water Resources Act (OWRA, 1990). Under CEAA, a broad view of the environment is taken and issues beyond the effects on the natural environment must be addressed. In case of discharge to surface water, approval under the OWRA is also required. Provincial water quality objectives established by the Ministry of the Environment, require any surface water discharges from a landfilling site must meet these criteria (Ontario, 1998c). Additionally, for a landfill discharging to a sewer, the quality and quantity of the discharge is controlled by local sewer use by-law, and the requirements or limitations of the receiving wastewater treatment plant.

In general, it is important to ensure that the regulatory agencies will approve a new landfill proposal. Incorrect interpreting and prediction of how the government agencies will respond can result in wasted investment in feasibility reports and other technical investigations, as well as lead to potential legal proceedings and other time-consuming and costly delays.

2.2. GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Geographic information systems (GIS) are computer systems that consist of hardware, software, and procedures designed to support the capture, storage, management, manipulation, analysis, modeling and display of spatially referenced data for solving complex planning and related problems (Clarke, 1999).

In general, GIS can be divided into the computer system and GIS software components. The computer system contains the operation system and the GIS software includes the program and user interface to run the GIS (Chang, 2002).

2.2.1. WHAT CAN BE DONE WITH GIS?

Since the late 1960s computers have been used to store and process geographic data and GIS has been playing an important role in natural resource management, such as land use planning, environmental studies, geological and hydrogeological studies and natural hazard assessment. In more recent years GIS has been used in emergency planning, market analysis, facilities management, transportation and forestry planning, military applications and academic pursuits. GIS in conjunction with other technologies such as global positioning systems (GPS) and the Internet has introduced new applications and become an essential component of information technology (IT) (Lo and Yeung, 2002).

Bob and Andy (1999) presented a list, showing typical examples of what can be done with GIS, as follows.

- Finding locations for new cell phone antennae.
- Monitoring water quality to protect public health.

- Studying the impact of construction plans on a watershed.
- Finding the least-cost path for a new pipeline.
- Modeling electronic circuits to minimize power loss and to plan the placement of new devices.
- Tracing and warning counties in the path of a severe storm.
- Evaluating locations for new retail outlets by considering nearby concentrations of customers.
- Finding the fastest route to an emergency.
- Designing and planning relief facilities by modeling demand and accessibility.
- Tracing upstream to find the possible sources of a contaminant.
- Predicting the spread of a forest fire using terrain and weather data.
- Producing land use maps for appraisers and planners.
- Monitoring the condition of roads and bridges and produce planning maps for natural disasters.
- Finding the valves to isolate a ruptured water main.
- Producing maps of bicycle paths for commuters.
- Studying crime patterns to intelligently deploy personnel and monitor the effectiveness of neighborhood watch programs.
- Prioritizing areas for repairs after an earthquake.
- Creating and suitability map to find the best site for a particular feature such as a new water treatment plant, school, hospital or landfill.

The ultimate purpose of working with GIS, however, is to provide support for making decisions and sometimes designing, based on spatial data.

2.2.2. GIS AND LANDFILL SITE SELECTION

Once criteria and constraints involved in a particular project have been identified and established, large amount of spatial data with respect to these criteria must be taken into consideration and made available. In order to identify the most suitable areas, maps relevant to criteria, must be intersected and combined with respect to the rules outlined in each criterion.

Lane and McDonald (1983) proposed a manual map-layer-based screening approach to perform multifactor land suitability analysis. However, implementing such a complex procedure according to a conventional information processing approach would be generally expensive, tedious and time consuming. Since these data are also available in the form of digital maps, geographic information system (GIS) at the preliminary level makes this task easier and more efficient. This task can also be done with the aid of GIS combined with a data management and processing program, as well as interfaces with other databases.

One of the capabilities of GIS is to provide spatial analysis tools to sort, retrieve, and manipulate geo-referenced computerized maps. Additionally, it is able to process and analyze a large amount of spatial data; thereby potentially saving time that would normally be spent in selecting an appropriate site manually (Kao and Lin, 1996).

In addition, because of the extensive GIS capability of manipulating and retrieving data, such a process may be repeated several times as new factors are introduced or as siting constraints are altered. This may also be beneficial to evaluate a large number of potential sites and make a list of candidate sites before selecting a particular site for detailed study and possible implementation (Kao *et al.,* 1997).

With the development of GIS, the landfill siting process is increasingly based on more sophisticated spatial analysis and modeling. Currently, GIS is widely used by several different organizations and many individuals to access and manage varied sets of geographically related information in various research fields, including producing suitability maps to find a best location such as a new landfill site.

GIS is certainly an ideal method for preliminary landfill site selection studies because it: (1) is capable of handling many complex geographic data and flexible in performing "what-if" data analysis, (2) presents objective zones based solely on a set of provided screening criteria and, (3) displays information according to user-defined specifications (Dikshit *et al.* 2001). The advantage of using GIS in landfill siting process was also demonstrated by James *et al.* (2002), Dikshit *et al.* (2001), Siddiqui *et al.* (1996), Green (1995) and McLean (1993).

The usefulness of applying GIS in the previous studies, however, was built on the assumption that the users have a previous knowledge of GIS and how to apply the software. Additionally, due to the limited capabilities of the older versions of GIS software, in some cases these need to be employed in conjunction with other data management or geoprocessing software tools.

2.2.3. GIS SOFTWARE – ArcGIS DESKTOP

There are several GIS software in the market. Chang (2002) introduced some GIS software producers and their main products as follow.

- ArcGIS Desktop (ESRI, 2001a)
- AutoCAD Map (AutoDesk, 2000)
- Texas GRASS (GRASS GIS, 1999)
- IDRISI (IDRISI, 1987)
- MapInfo (MapInfo, 2003)
- SPANS (PCI, 1982)

However, ESRI Inc. is leading the market for GIS software. ArcGIS Desktop package, one the most popular ESRI's products, is a suite of GIS software systems; *ArcView*, *ArcEditor* and *ArcInfo*. It is a comprehensive, integrated, scalable system designed to meet the needs of a wide range of GIS users and it can be used through any of three product levels. These three software products look and work the same way, however, each, providing different level of functionality. ArcView provides comprehensive mapping and analysis tools along with simple editing and geoprocessing tools. ArcEditor includes the full functionality of ArcView with the addition of advanced editing capabilities for coverages and geodatabases. Within the ArcGIS Desktop software family, ArcInfo is the most comprehensive GIS available. It includes all the functionality of ArcEditor and adds a complete set of data management, analysis, and conversion tools (Ormsby *et al.*, 2001). Because ArcView, ArcInfo, and ArcEditor all share a common structural design, users working with any of these programs, can share their work with other users. Maps, data, symbology, map layers, custom tools and interfaces, reports, metadata, and so on, can be accessed interchangeably in all three products (ESRI, 2002).

ArcView, one the ArcGIS functional products, supports a variety of extensions such as ArcGIS Spatial Analyst, ArcGIS Geostatistical Analyst, ArcGIS 3D Analyst™, and others. It also uses stand-alone utility to extend its capabilities.

ArcView is a suite of three integrated applications; *ArcToolbox, ArcCatalog* and *ArcMap*, as shown in Figure 2.1.

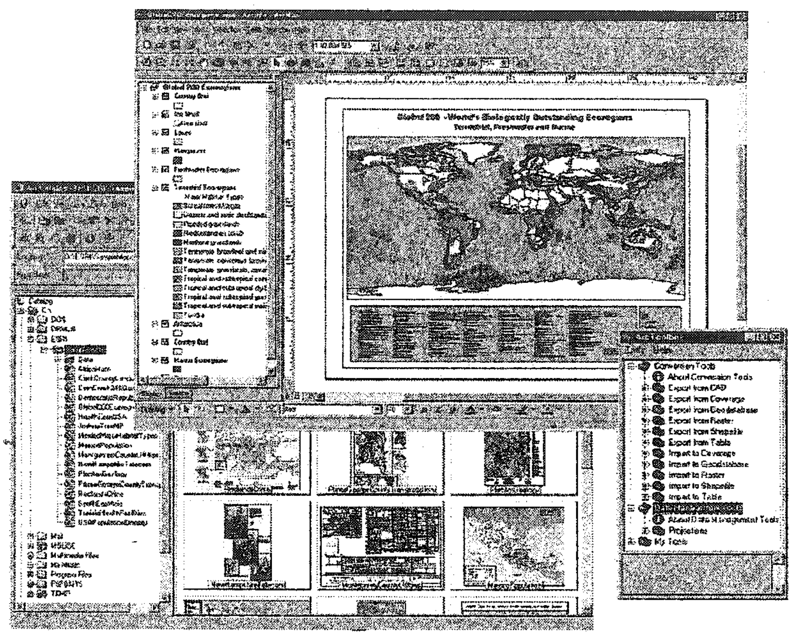


Figure 2.1 ArcView Software (ESRI, 2002)

Using these three applications together, any GIS task from simple to advanced can be done, including mapping, reporting, data management, data editing, geoprocessing and map based analysis as shown in Figure 2.2.

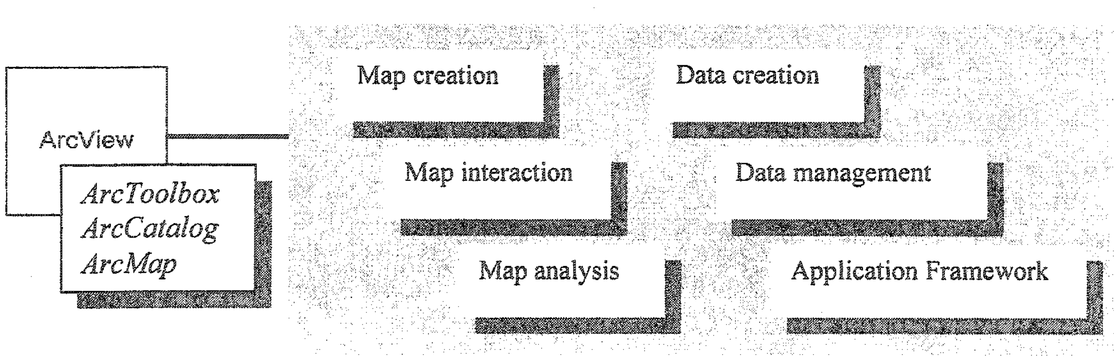


Figure 2.2 ArcView Package and its Capabilities

2.2.3.1. ArcToolbox Application

Figure 2.3 shows ArcToolbox application that provides a very rich and powerful GIS set of tools used for Geoprocessing. It allows performing tasks such as converting all major spatial formats to a usable GIS format, joining, clipping and merging map sheets, defining and changing the coordinate system (projection) of maps and many analysis tools (Corey, 1999).

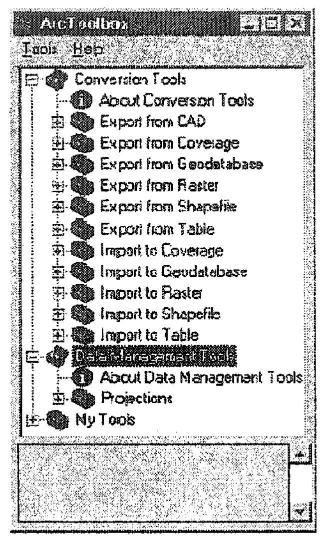


Figure 2.3 ArcToolbox Application

"Map Preparation" section in Chapter 4 covers some of the ArcToolbox features in detail.

2.2.3.2. ArcCatalog Application

ArcCatalog is an application for managing, organizing, holding and designing the spatial data. Information about metadata can be retrieved via this application as well as generating a sophisticated custom geodatabase to store the data for a particular project.

Metadata contains information about each dataset such as, source, processing status, data quality, attribute values and projection properties. As with many GIS projects, the data for a particular project comes from several different sources. Therefore, a personal geodatabase can be generated on the local machine, using ArcCatalog application, to minimize the duplication of datasets and have the data well organized and easily accessible especially if they are needed to revisit the project in the future.

Figure 2.4 shows ArcCatalog application.

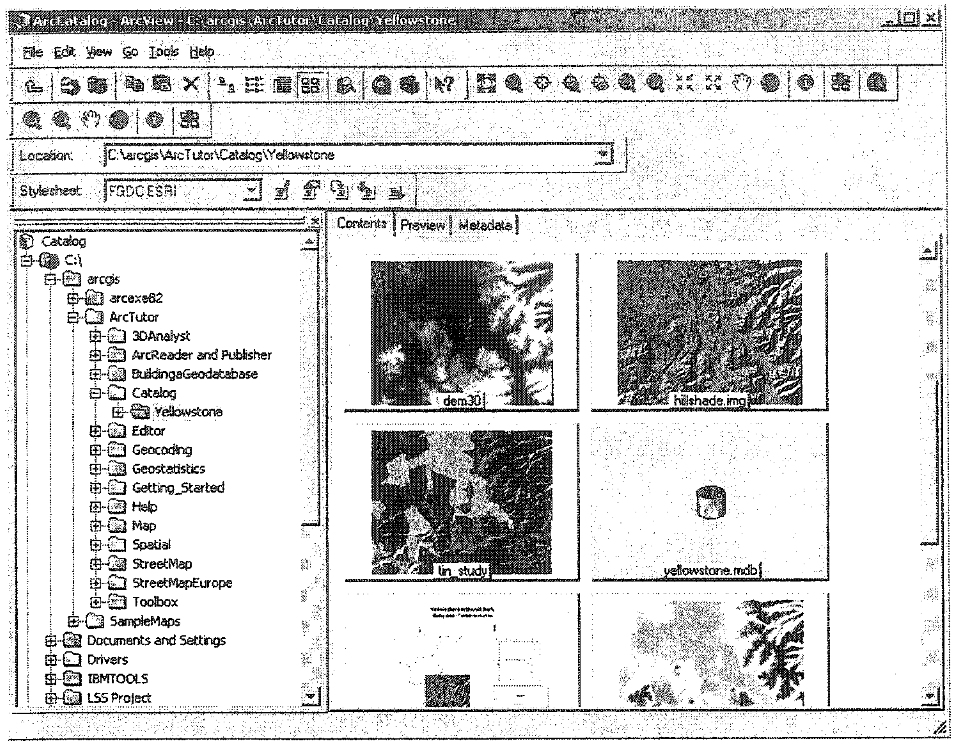


Figure 2.4 ArcCatalog Application

"Data Preparation" section in Chapter 4 covers database assembling in detail.

2.2.3.3. <u>ArcMap Application</u>

ArcMap is an application used for all map-based tasks such as viewing, editing and analyzing the geographic data. With ArcMap a wide range of data with different formats including shapefiles, coverages, tables, computer-aided drafting (CAD) drawings, images, grids, and triangulated irregular networks (TINs) can be integrated.

ArcMap enables the user to query spatial data to find and understand relationships among geographic features. ArcMap can also generate layout of maps and print the result according to the user-defined specifications.

Finally, ArcMap gives the power to develop and customize the user interface according to the needs of a particular study and make new tools to automate the work (Minami, 2000). Figure 2.5 displays ArcMap interface that is comprised of "Table of Content" for showing the layers (maps), "Map Display Area" for viewing the map and "Menus and Tools" for working with the map.

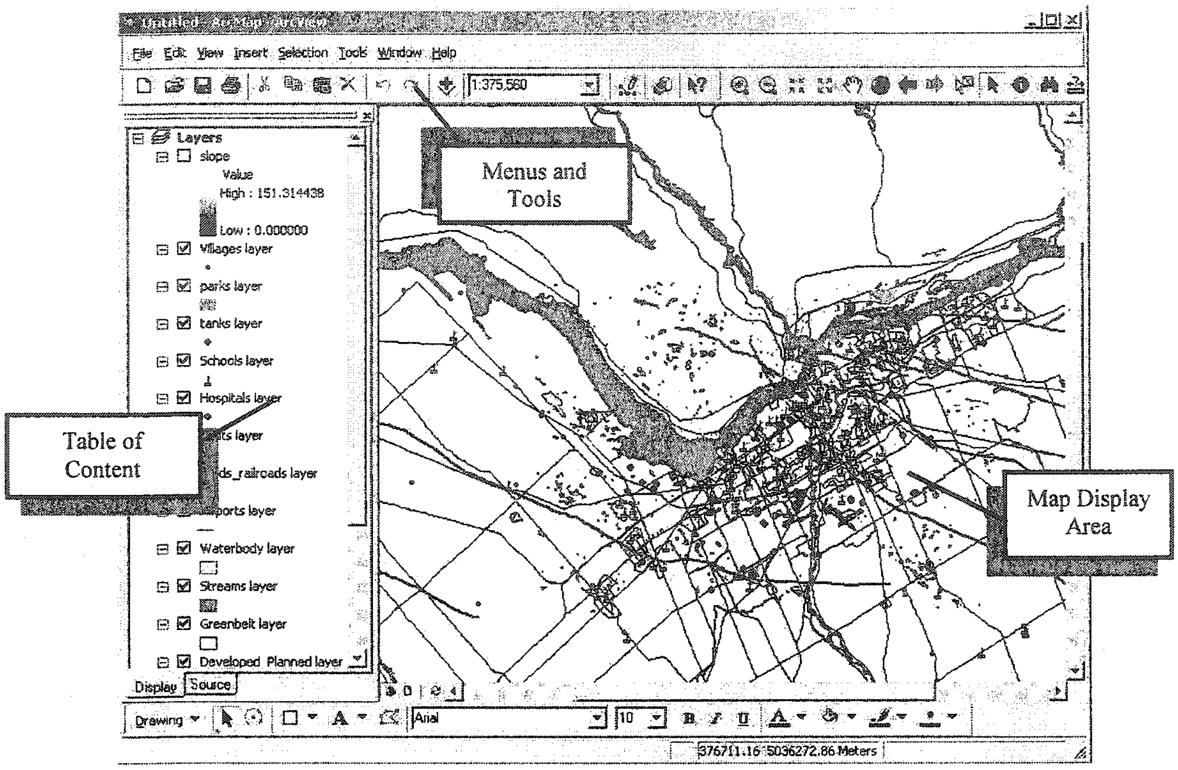


Figure 2.5 ArcMap Application

The interface of the ArcMap application can be customized to create toolbars, menus, keystrokes and add additional functionality in the most efficient way. Not only the existing work environment can be customized but it can also be linked to other developed commands or tools.

2.3. SUMMARY

The preliminary screening is a critical stage in the landfill site selection process. Hence, criteria and regulations used for this task must be identified and applied carefully in order to eliminate vulnerable areas concerning the environmental and socio-economic factors.

The use of geographic information system (GIS) is an efficient and suitable approach for the preliminary landfill site selection studies. GIS enables the user to work on all involved complex data, and outlines the results in a form that is transparent and understandable to the engineers and the general public. Using GIS in landfill siting is not new and has been applied by many users for different locations around the globe. Despite the variety of the approaches in each case, they are common in all or some of the following aspects. First, using the older version of GIS software in most cases, make the user apply additional data management or geoprocessing software in order to complete and obtain desirable results. Second, it is assumed that the users know the software and have an extensive knowledge regarding to GIS and map-overlay concepts.

The present study aims to introduce a new tool specifically designed for preliminary landfill siting within the most recent GIS software (i.e. ArcMap v8.2) to facilitate and systematize landfill siting procedure and assist developers, engineers and decision makers with different level of GIS knowledge to conduct this process. The new tool will also benefit from linking to data management and geoprocessing applications that make this tool more efficient and self-contained. Map-overlay interfaces designed as part of this tool facilitate and automate the map-overlay process and allow the user to repeat this process until acceptable results are obtained.

CHAPTER 3

LANDFILL SITE SELECTION TOOLBAR DESIGN

3.1. INTRODUCTION

The ArcGIS applications such as ArcMap are engineered for ease of use and powerful geographic display, query, and analysis. By their design, they are general and serve a broad audience of users. With the ArcObjects application framework, an unlimited freedom is provided to customize the user interface for users' business needs. New toolbars, buttons, tools, commands, and other elements can be added. Moreover advanced functions through custom commands can also be manipulated. Customizations can be selectively propagated through templates and above all, the functionality of applications may be significantly improved through extensions (Blades and Cameron, 2001).

In the present study and in order to enable site planners and engineers with different level of GIS knowledge to have an easily-applied tool for preliminary site–selection studies, ArcMap v8.2, a component of the ArcGIS Desktop, is customized and a new toolbar called landfill site selection (LSS) toolbar, is added to its interface. This toolbar is comprised of elements required for identifying potential sites for a landfill.

Such a customized toolbar will enable engineers to investigate and compare results of applying different criteria, constraints and scoring schemes on the final suitability map for landfill site in an area such as Ottawa, Canada.

3.2. ARCMAP CUSTOMIZATION - METHODS AND CONCEPTS

ArcMap customization can be accomplished through the following methods depending on the level of customization and security required.

a. "Customizing" dialog box
b. Full-Scale programming environment such as Visual Basic (VB)
c. Visual Basic for Application (VBA).

Applying the "Customizing" dialog box in ArcMap is the simplest way to modify the user interface without writing a single line of code. Figure 3.1 shows how to open this dialog box from within the ArcMap.

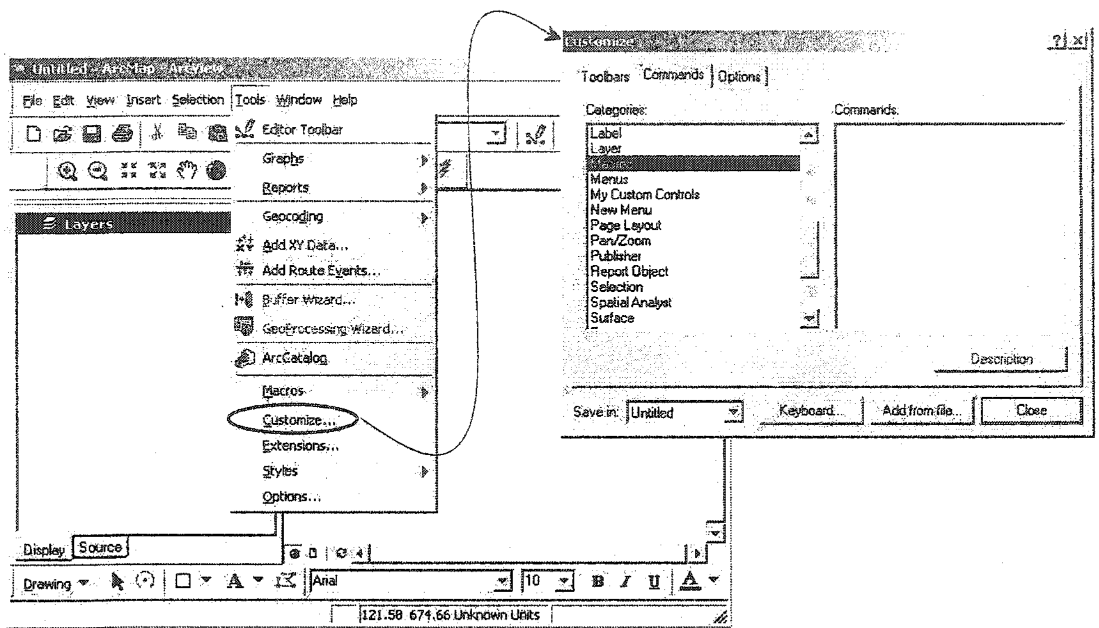


Figure 3.1 "Customizing" Dialog Box in the ArcMap Application

New built-in tools, commands, toolbars and keystrokes can be created, added or removed. In addition to changing and organizing the existing work environment, it provides the users an extra functionality by linking user's code to menu commands and tools.

In this method, however, it is not possible to create user-interface and interact with the user. Therefore, sometimes it is needed to dynamically alter the user interface programmatically by using VBA or VB.

The majority of customization needs can be achieved through using VBA inside ArcGIS Desktop. Tools, menus and modules can be extended with custom commands. In fact, VBA, embedded within ArcMap, is the most common way for developers to customize the ArcGIS Desktop applications such as ArcMap.

Figure 3.2 shows how to access visual basic editor (VBE) in the ArcMap that presents an environment for writing, testing and debugging Visual Basic code.

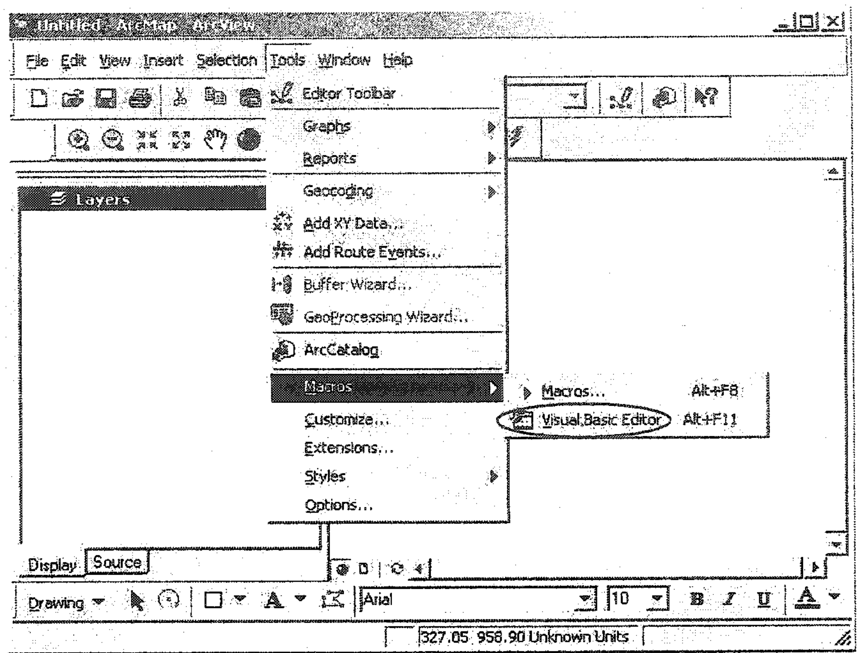


Figure 3.2 "Visual Basic Editor" Button in the "Tools" Menu

VBA macros and applications are stored in an ArcGIS document or template. They do not exist outside the document or template. Consequently, if the application requires to be distributed independently of an ArcGIS document, one of the other development environments such as Visual Basic must be considered. All customization will only appear while the current template or document is open. Once the document or ArcMap is closed, the changes are removed.

When working in the VBA development environment, it is automatically connected to the ArcObject library that contains the built-in interfaces and classes required for customizing ArcMap. In this method, however, executable file (EXE) or dynamic link library file (DLL) cannot be compiled and customization can only be saved as a map document (mxd) or as template (mxt) file (ESRI, 2003).

As stated above, one of the disadvantages of writing code in VBA is that it must be stored inside a document, such as a map file or template. Using a full-scale programming environment, such as Visual Basic or C++ allows compiling the code in a separate file. A DLL file, for instance, can be plugged into the application as a new component or toolbar. The advantage of having the code compiled in DLL is that it is easier to share with other users and it is much more secure because users cannot see or modify the actual code. Unlike programming with VBA, the ArcObject library will not be automatically available in this environment therefore the developer must make an explicit reference to ArcObject library (ESRI, 2003).

In the current study, LSS toolbar is developed by using VBA language. The next sections will go through the process of developing the LSS toolbar; however, some basic concepts must be discussed first as follows.

3.2.1. BASICS OF COMPONENTS OBJECT MODEL (COM)

ArcMap is based on Microsoft component object model (COM) technology. When an ArcMap application needs to be developed, ArcObject components are used. A complete discussion of COM is outside the scope of this study; however, the following sections cover the concepts that must be known in order to extend the existing ArcMap application through either VBA or VB. "The level of understanding required depends on the depth of customization or development that is undertaken" (Razavi, 2002).

To understand COM, it is important to know that it is not an object-oriented language, but a protocol or standard. COM is a methodology of software development. COM defines a protocol that connects one software component, or module, with another as well. It also allows building reusable software components that can be dynamically interchanged between applications (Cameron, 2001).

For example, an ArcMap application can also be considered a component because it offers an application-programming interface (API) so it is possible to develop applications for performing special queries. This means, ArcMap application is reused in order to develop new applications and developers do not require access to the source code, header files, or object libraries in order to extend the system. Software reuse is one the main COM objectives.

3.2.2. INTERFACE – CLASS

COM defines a programming model, known as interface based programming. ArcMap application is developed with manipulating ArcMap objects (i.e. classes) via their interfaces and therefore developing with COM means developing using interfaces.

Cameron (2001) defines an interface as a group of related methods or functions that interact with a class or object. A class describes the properties and methods that facilitate access and manipulation of objects. An object in an application is a piece of code derived from classes that maintains some property values and can operate on those values through several methods. Properties are attributes of an object and methods are used like a function to operate on the object or carry out a specific task (Razavi, 2002).

Figure 3.3 displays a sample class with its interfaces, methods and properties. Methods are illustrated with arrows and properties with squares.

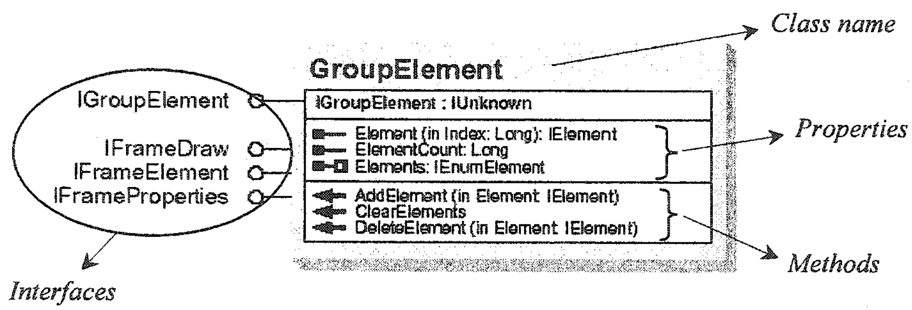


Figure 3.3 "GroupElement" Class, Interfaces, Properties and Methods

Each class and interface has a different identifier so that components do not conflict. COM uses globally unique identifiers (GUIDs), 128-bit numbers that are unique. Hence, components can be called and retrieved by their GUIDs during the development.

3.2.3. OBJECT LIBRARIES

Libraries are the way software components are defined independently of the programming language. In general, libraries contain class definition, which are stored in files with extensions such as DLL, EXE, OCX or OLB. Visual Basic for Application has its own library that contains all the required classes. This library is defined as ArcObject library and named esriCore.olb. In all cases when developing ArcObjects-based applications, it is required to load the ESRI Object Library esriCore.olb. When programming an application with VBA, a default set of class libraries are referenced automatically. This is not the case when programming in a standalone environment such as Visual Basic. Therefore an explicit reference to all external libraries is needed in order to locate the entire object and interface types (ESRI, 2003).

3.2.4. OBJECT MODEL DIAGRAM

To ensure that the components of the new developed toolbar will be understood by the ArcMap application, a series of related interfaces must be implemented for each component. For that reason, the relationship between classes and their interfaces can be reviewed efficiently by using an object model diagram.

ArcGIS include several object model diagrams that describe how the ArcObject library is put together. Theses diagrams are invaluable tools that indicate graphically how to work with certain classes and how each class is related to others. Conceptually, there is only one ArcObject model and all of the ArcObject classes are defined within a single class library (i.e. esriCore). However, for the sake of convenience, there are several ArcObject model diagrams, which describe subsets of ArcObject classes. The diagrams are organized according to a logical group of objects.

Object models and their components involved in the present study are discussed in detail in the sections that follow.

3.3. DEVELOPING THE LSS TOOLBAR USING VBA

The LSS toolbar structure presented in this thesis is designed to: (1) categorize and organize the built-in ArcMap tools required for landfill siting, (2) create two new interfaces associated with two map-overlay models to facilitate the map integration process and present the results more easily and more efficiently.

To achieve the abovementioned objectives, Visual Basic code is written in the VBE environment, embedded in the ArcMap application and saved as different macros. These macros make the LSS toolbar active and execute its components subsequently. The following steps indicate the process of developing these macros.

1. Launching Visual Basic editor (VBE)
2. Implementing the Required Interface(s)
3. Writing Code in VBE, Testing and Debugging
4. Saving and Running VBA Project
5. Protecting Code

Each of these steps is described in the following sections.

3.3.1. LAUNCHING VISUAL BASIC EDITOR (VBE)

Visual Basic editor (VBE) provides an interface for creating forms and writing code. It also provides several utilities for debugging and getting help. After starting the ArcMap application with a new or existing template, VBE can be executed using shortcut key "Alt + F11" as was shown in Figure 3.2.

Since VBA code in the macros are stored in the ArcMap templates, the latter must firstly be opened to access the VBA macros.

3.3.2. IMPLEMENTING THE REQUIRED INTERFACES

In order to identify the required interfaces to develop the new toolbar, the object model diagrams are used. These models describe components including the core ArcMap application that is a starting point for customizing the user interface and access to the map document data. They also provide an overview of each interface including a description of what they can be used for. The following object models are used in the present study.

1. "Application Framework" object model
2. "ArcMap" object model
3. "Spatial Analyst" object model

Each of these object models is described in the following sections.

Functions and Methods of the classes in the Application Framework object model allow customizing the user interface programmatically. This includes making new toolbars, menus and activates their components in ArcMap. Figure 3.4 shows a part of the Application Framework object model that includes the interfaces involved in the present customization. These interfaces and their variables, functions and methods are described in the following sections.

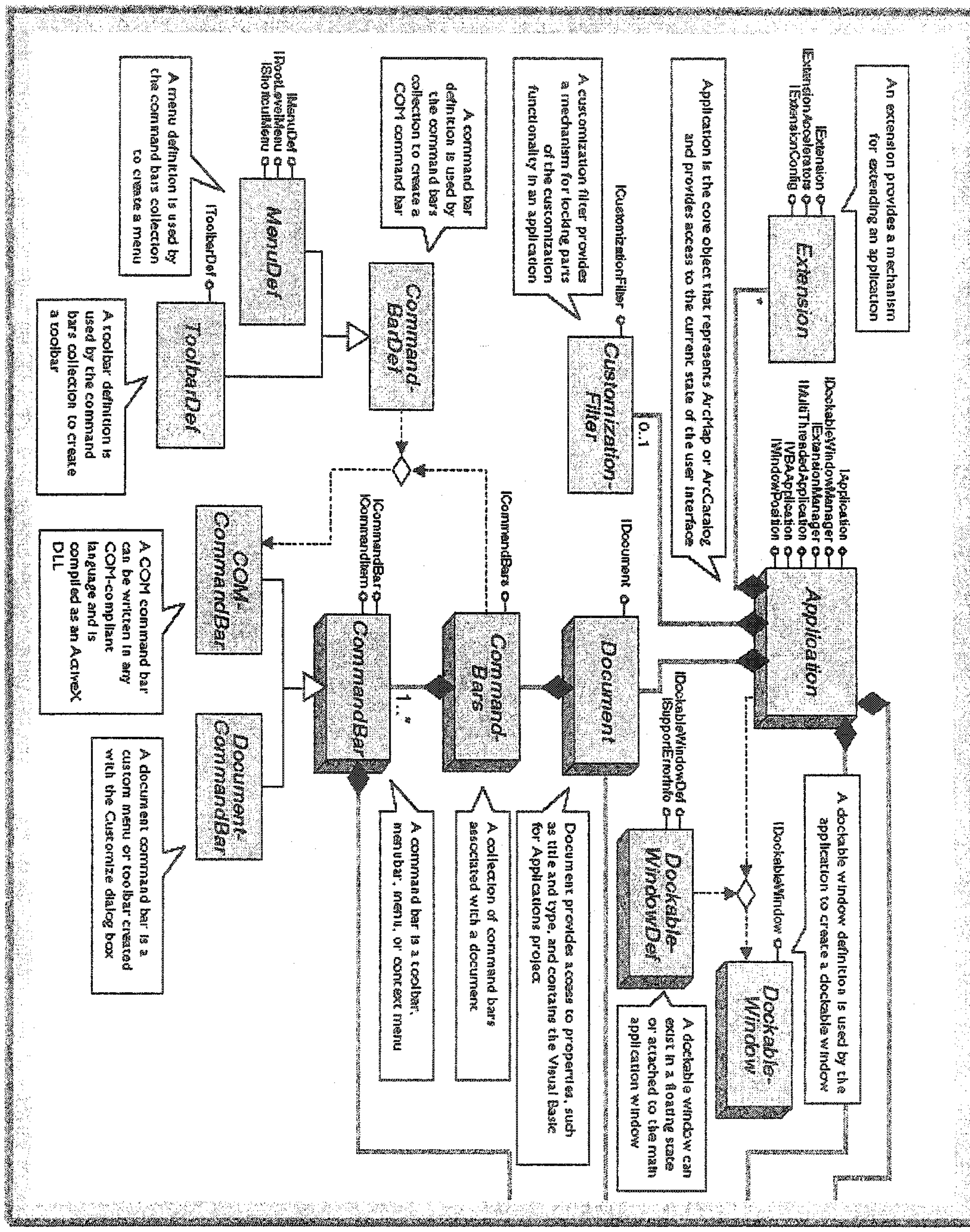


Figure 3.4 Application Framework Object Model (Blades *et al.*, 2001)

3.3.2.1. IApplication and IDocument Interfaces

As a starting point, ArcMap offers two preset variables, which are always available while running the ArcMap. The two objects can be accessed with the keywords *Application* and *ThisDocument*.

Application is the core object that represents an ArcGIS application (e.g. ArcMap). "*Application*" preset variable is the root object for the running application and points to the current application and IApplication interface that provides access to the document object, extensions, the statusbar, the currently selected tool and Visual Basic Editor. There are also several methods that allow opening, saving, and printing documents, locking and unlocking the application from user customizations, displaying dialogs, and exiting the application. Any other object related to the current map document, display environment, or application command functions may be found by starting here.

Whenever the user is using the ArcMap application, a document is open. "*ThisDocument*" preset variable points to the document that is currently open in the application (i.e. Normal.mxd). ThisDocument represents the document object and points to the IDocument interface. Through ThisDocument, all properties and methods on the IDocument interface can be accessed directly. These include the document's title, type, accelerator table, commandbars collection, parent application, and Visual Basic project (Burke, 2003).

Figure 3.5 shows the IApplication and IDocument interfaces and their methods and properties.

3.3.2.2. ICommandBars Interface

CommandBars is a collection of all the toolbars, menus and command bars available to a document. There are two types of custom command bars that can be created, (1) document commandbars, and (2) COM commandbars. Document commandbars can be created using build-in functionality in the application. COM commandbars can be produced through defining menus or toolbars in a COM base language (i.e. Visual Basic or Visual C++) and compiling them into an ActiveX DLL (Blades and Cameron, 2001).

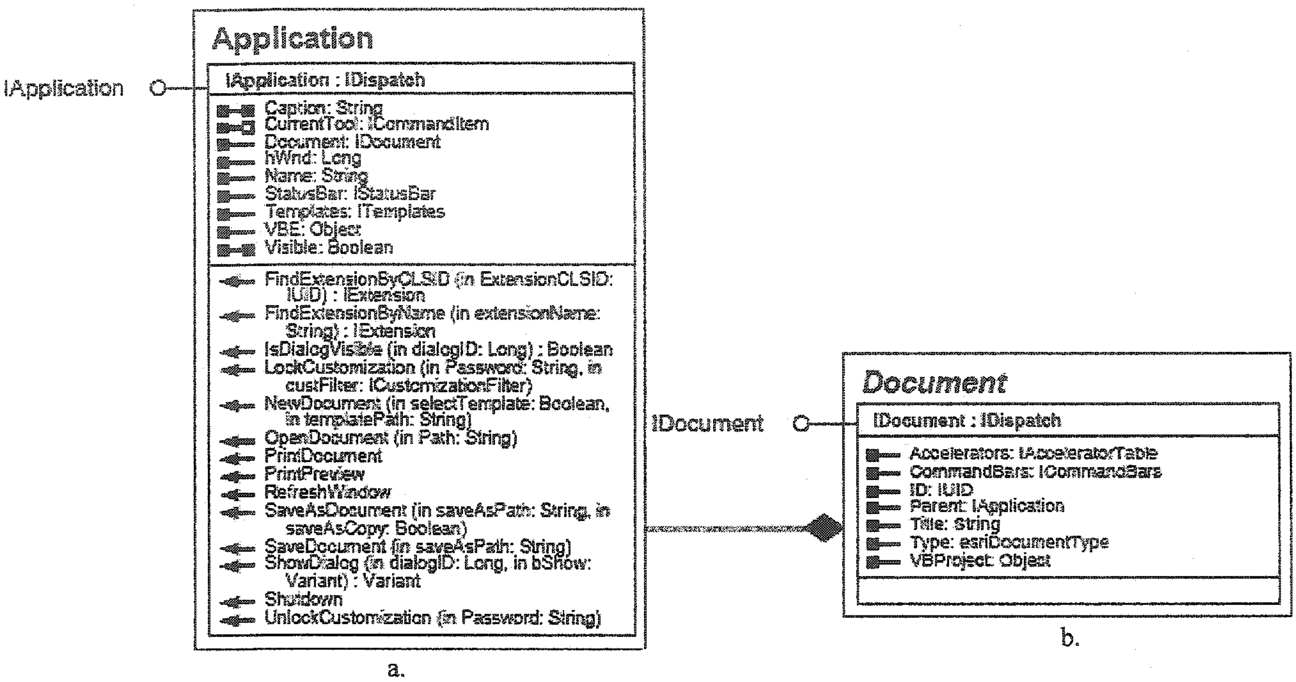


Figure 3.5 (a) IApplication and (b) IDocument Interfaces in the Framework Object Model (ESRI, 2001b)

ICommandBars interface allows setting properties for the command bars and to create, find or hide command bars. This interface is used to create a new commandBar by using "Create" method and find and locate a particular commandItem in the collection by using "Find" method. ICommandBars interface and its methods and properties are shown in Figure 3.6.

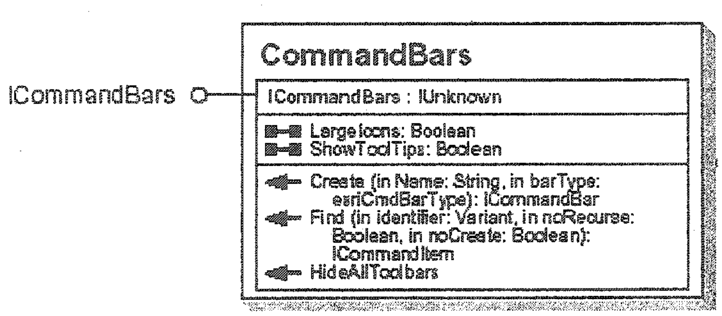


Figure 3.6 ICommandBars Interface in the Framework Object Model (ESRI, 2001b)

Three different types of command bars are available on the ArcMap: (1) Toolbars, (2) Menus, and (3) Pop-up menus. Toolbars may contain menus and these containers incorporate the commands. Menus must be contained by a toolbar or another menu. Pop-up menus are implemented when a user right-clicks the mouse. "Create" method can be used to produce new command bar objects. This method has two arguments; the name of the new command bar and the type. Since menu must always exist on another command bar, "Create" method on command bars cannot be used to generate a new menu. Nevertheless, "CreateMenu" method on the ICommandBar interface can be applied as discussed in the following.

3.3.2.3. ICommandItem and ICommandBar Interfaces

ICommandItem interface is composed of items such as buttons, tools, combo boxes, etc that appear graphically on the user interface. By using the ICommandItem interface, properties such as "Caption", "Image", "Message", "ToolTip", "Display Style" and "Help ContextID" can be declared.

To obtain a reference to a particular command item, "Find" method on ICommandBar interface must be used. The Find method places a command item using a unique identification number (UID) in the operating system and will be executed by calling the "Execute" method on the ICommandItem interface. Alternatively, ArcID module can look up the required UID using a name of command category followed by the name of the command itself.

"Dock" method on the ICommandBar interface can be called to have the toolbar be free-floating. Once a new toolbar is generated, command items can be placed using "Add" method on the ICommandBar. This method requires a UID that identifies the command item to add. Alternatively, a new menu can be added to the new toolbar (i.e. LSS), using "CreateMenu" method on the ICommandBar interface. "CreateMacroItem" method is used to add other macros to the toolbar (Blades and Cameron, 2001).

Figure 3.7 shows the ICommandItem and ICommandBar interfaces and their methods and properties.

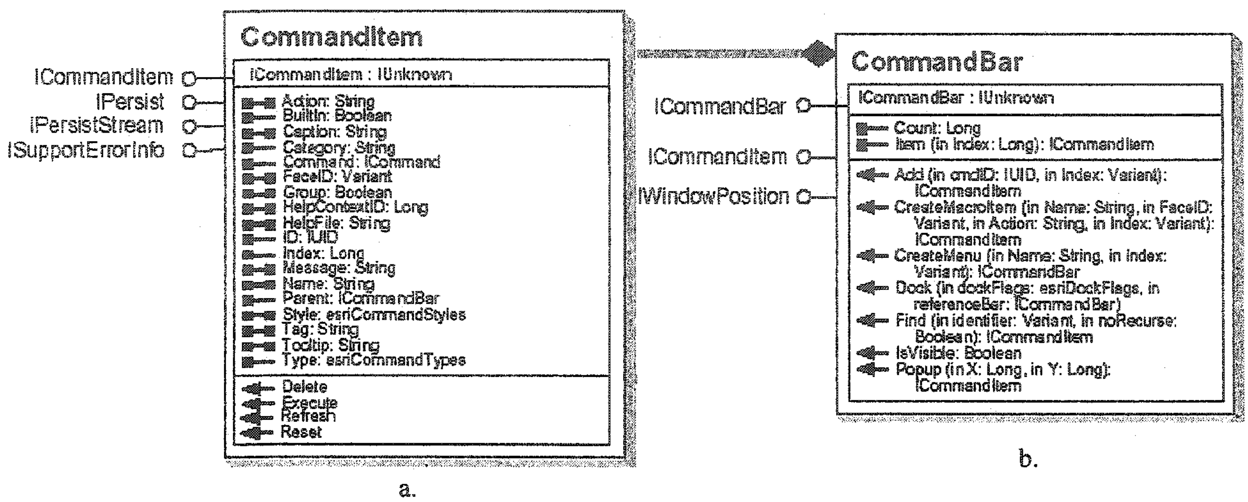


Figure 3.7 (a) ICommandItem and (b) ICommandBar Interfaces in the Framework Object Model (ESRI, 2001b)

3.3.2.4. <u>IGetUserAndPasswordDialog</u>

As an option, the user must provide username and password to access the LSS toolbar. IGetUserAndPasswordDialog interface provides access to members that work with a dialog for getting user and password information (Blades and Cameron, 2001). Figure 3.8 displays this interface and its properties and single method.

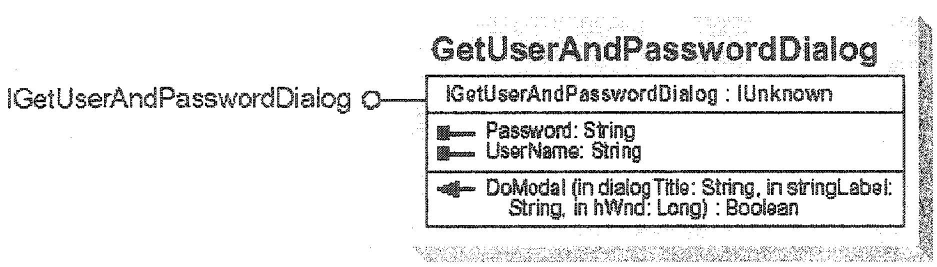


Figure 3.8 IGetUserAndPasswordDialog Interface in the Framework Object Model (ESRI, 2001b)

ArcMap object model diagram describes map components comprising a hierarchy of maps, layers, and elements. These objects are starting points to access the map document data. Similar to the application framework, this object model contains several interfaces.

The following are the interfaces involved in developing the LSS toolbar.

3.3.2.5 <u>IMxDocument interface</u>

IMxDocument interface is a first step for much of the other objects in ArcMap. MxDocument represents the current ArcMap document. This interface provides access to the current active view, the currently selected map, all of the maps, and the style gallery. For example, it has properties like "Maps" property that returns a collection of all maps in the document and "FocusMap" property will return the map that is currently selected for user interaction. Figure 3.9 illustrates the IMxDocument interface and its methods and properties.

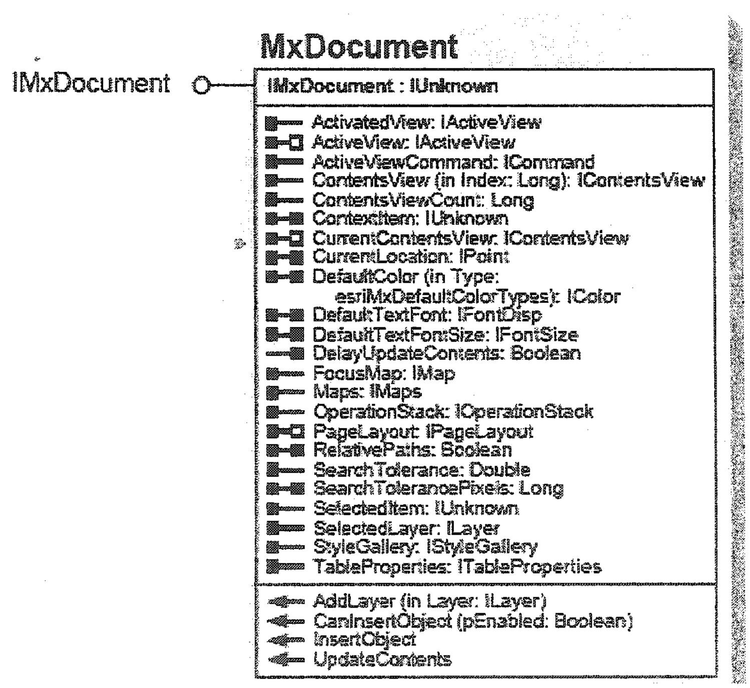


Figure 3.9 IMxDocument Interface in the ArcMap Object Model (ESRI, 2001b)

3.3.2.6. <u>IMaps and IMap Interfaces</u>

IMaps interface provides access to members that control the maps collection. For example, "Maps" property in the IMxDocument interface returns a collection object that contains the entire document's maps. Once a reference to this collection is made, each individual map can be accessed according to its index position that must be provided when "Item" property in the IMaps interface is applied. Index position counts maps in the collection from top to bottom, starting at 0.

Maps are nothing more than a collection of layers. As with accessing a map from the IMxDocument, it is possible to either access a particular layer or retrieve all layers in a map. Unlike the "Maps" property in the IMxDocument, which returns a collection of maps, the "Layers" property in the IMap interface, returns an object known as an enumeration or enum. An enumeration is a collection of objects accommodated in a single object. An individual layer can also be obtained directly from the IMxDocument interface by using the "SelectLayer" property (ESRI, 2003).

Each map in the same document can have a different set of layers with various extents and even with different spatial references such as map projections or map units. IMap interface maintains a collection of these types of map layers. It is also a starting point for many of the tasks with a map such as adding, deleting, and accessing map layers containing data from various sources. In order to determine the exact type of the layer, it is necessary to query the object for type-specific interfaces.

Properties and methods available in the IMap interface, allows performing the following tasks: (1) Accessing to associate map-surround objects such as legends and scale bars with the map, (2) Accessing the various properties of a map including the area of interest, the current map units, and the spatial reference, (3) Selecting features, and (4) Accessing the map's current selection. Figure 3.10 shows the IMap and IMaps interfaces and their methods and properties.

3.3.2.7. ILayer and IRasterLayer Interfaces

Once a particular map is referenced, the properties of the IMap interface enable user to refer to each individual layers within the map. A map may contain layers of different types such as raster layer, coverage annotation layer, group layer and feature layer. Despite this variety, all ArcMap layers will support the ILayer interface. On the other hand, ILayer interface provides access to members that work with all type of layers. To determine the exact layer type, a query must be made using "Type Of" command (Burke, 2003).

Figure 3.11 presents the ILayer and IRasterLayer interfaces and their methods and properties.

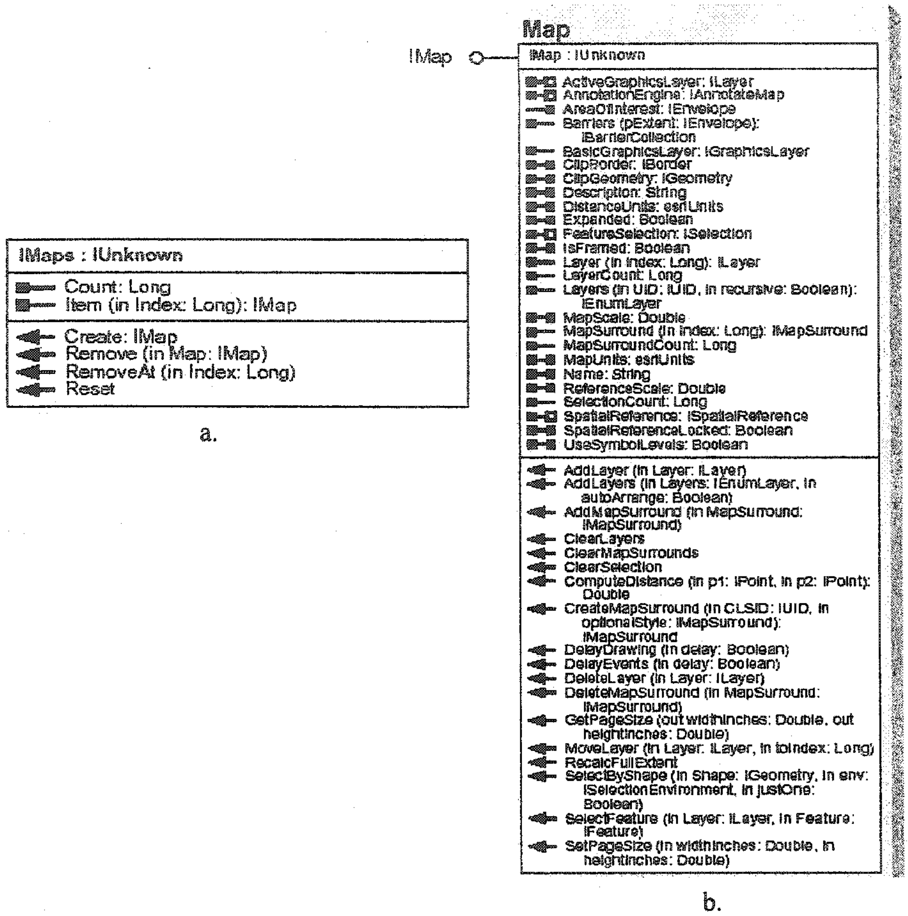


Figure 3.10 (a) IMaps and (b) IMap Interfaces in the ArcMap Object Model (ESRI, 2001b)

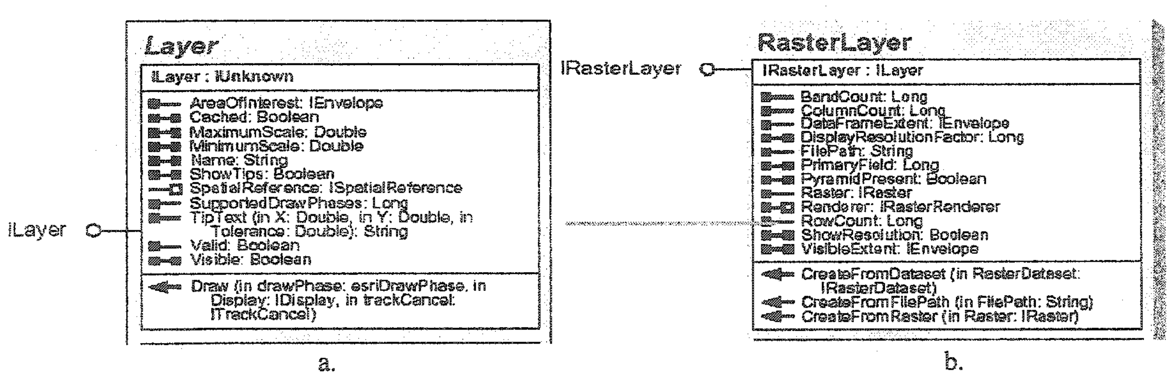


Figure 3.11 (a) ILayer and (b) IRasterLayer Interfaces in the ArcMap Object Model (ESRI, 2001b)

The last object model used in this study is "Spatial Analyst". This model works closely with the raster data and is composed of a collection of objects to perform raster analysis. Similar to the previous object models, spatial analyst model holds several interfaces. In the following, only those interfaces involved in developing the LSS toolbar are discussed.

3.3.2.8. IMathOp and IBitwiseOp Interfaces

Since in this study, map integration process involves arithmetical and bitwise operations on a set of layers, IMathOp and IBitwiseOp interfaces that provide access to members that control the mathematical and bitwise operations are applied. Figure 3.12 shows the IMathOp and IBitwiseOp interfaces and their methods. Methods such as "AND", "OR", "XOR", "SUM", "TIMES" and "DIVIDE" are some of the useful members that accomplish the map overlay task in this study.

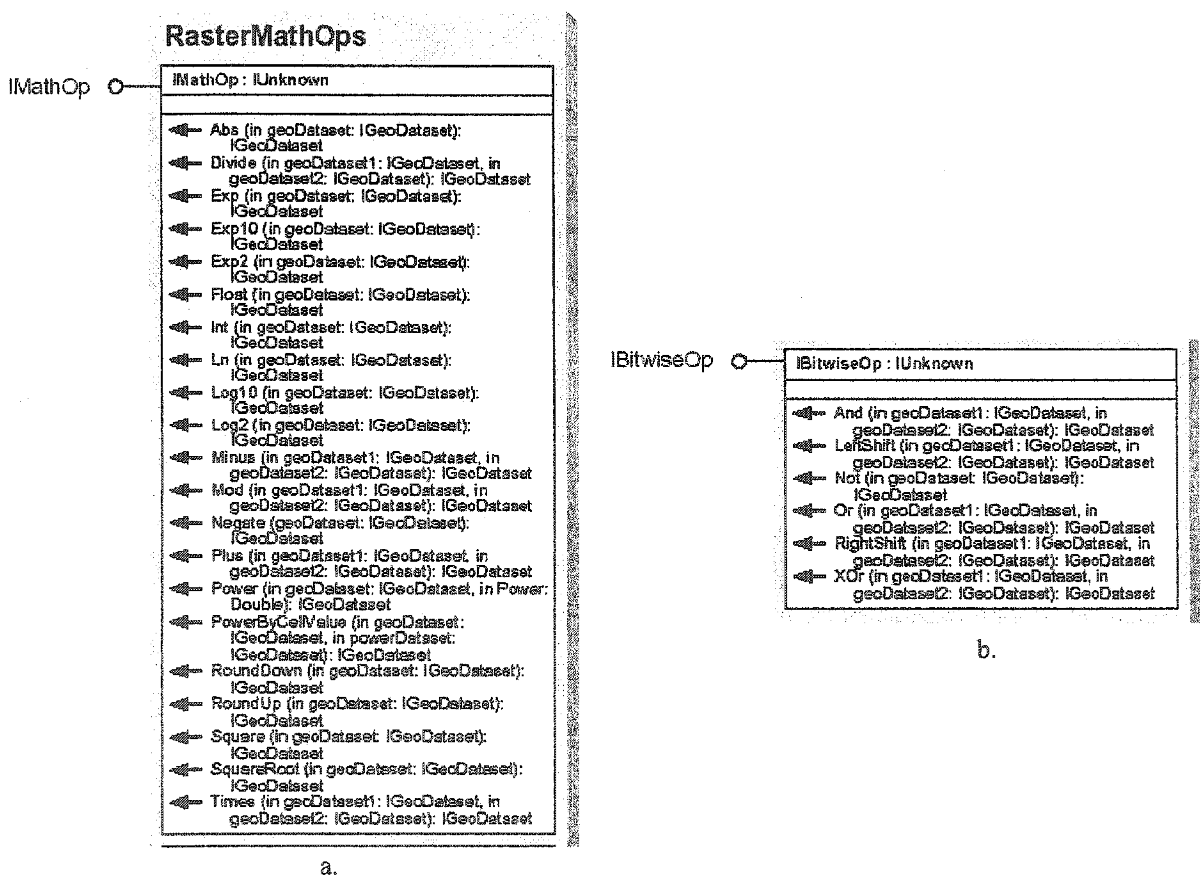


Figure 3.12 (a) IMathOp and (b) IBitwiseOp Interfaces in the Spatial Analyst Object Model (ESRI, 2001b)

3.3.3. WRITING CODE IN VBE, TESTING AND DEBUGGING

Once the required interfaces to develop the LSS toolbar were identified, the next step was to write code for the necessary methods and properties of each interface. In fact, this step is the core of the present study and it involved writing Visual Basic code in VBE to create macros and to execute the LSS toolbar. Visual Basic code written for this project is divided into five macros as follow.

1. GetUserPassDlg macro
2. Greeting macro
3. CreateLSSToolbar macro
4. Boolean User-form macro
5. Index User-form macro

A flowchart showing the general process of the aforementioned macros is shown in Figure 3.13.

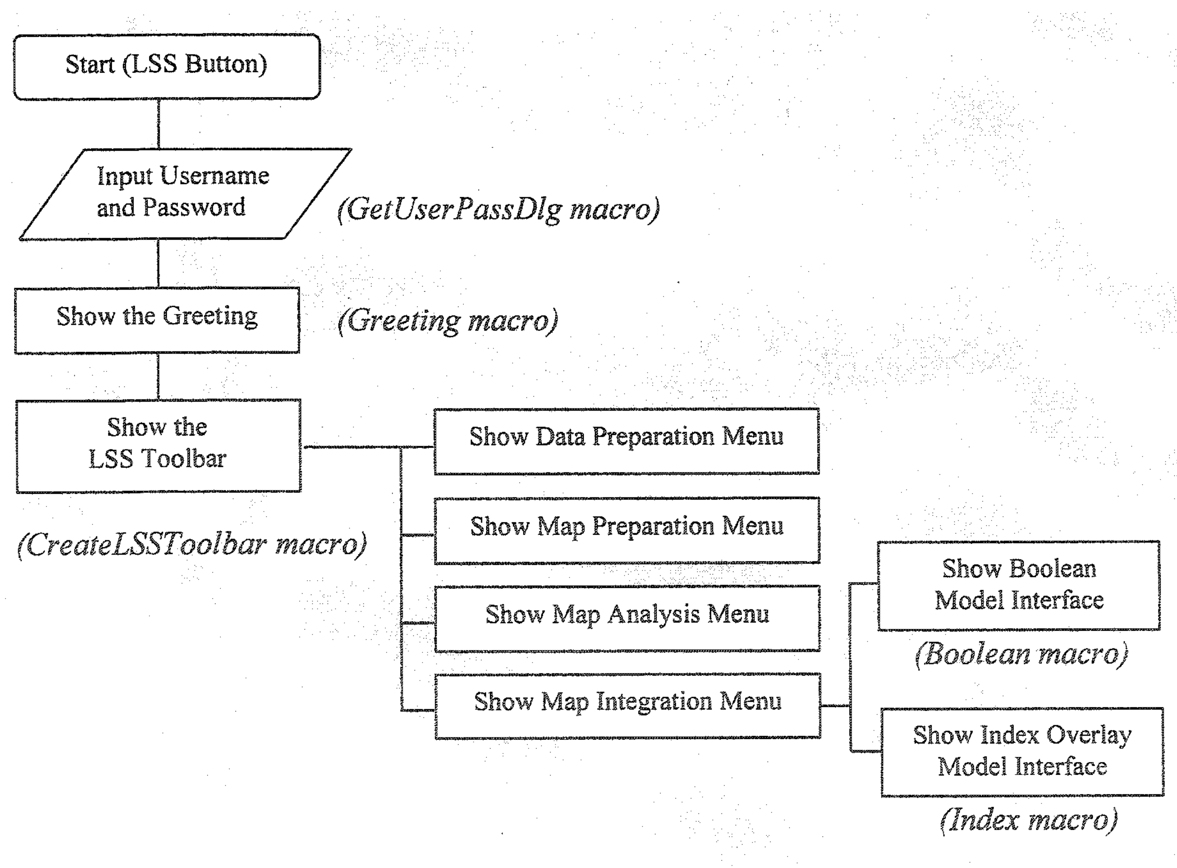


Figure 3.13 Flowchart of the Sequence of the Macros

Figure 3.14 displays these macros within ArcMap Macros dialog box. Each macro is a prerequisite for another one and therefore they need to be triggered in a correct sequence.

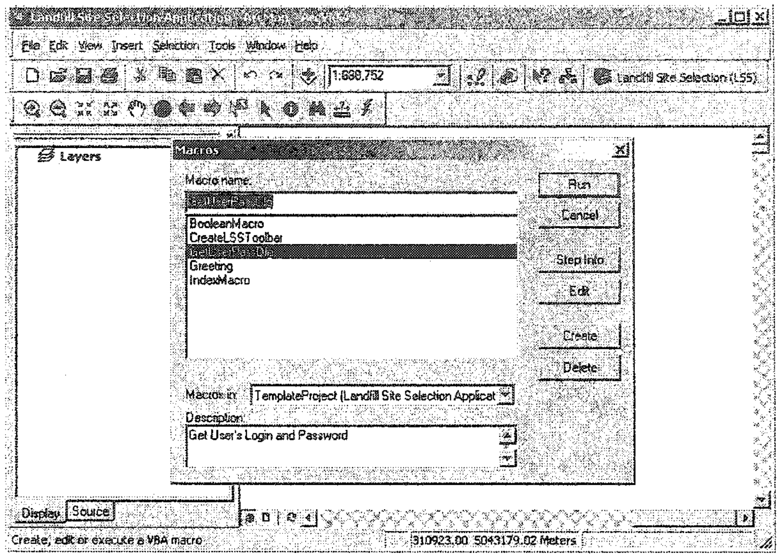


Figure 3.14 Macros Developed within the Landfill Site Selection Application

3.3.3.1. <u>GetUserPassDlg macro</u>

The starting point to run the application is GetUserPassDlg macro and it will be executed when the user clicks "Landfill Site Selection (LSS)" button located on standard toolbar as shown in Figure 3.15.

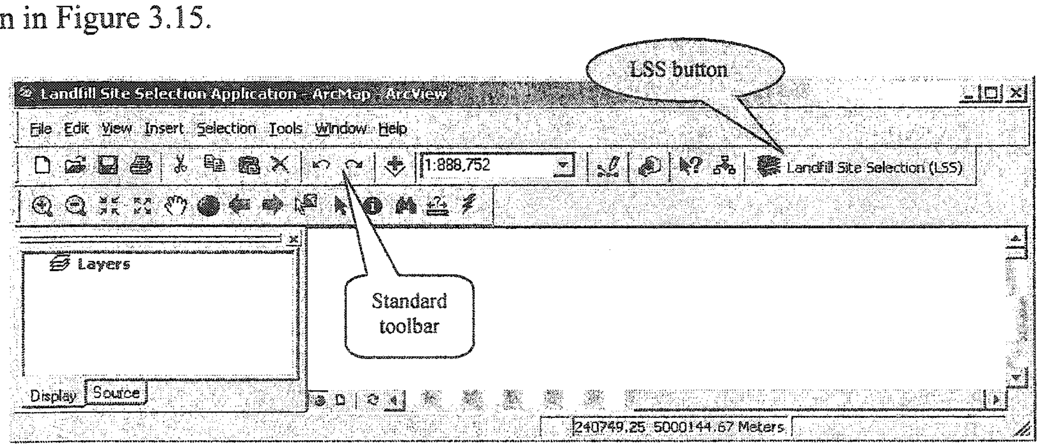


Figure 3.15 Landfill Site Selection (LSS) Button

Appendix A includes Visual Basic code written for this macro. This macro asks the "User name" and "Password" of the user as shown in Figure 3.16.

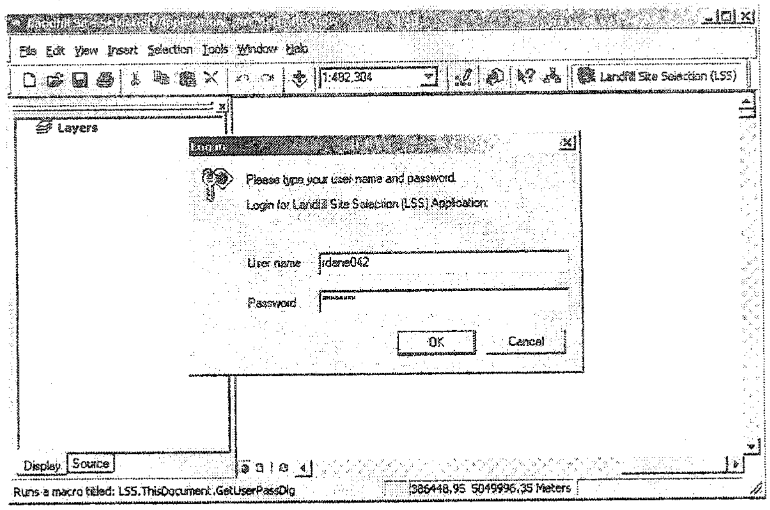


Figure 3.16 "Log in" Dialog Box

The user name and password properties can be modified in future and by the user who accesses this macro. As default, the user name and password are "*rdane042*" and "*72053000*" respectively.

3.3.3.2. <u>Greeting macro</u>

If the information entered by the user is correct, a greeting screen appears as shown in Figure 3.17. Greeting macro simply displays "frmGreeting" user-form with an "Image" control that holds the greeting image. The Visual Basic code written for this macro is available in Appendix B.

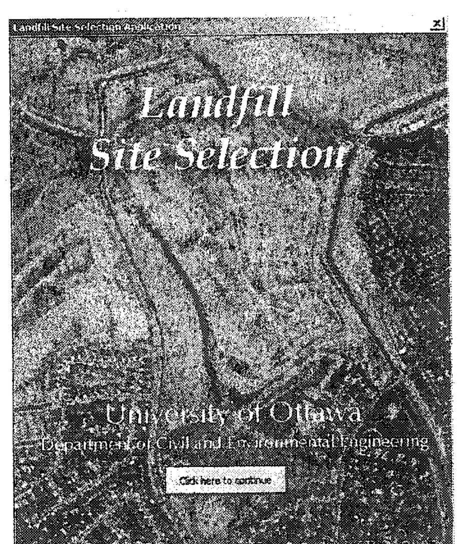


Figure 3.17 Landfill Site Selection Application Greeting

To continue the process, user must click "Click here to continue" button located on the button of the image that triggers the next macro as follows.

3.3.3.3. CreateLSSToolbar macro

Application Framework, part of the GIS Object Model diagram, and its interfaces allows the creation of the LSS toolbar structure, containing the existing built-in tools required for landfill siting within its first three menus names *Data Preparation*, *Map Preparation* and *Map Analysis* and two new interfaces required for map integration process within its last menu named *Map Integration*, programmatically. Figure 3.18 displays this toolbar and its menus. Visual Basic code written for this macro is available in Appendix C.

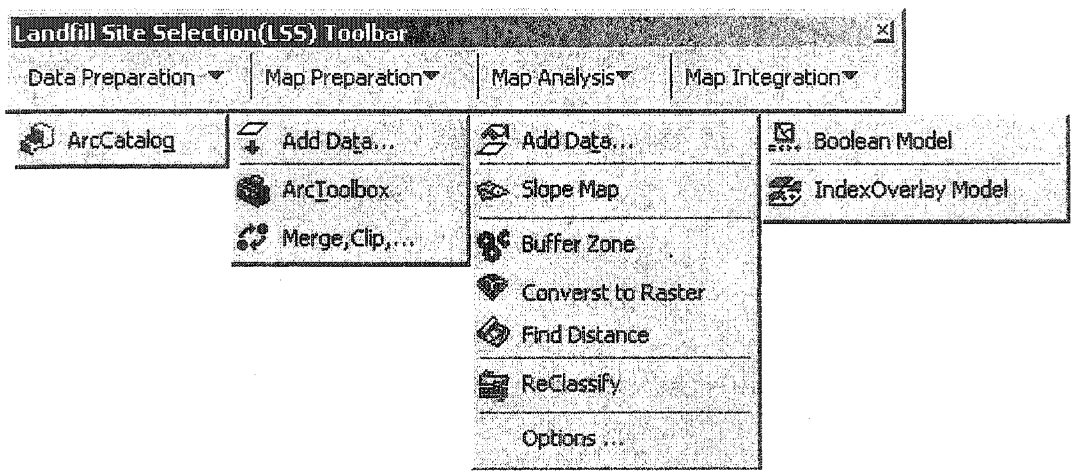


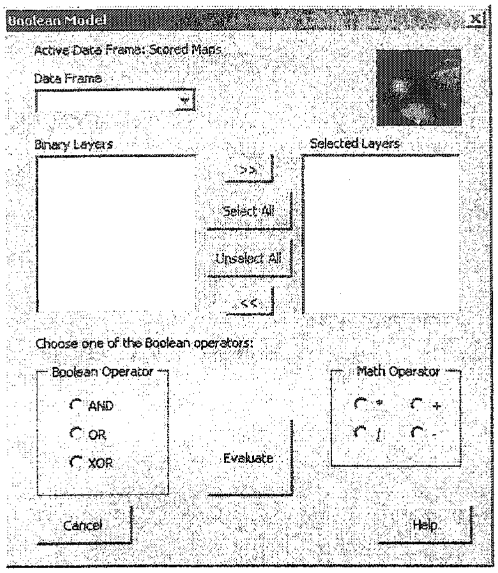
Figure 3.18 LSS Toolbar and its Menus

3.3.3.4. Boolean and Index User-form macros

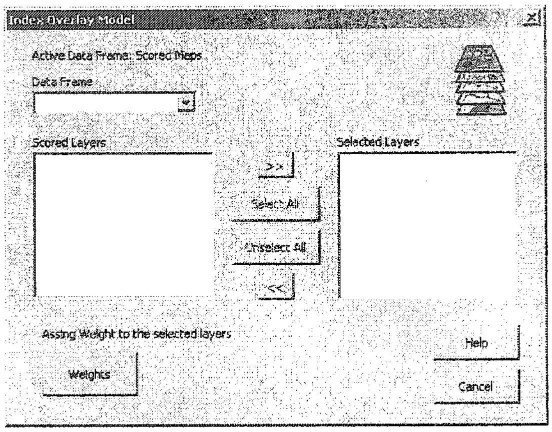
"Boolean" and "Index" user-form macros added to the "Map Integration" menu of the LSS toolbar provide two new interfaces developed in this study to facilitate map overlay process using the Boolean and the Index Overlay models.

Through the Boolean interface the user can combine the binary maps with one of the Boolean or mathematical operators and obtain the output map. Appendix D provides the Visual Basic code written for this user-form macro.

Index overlay interface enables the user to assign weight to the scored maps, combine and obtain the output map. Figure 3.19 illustrates these two new developed interfaces. Appendix E provides the Visual Basic code written for this user-form macro.



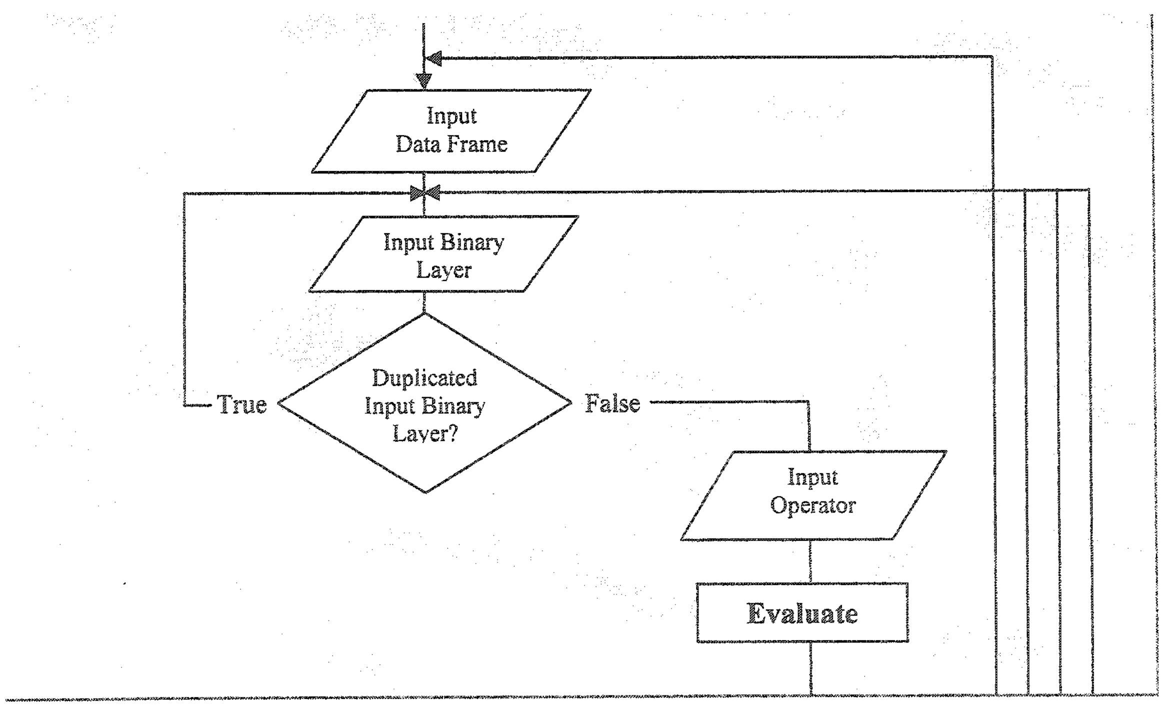
a.



b.

Figure 3.19 (a) Boolean Model Interface and (b) Index Overlay Interface Developed for the Map Integration Process

A flowchart showing how the Boolean Model interface works is shown in Figure 3.20.



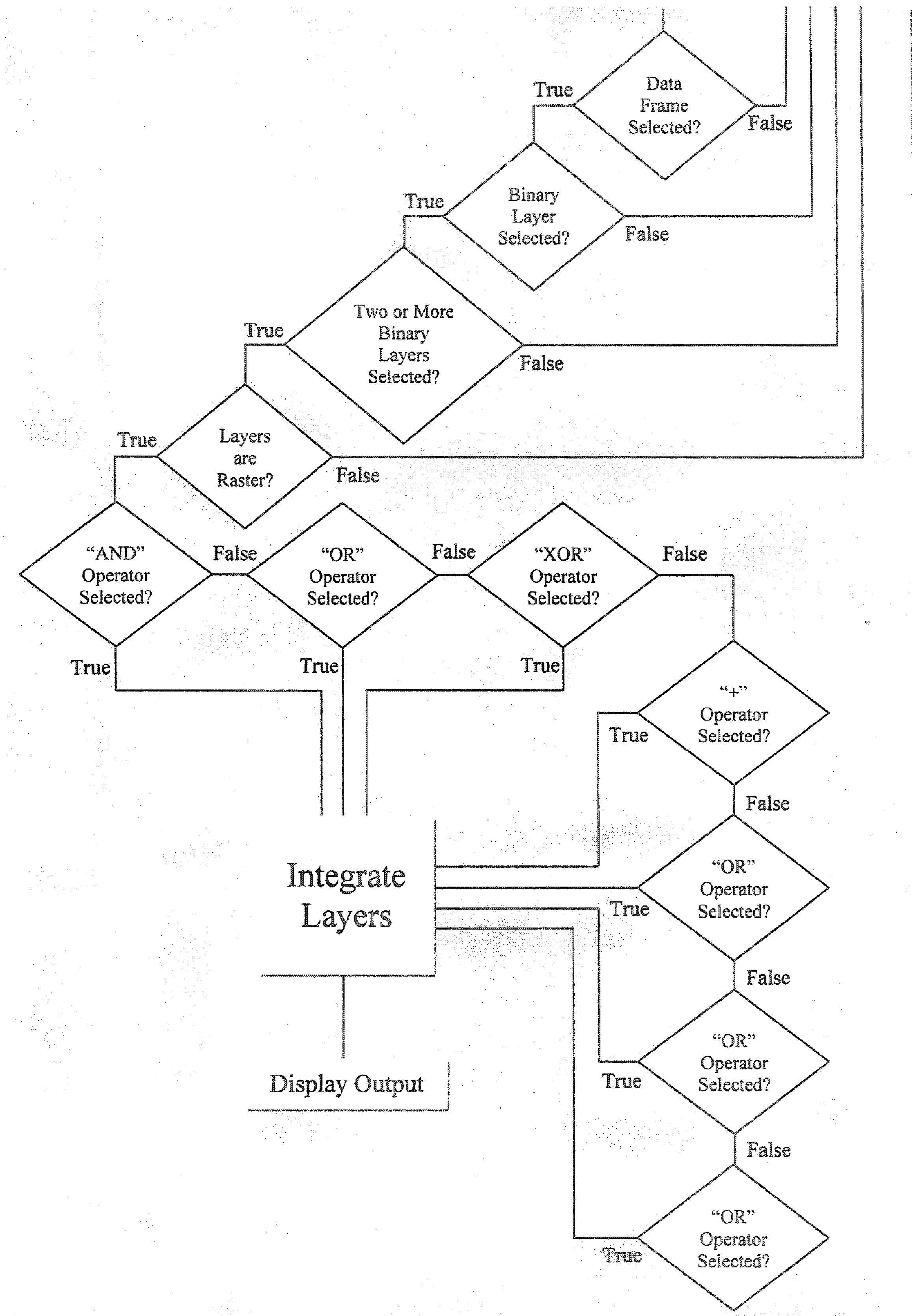


Figure 3.20 Flowchart of the Boolean Integration Process

A flowchart showing how the Index Overlay Model works is shown in Figure 3.21.

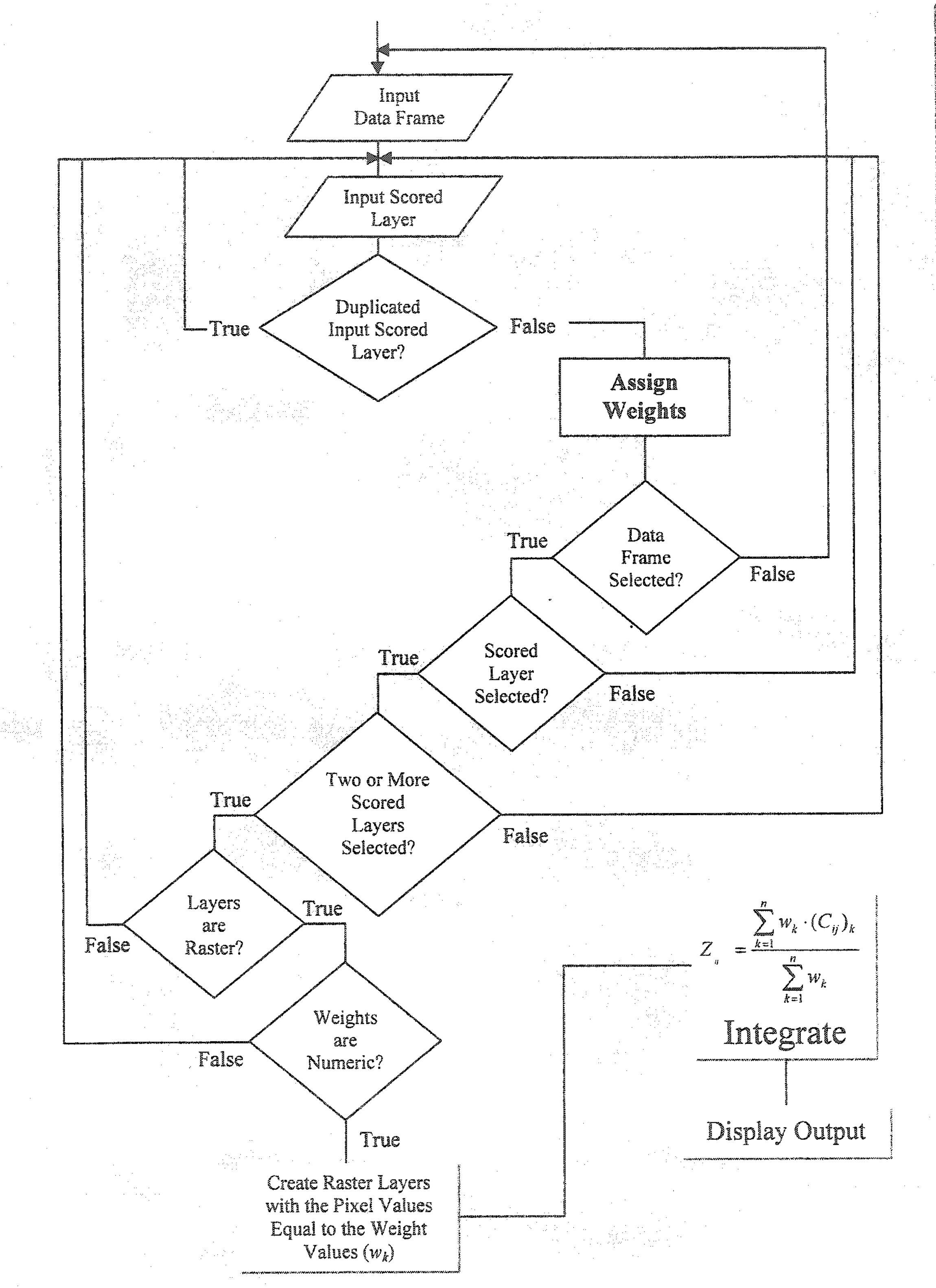


Figure 3.21 Flowchart of the Index Overlay Integration Process

3.3.3.5. Testing and Debugging

Visual Basic code written in the previous section must be verified before it can be executed and saved; therefore a thorough test is required. VBA interrupts running and displays a message when it encounters an error in the macro. The error that causes the macro to execute partially or incorrectly is known as a bug. In general there are three types of errors: (1) Language error, (2) Runtime error and Logic error, (3) Compile error associates with a mistake in the VBA programming syntax. A runtime error, as its name implies, occurs while the program is running. Logic error may not break up the execution of the macro still it generates an invalid result. These errors are usually more difficult to locate and correct (Perry, 1998).

Debugging is the process of testing the macro and removing bugs. It involves three tasks: (1) determine the problem bugs and their locations, (2) correct the bugs, and (3) reset the application to ensure that bugs were eliminated. VBE can help to avoid some of the compile errors while typing code. It also gives an option of going into break mode when a runtime error has occurred. The other option available in VBE is the ability of searching through the program code statements from the beginning or from a specific statement and executes them separately. This gives a chance to look for traces where a logic error might reside, examine variable values at each statement and consequently fixing the problem.

In the present study, Visual Basic code written for modules were tested, debugged and verified. Details of Debugging and testing techniques in Visual Basic such as adding break points, adding watch expressions, and stepping into and out of execution are beyond the scope of this thesis.

3.3.4. SAVING AND RUNNING THE PROJECT

In ArcMap there are three levels at which the macro and customization can be saved: (a) the normal template (normal.mxt), (b) an intermediate or base template (*.mxt), and (c) the current map document (*.mxd). The normal template contains all the original ArcMap graphical user interface settings. This template is stored in the user's Window's NT profiles directory. Base template can store customizations, which will apply to all maps subsequently produced from them. The most local level of customization is the map document that stores customizations only in that particular document (ESRI, 2003).

In the present study, all aforementioned macros are saved in a single module named "LandfillSiteSelection". Using a single module makes it easier to share VBA code with others. LandfillSiteSelection module and all user-forms are saved in a project with the default name as "TemplateProject" shown in Figure 3.22. Finally, the entire customization is saved as a template named "Landfill Site Selection Application" with (mxt) extension that contains the whole customizations code written in VBE.

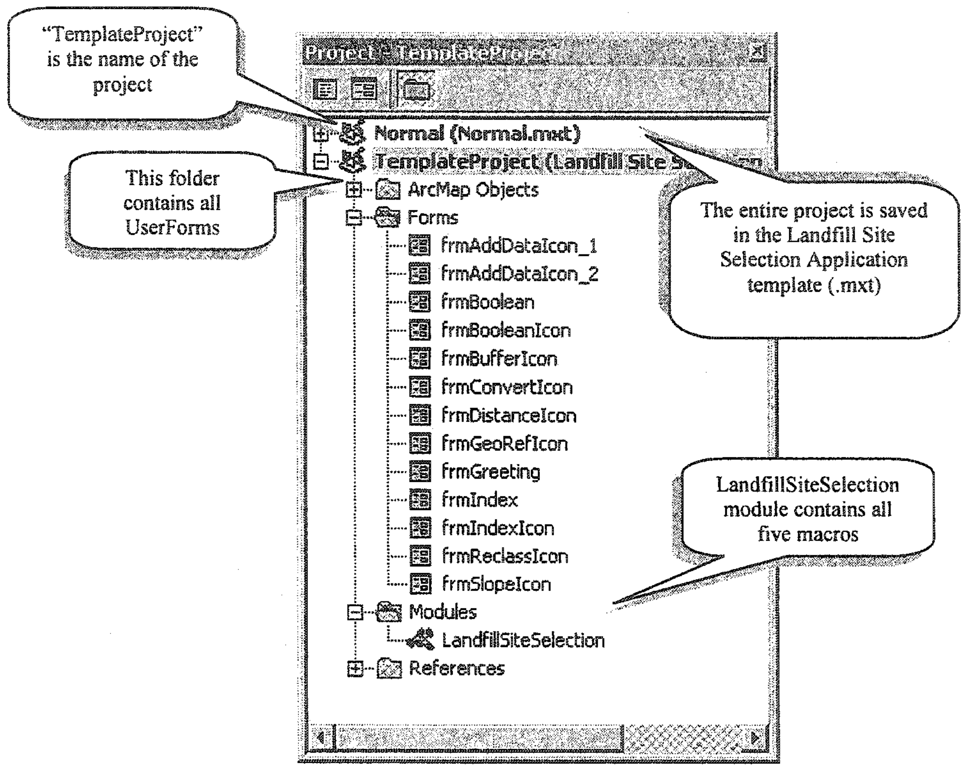


Figure 3.22 Landfill Site Selection Template and its Components

Additionally, code can be exported to a separate file and saved on disk as a backup. When exported, a module's extension will indicate whether it is a UserForm (.frm), a standard module (.bas) or a class module (.cls).

In the present study, "ThisDocument" class module, "LandfillSiteSelection" standard module and all "UserForms" are exported and saved in the "LSS_Exported_Code" folder as shown in Figure 3.23. These files can be imported into other projects such as another ArcMap document or even a standalone Visual Basic project; however, they cannot be executed except in the context of ArcMap application.Landfill Site Selection template can be saved anywhere on disk. Once it is saved, user can access the file and run it.

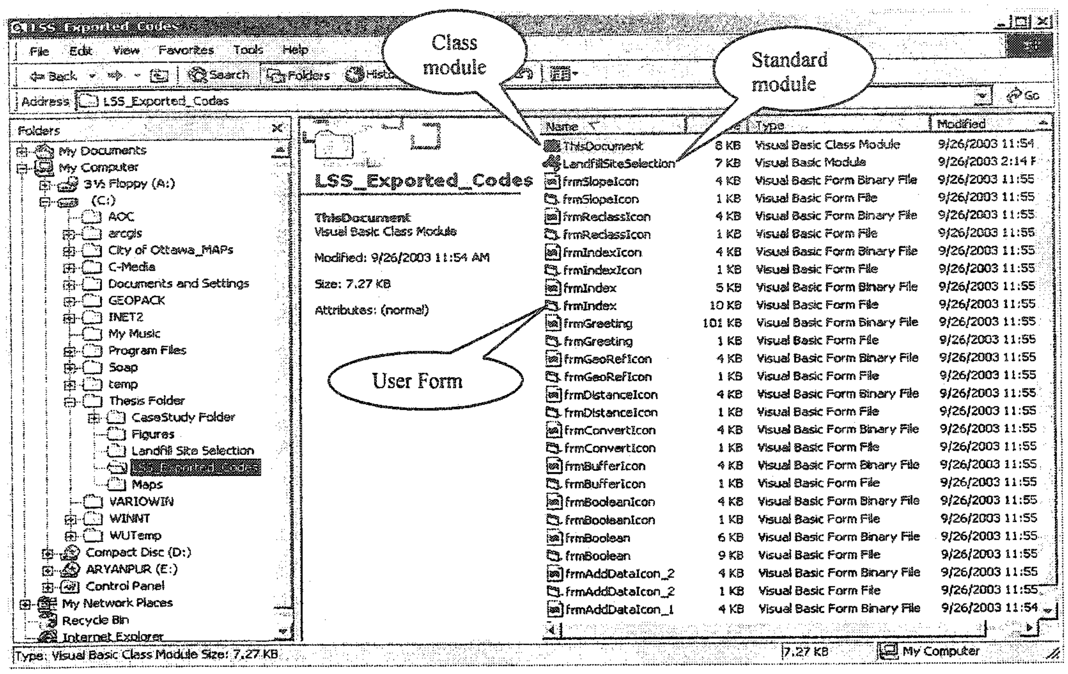


Figure 3.23 Landfill Site Selection Template Exported Files

3.3.5. PROTECTING CODE

In order to protect the code from modification or prevent others from accessing the code and customization, "Lock Customization" tool, available in the "Options" tab of the customizing dialog box, can be used as shown in Figure 3.24.

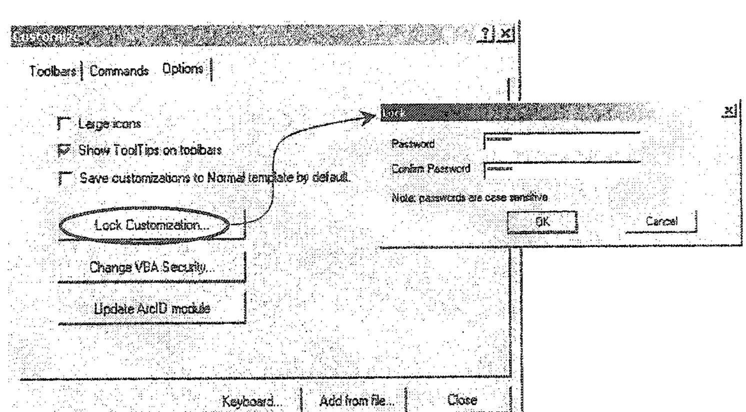


Figure 3.24 "Lock Customization" Dialog Box

A password must be provided before the code can be viewed in the project explorer. "Lock Customization" prevents access to the Macros dialog box and VBE as well.
Note that this option is available only when the project is saved as a document with (mxd) extension and not a template with (mxt) extension.

Alternatively, assigning a password to the project in the "Project Properties" dialog box can also lock and protect Landfill Site Selection Application template code as shown in Figure 3.25.

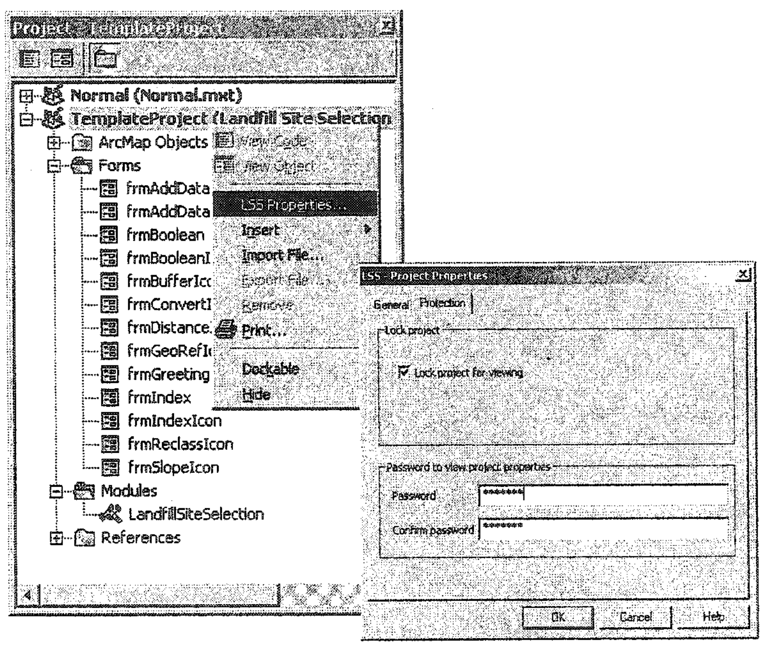


Figure 3.25 "Project Properties" Dialog Box

More advanced technique for locking application's user interface against any customizations is, using "LockCustomization" method available in IApplication interface [Fig. 3.5]. This method allows writing VBA code to create user's customization filter to control what aspects of the customization environment are locked instead of locking the entire customization environment.

CHAPTER 4

EXPLORING LANDFILL SITE SELECTION TOOLBAR

4.1. INTRODUCTION

Landfill site selection using LSS toolbar requires conducting the following steps:

Step 1- Identifying the Criteria and Regulations for the Region Being Studied

Step 2-Create a Database for Analysis

Step 3- Map Preparation

Step 4- Map Analysis

Step 5- Map Integration and Presenting the Results

Figure 4.1 shows these steps.

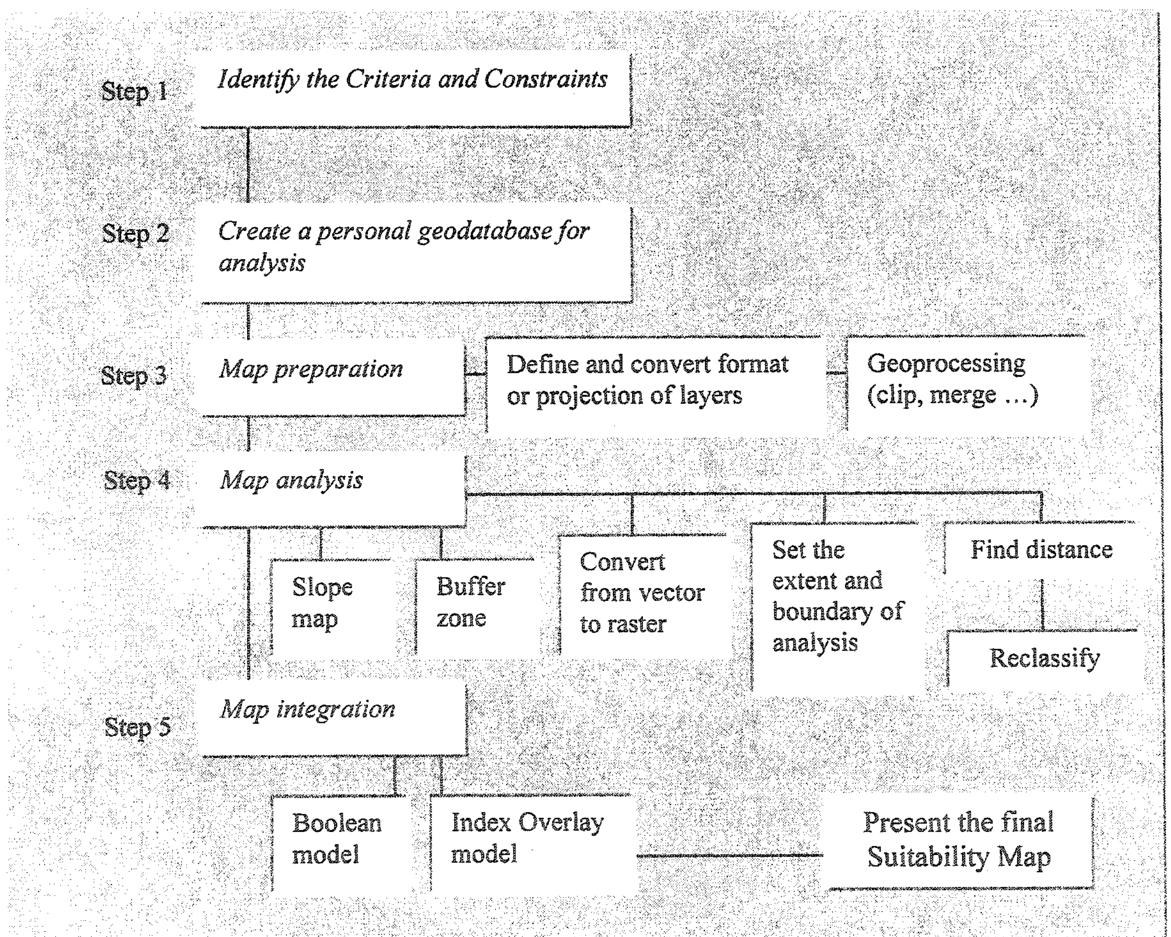


Figure 4.1 Flowchart of Landfill Site Selection Steps Using LSS Toolbar

Except step one which must be carried out separately, the rest of the steps are implemented using tools and functions accommodated on LSS toolbar.

This chapter aims to explore the components of the LSS toolbar including built-in and new designed interfaces and describe their functions and capabilities.

4.2. LSS TOOLBAR COMPONENTS

Once Visual Basic code for LSS module is written, verified and saved, it is ready to be executed by a user. LSS template can be opened in ArcMap by selecting File/Open and point the folder that contains the "Landfill Site Selection.mxt" template.

Note that "ArcMap Templates (*.mxt)" must be selected in the "Files of type" dropdown list so all available templates including "Landfill Site Selection Application" template are listed as shown in Figure 4.2.

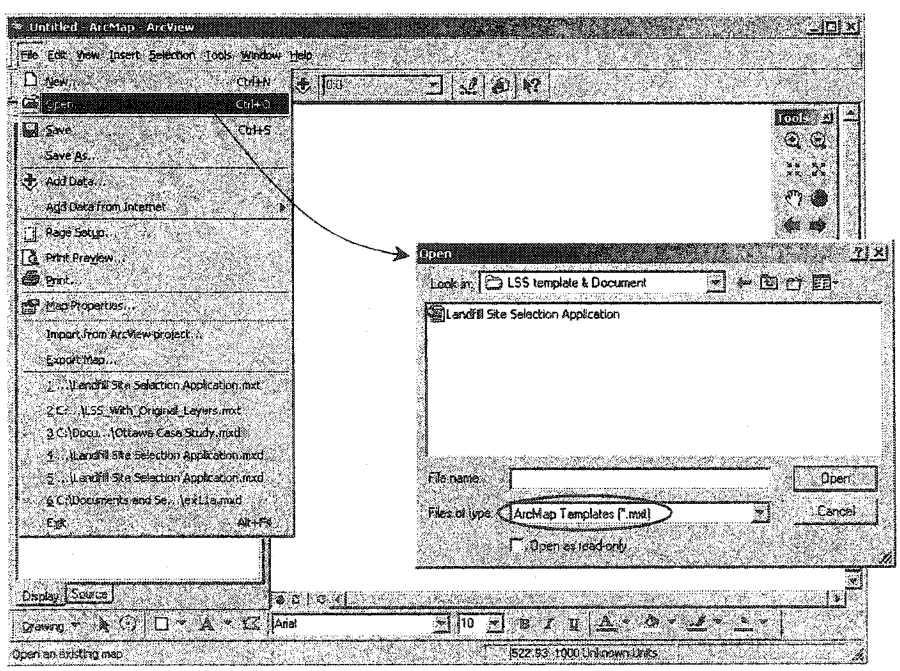


Figure 4.2 Landfill Site Selection Application Template

Upon opening this template, a "Landfill Site Selection (LSS)" button will be available on the standard toolbar in ArcMap as shown in Figure 4.3. This button triggers the first macro and asks the user to enter the login name and password.

Once the required information provided by the user, a greeting page and finally LSS toolbar will be displayed, as shown in Figure 4.3.

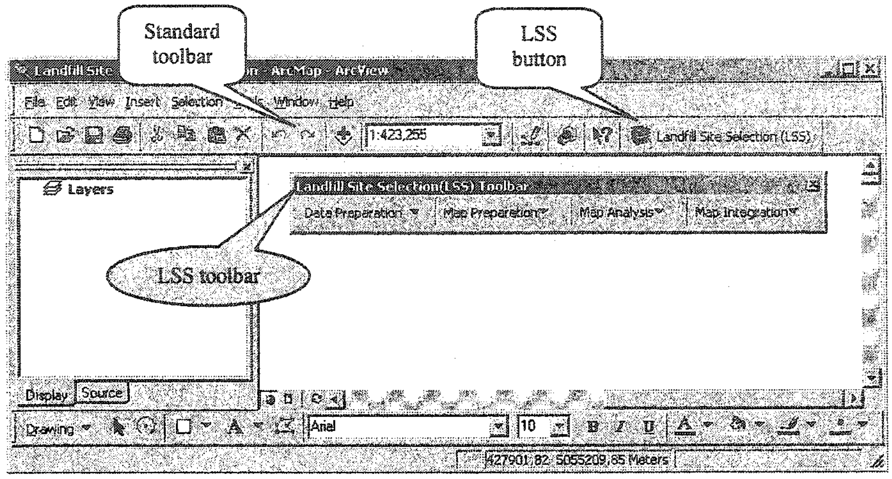


Figure 4.3 LSS Button and LSS Toolbar

This toolbar can be hidden or shown based on user's need via customize dialog box. Customize dialog box can be opened by selecting Tools/Customize. All available toolbars are listed in "Toolbar" tab. A check mark next to a toolbar indicates its visibility. For example, LSS toolbar is displayed when there is a check mark and it is hidden when there is no check mark. Figure 4.4 displays customize dialog box and LSS toolbar.

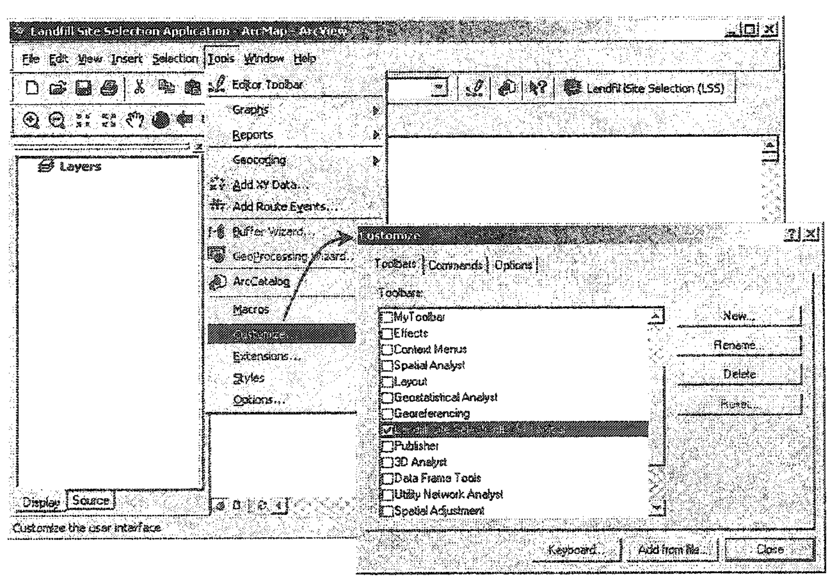


Figure 4.4 Landfill Site Selection Toolbar in the "Customize" Dialog Box

LSS toolbar is comprised of four main menus as follow:

a) Data Preparation
b) Map Preparation
c) Map Analysis
d) Map Integration

Each of these menus and their components are described in the following sections.

4.2.1. DATA PREPARATION

Data required for the project may be originating from many diverse sources for example City Hall or university database and in different formats. In order to conduct the analysis, data and information about them must be accessed and copied into an appropriate workspace.

ArcCatalog application, a component of ArcGIS Desktop, allows exploring and organizing the data efficiently. As shown in Figure 4.5, "Data Preparation" menu on LSS toolbar contains a link to this application in order to organize, preview and hold the project database during the analysis.

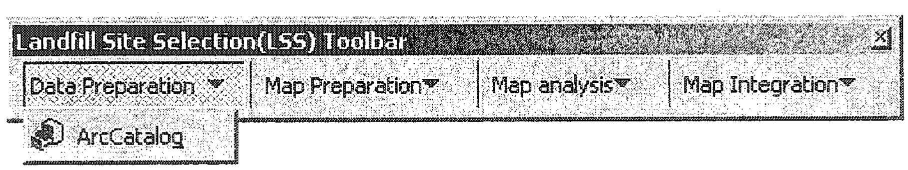


Figure 4.5 A Link to "ArcCatalog" Application in the "Data Preparation" Menu

Among the variety of ways to organize a project database, one good idea is to create a single project folder, and subfolders to hold the input datasets, and another subfolder to hold the output datasets, which are created during the analysis. In fact, the structure of a project database solely depends on personal preference. However, the common goal is to minimize duplication of datasets and to have the data well organized and easily accessible. This will help to avoid confusion during the project as well as if it is needed to revisit the project in the future (Bob and Andy, 1999).

Next chapter gets through the process of working with ArcCatalog to generate a personal geodatabase for the case study.

By previewing the data in ArcCatalog, it is also possible to see which layers need additional processing to be usable for the analysis. The required process can be carried out using tools available in the "Map Preparation" menu.

4.2.2. MAP PREPARATION

The data for a particular project come from several different sources. Some of them are in different coordinate systems (Projection) or data formats. Furthermore they might have different geography extent as well. Therefore, some of the data are usable as they are, whereas some need additional processing before they can be analyzed, integrated and combined.

Making data usable for analysis can encompass a variety of tasks. "Map Preparation" menu contains the necessary tools to accomplish these tasks efficiently. As shown in Figure 4.6, this menu is comprised of three submenus: (1) ArcToolbox, (2) Add data, and (3) Merge, Clip.

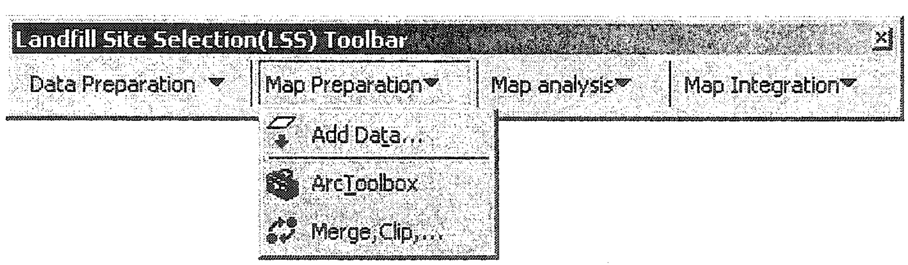


Figure 4.6 "Map Preparation" Menu and its Components on LSS Toolbar

4.2.2.1. Map Projection – Datum

To overlay maps, first their projection must be defined; second it is preferred to have them in a similar projection. Generally, vector features, in ArcMap are stored using x, y coordinates. These coordinates are linked to real-world locations (i.e. latitude and longitude) by a coordinate system, which specifies a datum and a map projection. A datum represents the shape of the globe surface mathematically. A datum (i.e. the shape and size of a geographic coordinate system's surface) is defined by a sphere or spheroid, which approximates the shape of the earth. There are different types of spheroids that represent the shape of the earth and many more datums based on them. The two horizontal datums, for example, used almost exclusively in North America are North American Datum, NAD 1927 and NAD 1983 that are designed to fit North America reasonably well (Kennedy and Kopp, 1994).

One way to think of a projection is a transformation of a three-dimensional earth surface to a two dimensional or flat map sheet. This mathematical transformation is commonly referred to as a map projection (Longley *et al.*, 2001).

Projection necessarily distorts one of the shape, area, distance or direction properties. So it is impossible, in principle, for the scale of any flat map to be perfectly uniform. However, it is likely to preserve certain properties using different projection techniques. For example, "Conformal" projections preserve directions and local shape "Equal area" projections preserve the area of displayed features and "Equidistant" projections conserve the distance between certain points. Based on the size of the study area, a map projection with a minimum distortion is selected (Clarke, 1999).

Each map projection uses different mathematical formulas and algorithms to relate spherical coordinates on the globe to flat, planar coordinates. Many common map projections are classified according to the projection surface used, such as conic, cylindrical, or planar projection. Perhaps the most prevalent plane grid system used in many GIS applications is Universal Transverse Mercator (UTM). It has been adopted for topographic map preparation, natural resource database development and civilian and military topographic applications (Demers, 2003). Since distortion is minimized in this projection, many countries particularly Canada and the United States have accepted it and used this coordinate system widely for the national mapping programs (Lo and Yeung, 2002).

The basic unit of measure is the meter. The UTM will not display or overlay correctly, unless the GIS dataset have the same zone. It is also preferred to have the same datum between maps to be overlaid.

ArcCatalog application helps to locate and access the dataset needed to complete a variety of tasks including coordinate system conversion. Once the data required for this task were identified, their coordinate systems or projection can be converted to one single form easily and efficiently using "Project Wizard" in ArcToolbox application.

A link button to ArcToolbox application is available in the "Map Preparation" menu as shown in Figure 4.6. Coordinate reference system of data is one of the advanced capabilities in ArcToolbox application. A coordinate system can be defined in different ways in ArcToolbox: (1) Using a predefined coordinate system stored as a .prj file, (2) Importing the coordinate system of an existing map through specifying the name of the map, or (3) Specifying a projection parameters and a datum (Corey, 1999).

The process of how to work with ArcToolbox application and convert the projection of some layers to UTM projection is presented in Chapter 6 as part of the case study.

Once a unique projection is assigned to all layers required for the analysis, layers are added into ArcMap, by selecting "Add Data" button available in the "Map Preparation" menu. Add Data dialog box allows user to locate the personal geodatabase created in the previous step as shown in Figure 4.7.

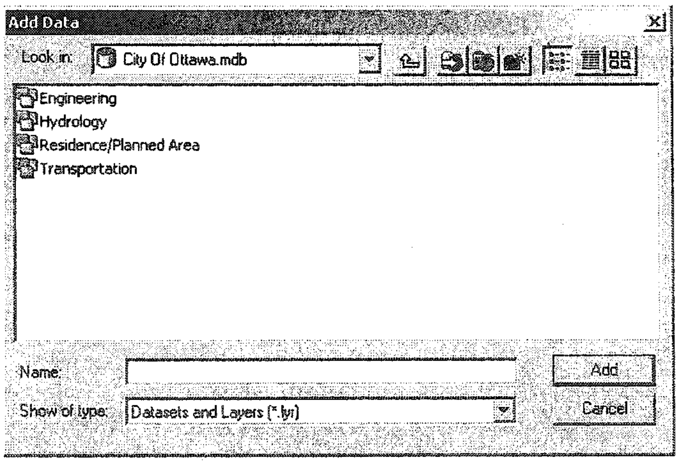


Figure 4.7 "Add Data" Dialog Box Imports Layers for the Analysis

4.2.2.2. <u>Merging – Clipping</u>

Sometimes two or more data need to be merged into a single layer. In some other cases, they may not have the same extent; therefore boundaries must be clipped to match the study area. "Merge, Clip" tool available in the "Map Preparation" menu is the most appropriate tool to perform such tasks.

"Merge, Clip" tool, available in the "Data Preparation" menu allows implementing these tasks. The process of working with this tool is presented in Chapter 6 as part of case study.

4.2.3. MAP ANALYSIS

First step of landfill site selection procedure identifies criteria and constraints and data associated to them. In the "Data Preparation" step, data are assembled and prepared for the analysis. Therefore, they are ready to perform the analysis.

The phrase "Map analysis" encompasses a wide variety of operations and methods that can be implemented with GIS and obtain the end result. The required approach is generally dictated by the problem.

In the present study, "Map analysis" involves making slope map, buffering, feature to raster conversion, finding distance and reclassifying.

Figure 4.8 shows the required tools arranged in the "Map analysis" menu.

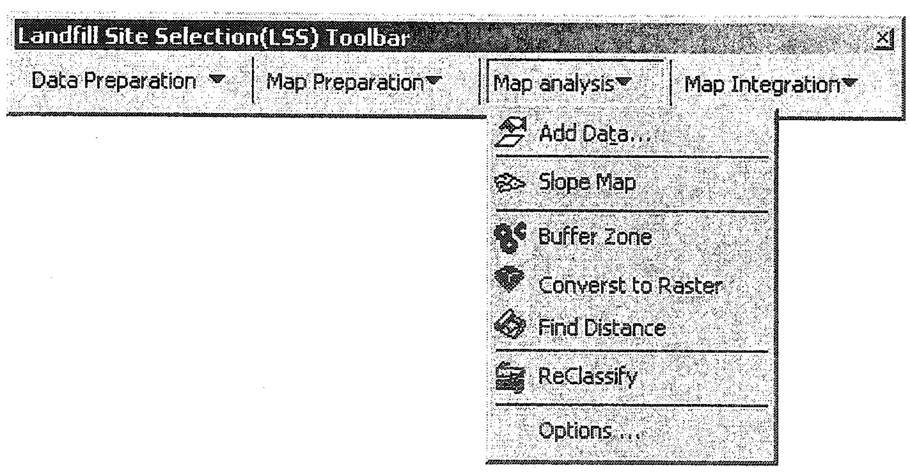


Figure 4.8 "Map analysis" Menu and its Tools on LSS toolbar

Each of these tools is explained in the following sections.

4.2.3.1. <u>Making a Slope Map</u>

It is preferred to restrain landfill sites from being placed within a steep area to avoid difficulties for construction and maintenance of a landfill. Also, it is important to identify the areas most at risk of landslide based on the angle of slopes in an area. (i.e. steeper slopes being those most at risk).

In order to know where the flattest parts lie, a map displaying the slope of the land is required. The process model involves calculating the slope of the land from an elevation dataset such as triangulated irregular networks (TIN), contour map or digital elevation model (DEM). Finding slope is a simple process conceptually; if the relationship between the horizontal distance and the vertical change in elevation from bottom to top is available, slope can be calculated.

Slope may be expressed as percent slope or degree slope. Figure 4.9 displays examples of slope calculation.

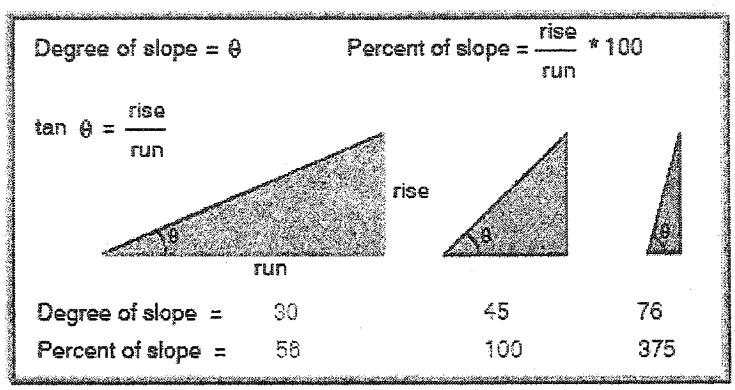


Figure 4.9 Three Examples of Slope Calculation

Chang (2002) defines slope (S) at the point as a function of the first –order derivatives of the surface in the x and y directions:

$$S = ((\partial z/\partial x)^2 + (\partial z/\partial y)^2)^{0.5} \quad (4.1)$$

where S = Slope

x = horizontal distance between two points in x direction, m

y = horizontal distance between two points in y direction, m

z = difference in height between two points, m

"Slope Map" function, available in the "Map analysis" menu, calculates the maximum change in elevation over distance between the center of each cell and its eight neighbors. Therefore an expanded version of the equation (4.1) that contains eight directions is applied. Every cell in the output raster has a slope value. As the slope value decreases the terrain flattens. The output slope dataset can be calculated as percent slope or degree of slope. Queries can be made from the output slope map to produce the scored or binary map based on the criteria or constraints. Figure 4.10 shows the "Slope" dialog box.

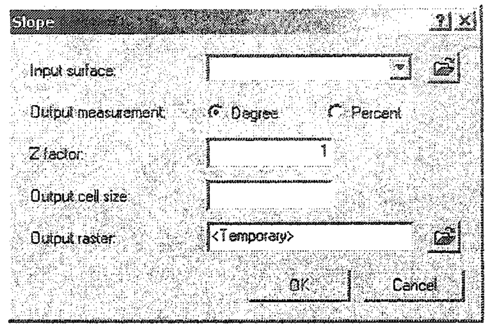


Figure 4.10 "Slope" Dialog Box

4.2.3.2. <u>Buffering</u>

Some constraints mandate new landfill site of being located within or beyond a certain specified distance of an existing object. The object can be a point (e.g. tank, well), line (e.g. river) or area (e.g. waterbody, airport). "Buffer Wizard" function available in the "Map analysis" menu, is a powerful tool particularly to develop binary maps. This function in conjunction with "Reclassify" function is able to present maps with two classes, indicating whether the area lies outside or inside the buffer zone. The areas delineated by these maps become acceptable and unacceptable areas for a new landfill site. Figure 4.11 displays "Buffer Wizard" dialog box that helps to make a buffer zone around the features.

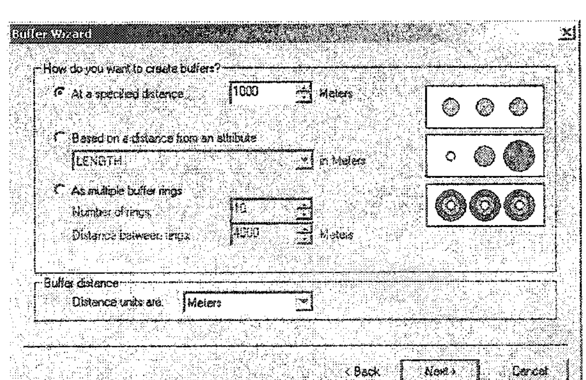


Figure 4.11 "Buffer Wizard" Dialog Box

4.2.3.3. Converting to Raster

When using "Map Integration" methods for overlaying, the objective is to generate a suitability map, which is based on the pixel value of every location on the map. Moreover, mathematical calculation involved in the map overlay models, are also based upon the pixel values. Therefore, it is essential to convert not only all vector input data, but also the output layers resulting from buffering, which are also in vector format, to raster format. This conversion allows the layers to participate in the map integration process.

"Convert to Raster" tool available in the "Map analysis" menu, lets the user convert feature (vector) layers to raster layers.

Figure 4.12 illustrates the "Feature to Raster" dialog box.

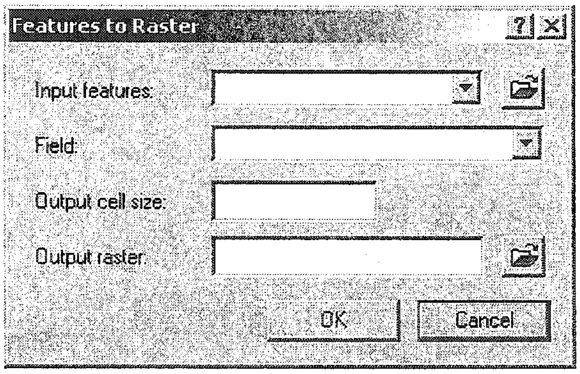


Figure 4.12 "Feature to Raster" Dialog Box

4.2.3.4. Making Distance Maps

In general, locational criteria can fall into two main categories: (1) features the landfill is preferred to be away from or outside of (e.g. away from national parks and residential area and outside the wetlands), and (2) features the landfill is preferred to be near or inside of (e.g. roads). The areas delineated by these criteria are ranked according to their relative distance to or from an existing feature and from best to worst.

There are several distance mapping tools for measuring both straight line distance and distance measured in terms of other factors, such as the cost to travel over the landscape.

The "Find Distance" function, available in the "Map analysis" menu, enables the user to calculate how far each cell is from the nearest source and makes a distance map for each criterion. The source identifies the objects of interest, such as roads, airports or streams. The distance is measured from cell center to cell center (McCoy and Johnston, 2001).

Unlike Buffering, distance maps are raster dataset in which every cell represents the distance to the nearest source. By using "Reclassify" function, a distance map can be simply scored or ranked. Figure 4.13 shows the "Straight Line" dialog box.

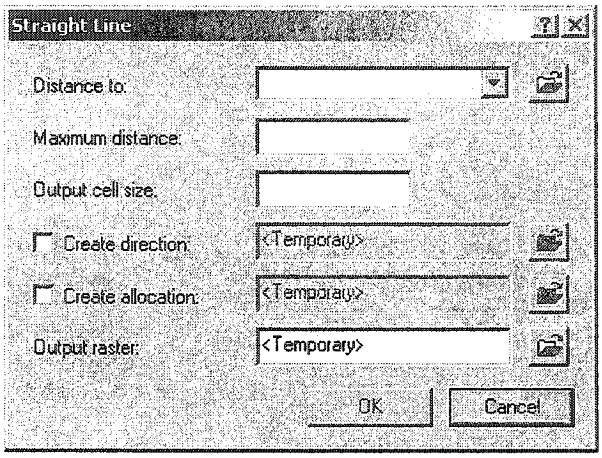


Figure 4.13 "Straight Line" Dialog Box

4.2.3.5. Reclassifying Maps

Reclassifying data in a map simply means replacing input cell (pixel) values with new output cell values. The input data can be in any supported raster format. There are many reasons to reclassify maps; however, in the present study they are reclassified to:

1. Generate "Binary" maps from buffering outputs to correspond to the constraints,
2. Generate "Scored" maps to represent the other locational criteria,
3. Set an analysis mask to define the extent of the analysis outputs.

Pixel values of a raster layer resulted from buffering and raster-conversion functions can be changed to only zero (0) and one (1) value. Area with pixel value equal to zero implies unacceptable area for locating a new landfill. In contrast, area with pixel value equal to one means acceptable area for siting a new landfill. The produced layers are called "Binary" maps.

Another reason of using reclassification function is to assign new values to each class of raster layers, resulting from "Straight Line" function. New values must have a common scale, for example ranging from 0 to 10 with 0 being the worst and 10 the best. The range of scores is user-defined and can be chosen as positive integers, with no limit on the numerical range. Layers resulting from this reclassification are called "Scored" or "Ranked" maps.

All of the "Map Analysis" functions require performing analysis on a selected set of cells and the rest must be masked. Reclassify function allows generating an analysis mask by assigning "NoData" value to all cells that need to be eliminated. As a result, "NoData" cells in all analysis will be masked.

"ReClassify" function available in the "Map analysis" menu allows implementing the aforementioned tasks. Figure 4.14 shows "Reclassify" dialog box.

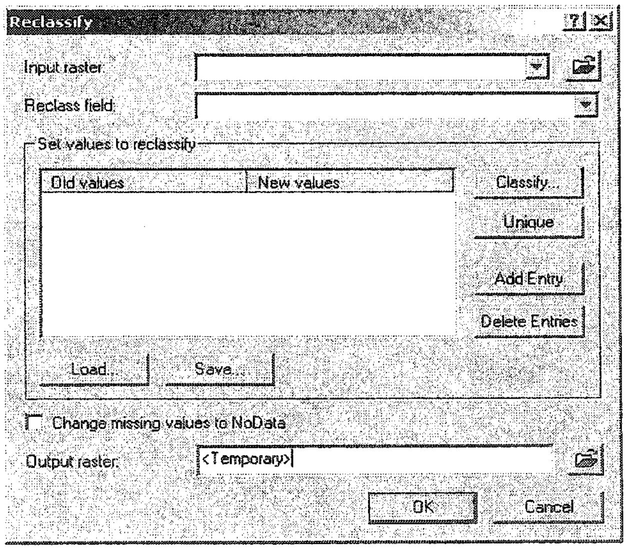


Figure 4.14 "Reclassify" Dialog Box

4.2.3.6. Options

The last element in the "Map analysis" menu is the "Option". This tool allows setting up the analysis environment..

Figure 4.15 shows the "Options" dialog box that contains three taps: (1) General, (2) Extent, and (3) Cell Size. Setting the options for the analysis process enables the user to control the output location for saving the results, defining the analysis extent and the output cell size.

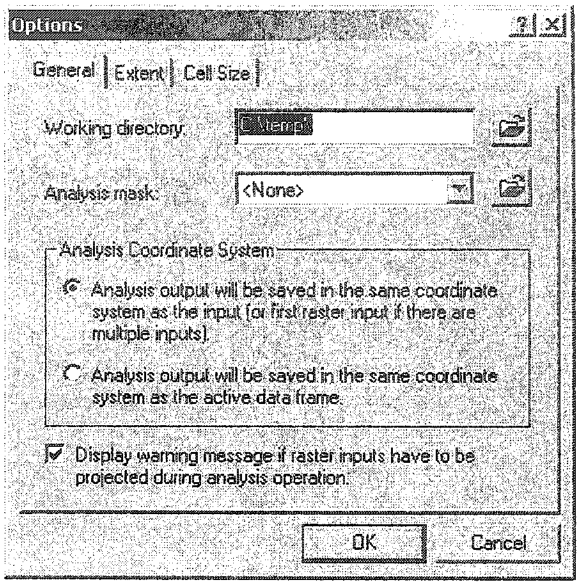


Figure 4.15 "Options" Dialog Box

Specifying these properties is a prerequisite for performing analysis. It is suggested to specify the analysis options before performing analysis on a dataset otherwise it is assumed that defaults are accepted. By default, most results from analysis are temporary. For instance, the location for saving the analysis results is set to the temporary directory for example "C:\temp" directory, the cell size is set to that of the largest cell size of inputs, and the extent is set to the intersection of input data (McCoy and Johnston, 2001).

"Working directory" input box, allows user to specify a location to save the analysis results. If it is intended to sort the results into different folders, user can specify a location on disk each time an analysis is performed.

"Analysis mask" input box allows user to identify those cells that must be considered when performing an operation or function. Analysis mask is generally created using "Reclassify" function. The mask defines the cell locations within the extent and assigns "NoData" value on all location outside the desired area. All NoData cells in the analysis mask will be masked on all subsequent output raster datasets.

The "Extent" tab defines the area on which the operation needs to be preformed. The "Analysis extent" can be specified in the "Extent" tab on the "Options" dialog box via different options available in a drop-down list as shown in Figure 4.16.

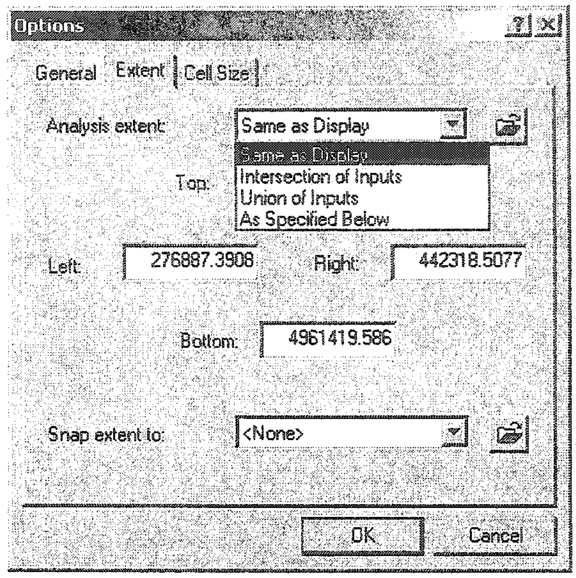


Figure 4.16 "Extent" Tab in the "Option" Dialog Box

In the following, each of these options is briefly described. "Same as Display" option only performs analysis on the area visible in the map. "Intersection of Inputs" option limits the extent of the analysis results to where all layers intersect. This option is the default extent. "Union of Inputs" option sets the extent of the results to be the same as the combined extent of inputs and finally "As Specified Below" option allows setting a custom extent.

By default, the resolution of the output layers, resulted from the analysis, is equal to the input raster dataset with the largest cell size. However, "Cell size" tab on the "Options" dialog box, allows user to choose an alternative cell size from the drop-down list as shown in Figure 4.17. The specified cell size will be applied to all subsequent results. The options available in the drop-down list are briefly described as follow.

"Minimum of Inputs" option sets the cell size of analysis results to the input raster dataset with the smallest cell size. "Maximum of Inputs" option, which is the default option as well, locates the cell size of analysis results to the input raster dataset with the greatest cell size and finally "As Specified Below" option enables the user to specify a cell size for analysis results. In addition, the user can specify the number of rows and columns to split the analysis extent into. In this case an appropriate cell size will be applied automatically. Alternatively, a button next to the drop-down list enables user to point an input raster layer from dataset that governs the cell size for the analysis results.

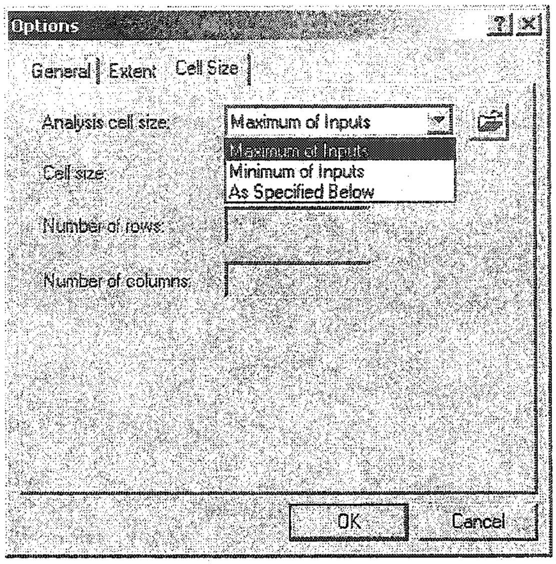


Figure 4.17 "Cell Size" Tab in the "Option" Dialog Box

Note, although "Options" dialog box settings do nothing to the original data, the "Extent" and "Analysis mask" explained before, affect the locations where the operation occurs.

4.2.4. MAP INTEGRATION

In GIS, there are several alternative methods that can be used to get to the end result. In a general sense, the GIS model can create new information when overlaying one set of features with another. There are several types of operations for map integration; however, they all involve joining two or more existing sets of features into a single new set of features. The selected approach is partly dictated by the problem characteristic, partly by the available data and partly by personal preference.

There are also various models available in GIS for map overlay, such as: "Boolean" model, "Index Overlay" model, "Fuzzy Logic" model, "Logistic Regression" model, "Weight of Evidence" and "Dempster-Shafer" model, each answering specific user needs. Although they are different in the degree of difficulty, they have two common elements: (1) A set of selected spatial variables, and (2) The function or mathematical link between variables (Chang, 2002).

Models built with a GIS can be vector-based or raster-based or both. Vector data is based on objects such as points, lines and polygons. Raster data is described by a grid and a value for each grid cell. These grid cells are also called pixels. Vector models are generally recommended for describing discrete and well-defined locations and shapes whereas raster models are preferred for modeling the phenomenon varying continuously. In raster data, because of the relatively simple data structure, map overlay process can be accomplished easier. In addition, the simplicity of the raster overlay process enhances the degree of flexibility and speed of the overlay operation (Demers, 2003).

The choice between vector and raster based model, depends on the nature of the model, data sources, computing algorithm, efficiency and the expected result. When finding the best location for the new landfill site, most of the dataset such as land use, soil type, geological map and elevation vary continuously over the space therefore raster format is an appropriate model to reflect these variations.

Considering the advantages of raster-based overlay over vector-based overlay, it is more convenient to perform the operations involved based on raster overlay.

There are several logical ways to go about performing map overlay. For example, obtaining a Boolean result of true or false area that simply represents the acceptable and unacceptable area or creating a ranked map to find out the degree of suitability of every location on the map. For either case, layers must be prepared using functions and tools available in the "Map analysis" section.

Figure 4.18 shows "Map Integration" menu on LSS toolbar that includes two buttons corresponding to two new developed interfaces for overlaying maps with "Boolean" model and "Index Overlay" model. Fundamental concepts of these models and their new designed interfaces are described in the following sections.

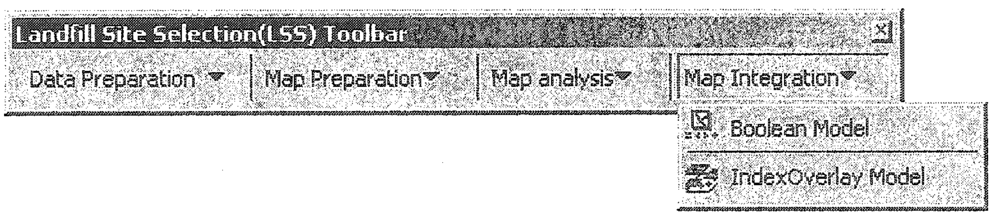


Figure 4.18 "Map Integration" Menu on LSS Toolbar

4.2.4.1. Boolean Model

Boolean is among the most frequently used and simplest type of GIS model, which involves the logical combination resulting from the Boolean operators. Figure 4.19 illustrates the Venn diagrams showing the concept of Boolean operators between two sets.

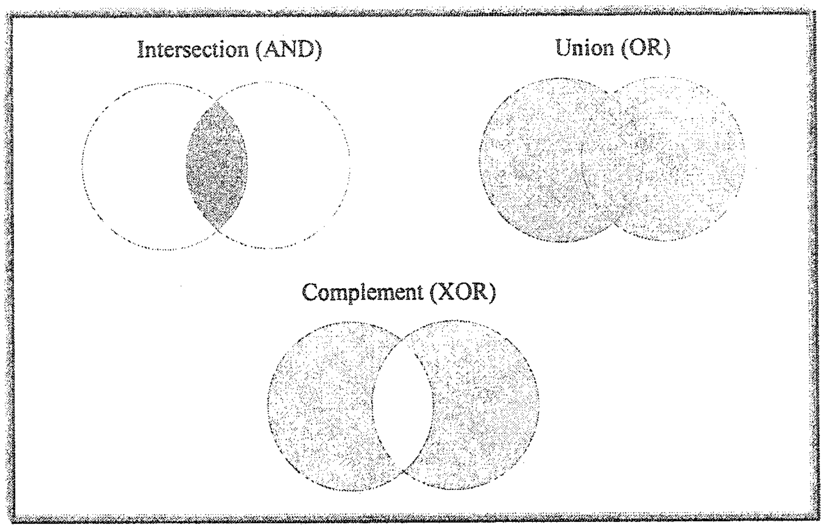


Figure 4.19 Venn diagram - "AND", "OR" and "XOR" Operators

In the Boolean model, each of the maps used as a condition can be considered as a layer. The various layers need to have only two classes with a value of 0 or 1. On the other hand, this model can only be applied to a set of "Binary" maps to combine them and obtain the result map. Each location is tested to determine whether it belongs to the locations for which the criteria are satisfied. The output map will also be in a binary format and contains two classes: (a) 1 or true, and (b) 0 or false, with 1 showing the acceptable and 0 representing the unacceptable area for a new landfill site.

In cases where criteria have been defined as deterministic set of rules, this model is a useful and practical approach (Bonham-Carter, 1994).

Figure 4.20 shows the "Boolean" overlay process schematically. Each pixel value in the output layer is calculated by combining all corresponding pixel values on each input layers based on the selected Boolean operator.

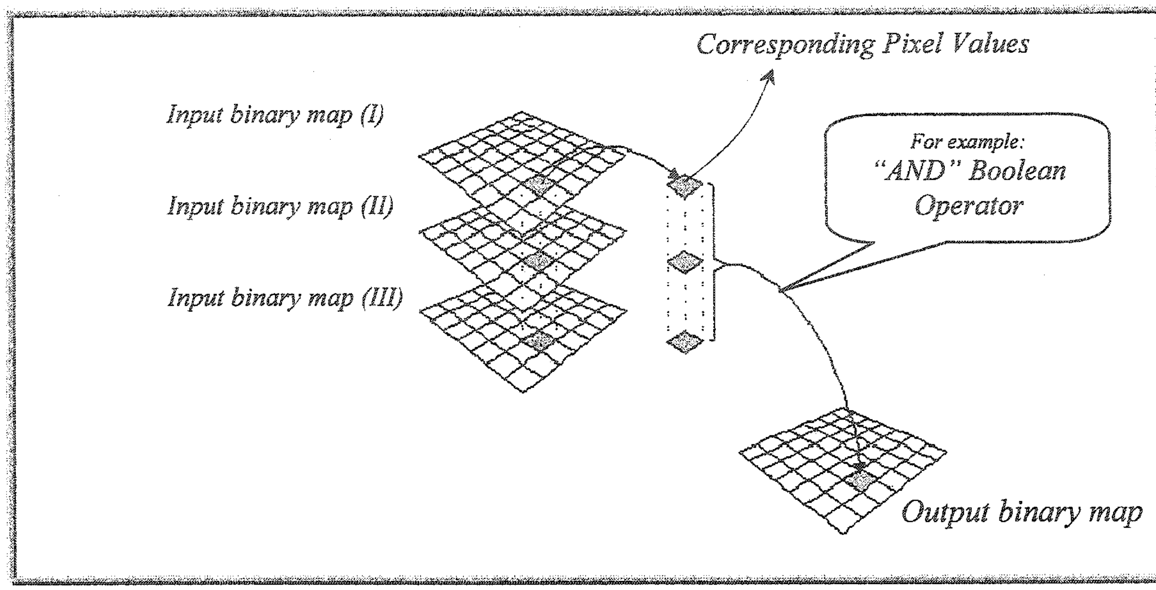


Figure 4.20 Map Overlay Using a Boolean Operator

Boolean logic overlay is performed by using the "Boolean Model" interface developed in this study as shown in Figure 4.21. This interface enables the user to select and add the "Binary" maps prepared in the "Map analysis" section, combine them with one of the Boolean operators and finally display the result map.

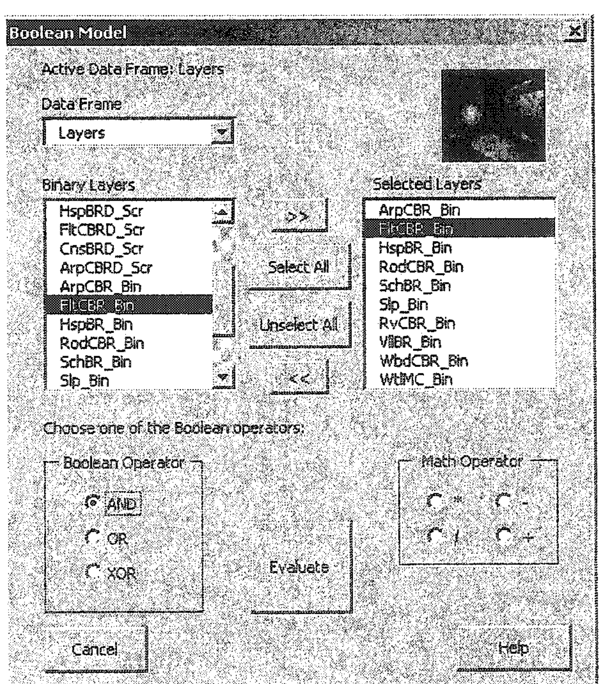


Figure 4.21 "Boolean Model" Interface

4.2.4.2. Index Overlay Model

Index overlay model, is built based on two concepts: First, as opposed to the "Boolean" model, it is applied to a set of "Scored" layers prepared during the "Map analysis" process. "Scored" layers are also referred to as a "Ranked", or "Suitability layers". Second, the relative importance of each layer is evaluated against other layers. Therefore, layers are assigned different weights depending on their relative significance (Bonham-Carter, 1994). Layers are combined to produce an output map showing regions that are ranked according to the scores. The average score for each pixel value in the output layer is obtained by applying the equation (4.2) to all corresponding pixel values on each input layers.

$$Z_{ij} = \frac{\sum_{k=1}^{n} w_k \cdot (C_{ij})_k}{\sum_{k=1}^{n} w_k} \qquad (4.2)$$

where Z_{ij} = pixel value located in row 'i' and column "j" of the output map

$(C_{ij})_k$ = corresponding pixel value in row 'i' and column "j" of the k^{th} input scored map

W_k = weight of the k^{th} input scored map

n = number of input map

The process of combining scored maps using Index Overlay model is shown schematically in Figure 4.22.

4.2.4.3. Weighting Layers

In the Boolean model, layers are given an equal importance. However, in practice, this may not be appropriate. In the Index overlay model, layers that are considered more important are given higher weight values than other variables in computing the final map.

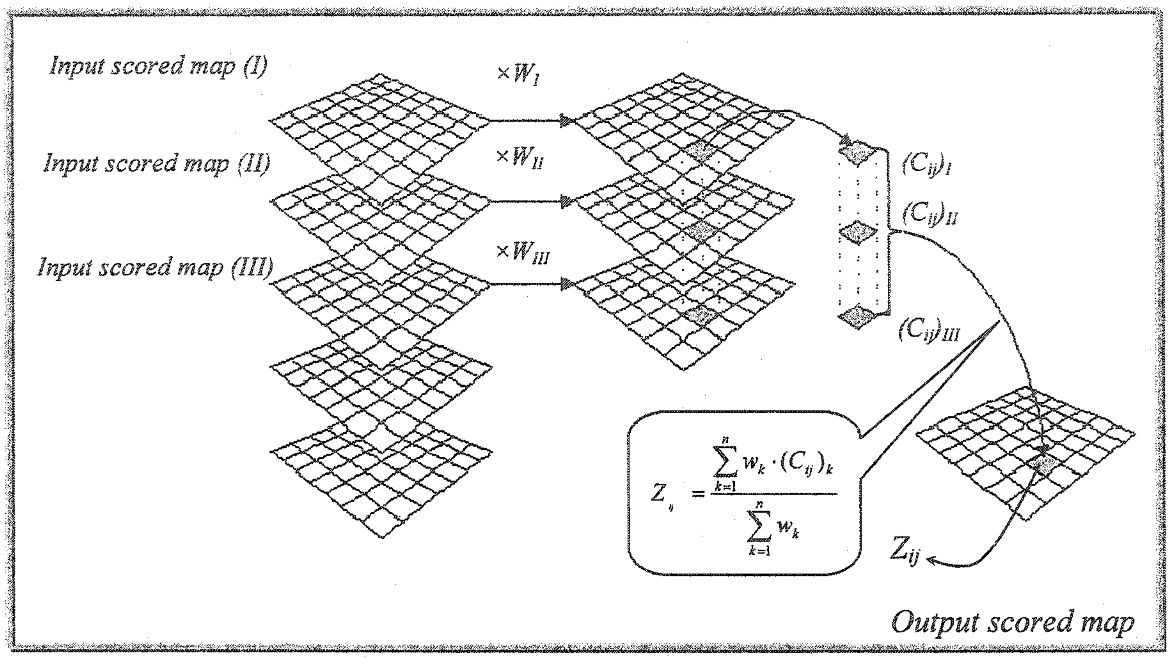


Figure 4.22 Map Overlay Using Index Overlay Model

The process of assigning weights to each input layers can be accomplished by using "Weight" button provided as part of the "Index Overlay" interface as shown in Figure 4.23. In summary, Index Overlay interface developed in this study enables the user to select the scored maps, assign weights, integrate and obtain the output map.

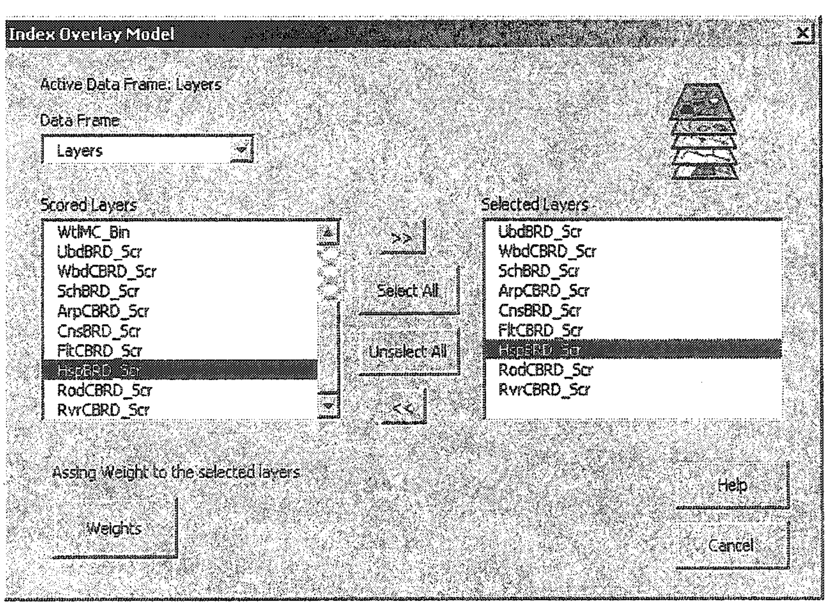


Figure 4.23 "Index Overlay" Model Interface

CHAPTER 5

LANDFILL SITE SELECTION TOOLBAR: CASE STUDY

5.1. INTRODUCTION

This chapter presents an example for solving a landfill-siting problem using the LSS toolbar. Each of the steps is described in detail and in the form of a user-manual format.

A hypothetical case study is presented for Ottawa, Canada, to find potential candidate sites for a new landfill. As a result, the capability of the LSS toolbar is illustrated.

As a starting point, the current solid waste management practice in Ottawa is briefly discussed.

The capital region of Canada, Ottawa, has experienced a substantial increase in population and consequently increases in waste generation. Demographic data suggest this increase has occurred due to people with children moving to the region, taking advantage of the many high tech job opportunities and recreational facilities located nearby. In order to implement the City's environmental strategy and solid waste management, there are some key plans, such as (1) integrating waste management, (2) providing policies and programs for the provision of solid waste services in the areas of collection, (3) processing and disposal for future, (4) reviewing waste diversion goals, existing landfill capacity, import and export of waste, costing, service levels and technology and finally (5) expanding existing landfills or developing new landfills and facility design.

The city of Ottawa has been successful in diverting solid waste from landfilling. In the year 2000, about 31% of the residential waste stream was diverted (Duff, 2003).

While the City continues its efforts to improve this diversion rate, there will still be a significant fraction of solid and residual waste stream that requires disposal in landfills. Hence, there are two alternative proposals, one expanding the existing facilities and the second developing new landfills.

Currently, the City is looking at methods of expanding its landfills to extend their operating life to serve the City's future solid waste disposal needs. Increasing height, area or landfill mining are potential techniques to achieve this goal. The expansion should be limited to the landfills property boundaries and should provide tones of additional landfills' capacity in order to be justified economically. The extra capacity should also add 10 to 40 years of site life to the landfill, depending on future levels of waste diversion, site operating practices and use of other new private landfills. Therefore, it is likely that the City will issue approval for new private landfill establishments during this period as well (City of Ottawa, 2003c).

In the present case study, considering the data availability for the Ottawa area, it is assumed that the City has decided that a new landfill must be built to take the strain off the existing landfills, and town planners have been assigned the task of finding the potential sites using LSS toolbar.

5.2. CONDUCTING PRELIMINARY LANDFILL SITING FOR OTTAWA, CANADA

When siting a new landfill, prior to construction, several steps must be taken into account including identifying potential sites for a particular region. For the present case study, this step involves finding potential locations within the Ottawa region that comply with landfill location standards and local criteria, specified in zoning by-laws.

Identifying potential sites in Ottawa by using the LSS toolbar requires performing five steps: (1) Identifying important landfill siting rules, (2) Preparing and organizing data, (3) Preparing the matching layer properties, (4) Analyzing maps and producing binary and scored layers, and finally (5) Combining layers and presenting the results.

This Chapter aims to cover each of these steps in detail with explanation of how to use the corresponding tools and functions of the LSS toolbar.

5.2.1. IDENTIFYING IMPORTANT LANDFILL SITING CRITERIA AND CONSTRAINTS FOR OTTAWA, CANADA

The City of Ottawa will evaluate applications for the establishment of any new solid waste disposal site, based on the compliance with a "Terms of Reference" as approved by the minister of the environment under the EAA. Constructing new landfill sites also requires meeting the City's official plan framework and zoning by-laws approval (City of Ottawa, 2003a).

The City's official plan provides a policy framework to guide for future land use and development within the city. The zoning by-laws restrict the location of solid waste disposal facilities to particular sites. It also provides more detailed direction for the use of land within specific areas of the City. These areas are identified by land-use designations and must be identified and eliminated from the region during the analysis (City of Ottawa, 2003d).

According to the zoning by-laws, the following designations and land use in Ottawa cannot accommodate any waste disposal facilities inside or within a certain distance from them (Ottawa 20/20, 2003).

- The "National Capital Greenbelt", is a 20,000-hectare rural landscape that is a distinguishing feature of Ottawa, providing a separation between the urban area within the greenbelt and the urban communities outside it. The greenbelt is designated to a variety of land uses such as natural environment areas, significant wetlands south and east of the Canadian Shield and agricultural resource areas.
- The "Urban Developing Community" designation in this region identifies parts of the city that are undeveloped or substantially underdeveloped.
- The "Ecology and Nature Reserve Districts" or any threatened and endangered species area. Endangered and threatened species are those species either listed under the regulations of the Ontario endangered species act (OESA) or are considered by the provincial government to be at risk of becoming endangered through all or a portion of its Ontario range. The habitat of these species is identified and protected by the Ministry of Natural Resources.

In addition to the rules outlined in zoning by-laws, landfill site must also comply with the general regulations and health and safety of the public as described in Chapter 2.

By reviewing similar case study reports, consulting with experts and private solid waste facility owners as well as considering data availability, the following criteria and regulations in conjunction with zoning by-laws standards, are selected and applied to the present case study. However, criteria can be easily expanded to include other environmental and public concerns as well. The present tool has the capability to include as many parameters as desired.

- City of Ottawa prefers that the landfill site be located on soil with low permeability in order to safeguard the integrity of groundwater resources.
- Because landfills draw birds and increase collision possibility that may cause damage to the aircraft or injury to its occupants, City recommends the owners not to construct their facilities within 3000 meters of the airports.
- Wetlands are essential components of ecosystems that contribute to the high quality of the environment in Ottawa. Therefore, new landfills and laterally expanding ones may not be built in wetlands.
- The City will not allow any construction including landfills to be located in unstable areas that are subject to landslides, mudslides or sinkholes.
- Although Ottawa is not located in a high-risk seismic area, it is preferred that new landfill not to be constructed within 60 meters from faults that are prone to earth movement.
- Landfills are also preferred to be located within 1100 meters from the major accessible roads or highways to reduce the MSW collection and transportation costs.
- Landfills should be kept more than 300 meters from rivers and water bodies
- Landfills must also be kept more than 1500 meters from towns or villages and 3000 meters from hospitals, school and other institutes.

Additionally, the candidate sites must satisfy the space requirement constraint, which is determined according to the waste generation that the new waste facility will receive during its operating life.

Note accuracy and precision is a requirement to locate the landfill site in a real case study, therefore, a broad knowledge of criteria and constraints must be employed for the analysis. The incorporation of the criteria and constraints from each of the environmental, socio-political, engineering, and economic factors are necessary for an extremely precise conclusion to be made. In the following sections, however, landfill siting procedure is conducted only based on the abovementioned criteria.

5.2.2. DATA PREPARATION – CREATE AND DESIGN THE DATABASE FOR THE CASE STUDY

This step involves managing and organizing the project database that contains the layers related to each criterion. Creating and organizing a project database makes it easier to find the data needed during the analysis, and also by reviewing the data, it is possible to determine which maps or layers need additional processing to be usable for analysis.

As with many GIS projects, the required maps for this case study were collected according to the selected criteria and constraints and from different sources including City of Ottawa database (City of Ottawa, 2003b), University of Ottawa database (University of Ottawa, 2003) and natural resources Canada (NRC) database (NRC, 2003). They are all in shapefile format but with different projections. The following are the shapefiles used in the present case study.

1. "Greenbelt" shapefile, presents the Greenbelt zone in Ottawa
2. "Urban development" shapefile, shows the area which are under development
3. "Conservation area" shapefile, displays the protected area for endangered and threatened species in Ottawa
4. "Aquifers" shapefile, presents the type of aquifers
5. "Airport" shapefile, shows the location of airports in Ottawa
6. "Wetlands" shapefile, indicates the location of wetlands in Ottawa
7. "Landslides" shapefile, shows the area with high risk for land sliding
8. "Faults" shapefile, displays the location of faults in Ottawa
9. "Roads" shapefile, shows the major road network in the Ottawa region
10. "Rivers" shapefile, displays the streams in Ottawa
11. "Water bodies" shapefile, exhibits the location of water bodies in Ottawa
12. Villages" shapefile, presents the villages in the Ottawa region
13. "Hospitals" shapefile, shows the location of existing hospitals in Ottawa
14. "Schools" shapefile, shows the location of existing schools in Ottawa
15. "City boundary" shapefile, used for cutting layers that exceed the boundary of the region being studied. Its raster version is used to define the extent of the analysis.

There are many ways to organize a project database. One strategy is to create a single "LSS project" folder then a subfolder to hold the input datasets (i.e. City layers), and another subfolder to hold the datasets created during the analysis (i.e. Analysis). Next, a personal geodatabase is created within the "LSS Folder" to store several of the updated and modified datasets that are generated during the project. Creating the personal geodatabase is an efficient way of storing, managing and accessing data.

ArcCatalog application allows user to implement these tasks. Figure 5.1 shows "ArcCatalog" link button in the "Data Preparation" menu on LSS toolbar that connects ArcMap application to ArcCatalog application.

In the following sections, steps for creating "LSS Folder", its subfolders and a personal geodatabase are described.

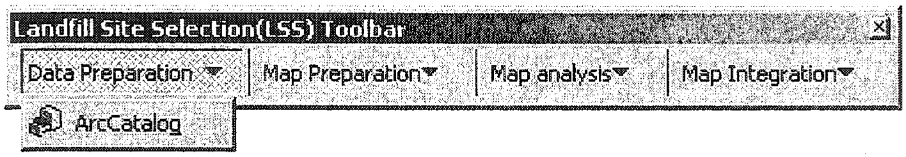


Figure 5.1 "ArcCatalog" Button in the "Data Preparation" Menu

5.2.1.1. Creating the LSS Project Folder and its Subfolders

The "LSS Project" folder contains data required for the analysis in a user specified drive. If there are many folders on the user drive, it can become tedious to scroll to the project folder that is used frequently. Making the LSS project folder in the root puts that folder at the fingertips.

The procedure follows:

1. Click "ArcCatalog" button in "Data Preparation" menu to open the ArcCatalog application. Right-click on the "C:\" drive and select "New Folder"
2. A new folder will be created. While the new folder is highlighted, rename it and type "LSS Project" as a new folder name
3. Press "Enter".

The new "LSS Project" folder is now listed in the Catalog tree as shown in Figure 5.2.

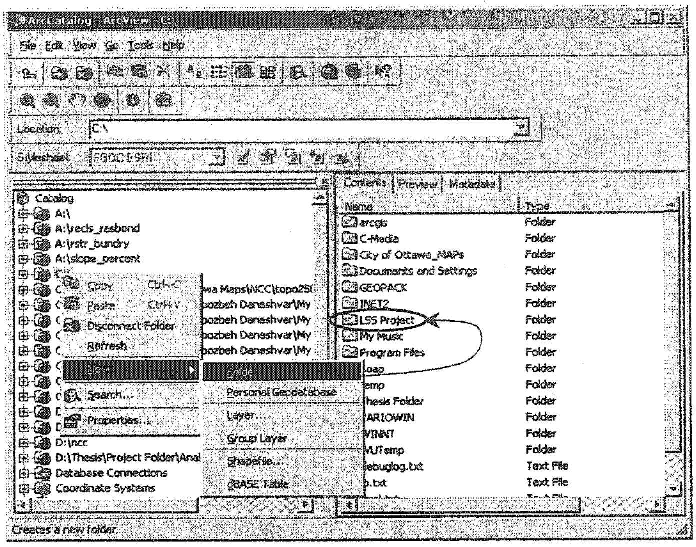


Figure 5.2 "LSS Project" Folder

Now, two new folders within the "LSS Project" folder are created to hold the original data collected for the present case study and data created during the analysis.

The following steps describe how to create these two folders.

1. Right-click on the "LSS Project" folder, point to "New", and click "Folder"
2. A new folder is listed on the right side of the ArcCatalog window with its name highlighted as New Folder. Rename the folder by typing "City_layers" over the highlighted text
3. Press "Enter".

The "Analysis" folder is also created with a similar method. Figure 5.3 displays "City_Layer" and "Analysis" folders created under the "LSS Project" folder.

5.2.2.2. <u>Creating a Personal Geodatabase</u>

A personal geodatabase is now created within the "LSS Project" folder. The procedure follows:

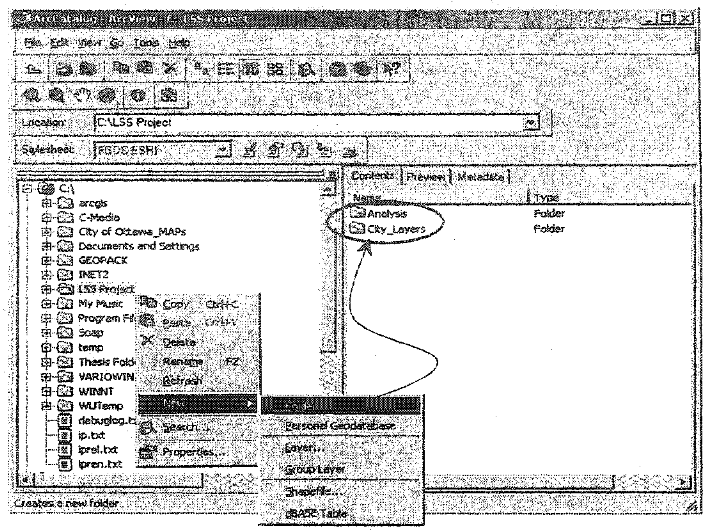


Figure 5.3 "Analysis" and "City_layer" Folders

1. Right-click on the "LSS Project" folder and select the "New" and click "Personal Geodatabase"
2. The new geodatabase is listed in the right side of the Catalog window with its name highlighted as "New Personal Geodatabase". Rename the geodatabase by typing "OttawaLayers" over the highlighted text
3. Press "Enter".

Figure 5.4 shows "OttawaLayers" personal geodatabase created under LSS Project folder.

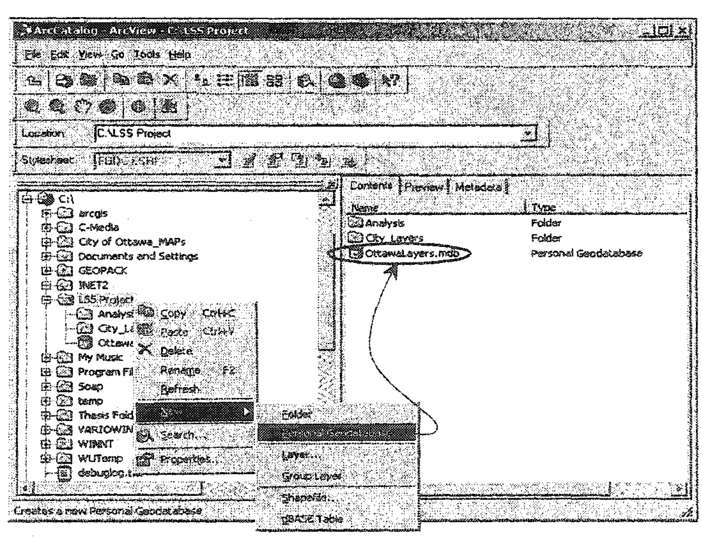


Figure 5.4 "OttawaLayers" Personal Geodatabase

5.2.2.3. Adding Data to the "LSS Project" Folder

The layers required for this project, must be added to the "LSS Project" folder and personal geodatabase. Since some data need to be modified before they can be used in the overlay process, they are copied to the "OttawaLayers" geodatabase that was just created.

Data in the "OttawaLayers" geodatabase can be categorized into four feature-datasets according to their characteristics, as follows.

1. Engineering Dataset
2. Hydrology Dataset
3. Residence/planned area Dataset
4. Transportation Dataset

The following steps get through the process of creating these feature-datasets.

1. Right-click on the "OttawaLayers" geodatabase and select "New" and point to "Feature Dataset"
2. Type the name of the feature-dataset
3. Click "Ok".

Figure 5.5 shows these four feature-datasets created in the "OttawaLayers" personal geodatabase.

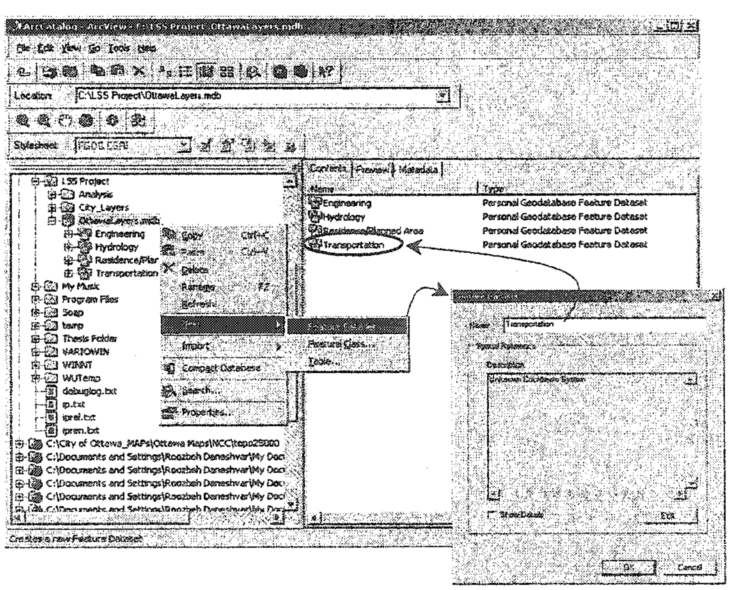


Figure 5.5 Feature Datasets in the "OttawaLayers" Personal Geodatabase

Layers that require an additional processing and preparation such as clipping, merging or changing the coordinate systems are copied from their original location into the personal geodatabase. The procedure follows:

1. Right-click on the "OttawaLayers" geodatabase and select "Import" and point to "Shapefile to Geodatabase" as shown in Figure 5.6.
2. The new dialog box allows locating and selecting the desired layers from their original place. Layers are copied based on their characteristics into one of the four feature-datasets. Figure 5.7 shows layers imported into each feature-datasets.

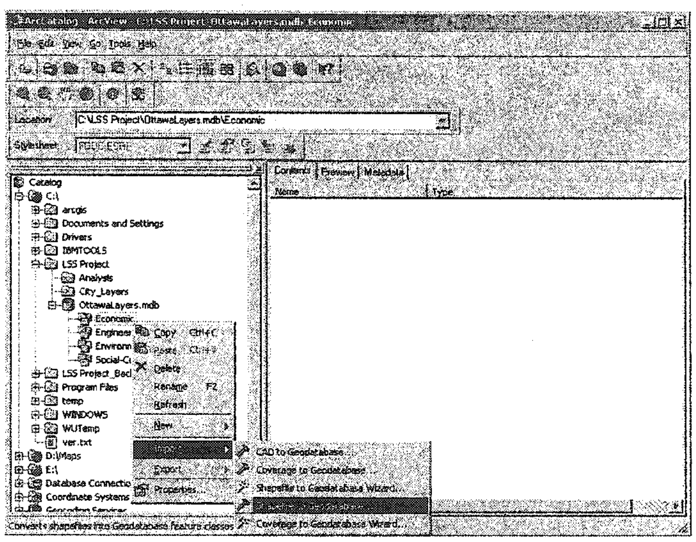


Figure 5.6 "Shapefile to Geodatabase" Submenu in the "Import" Menu

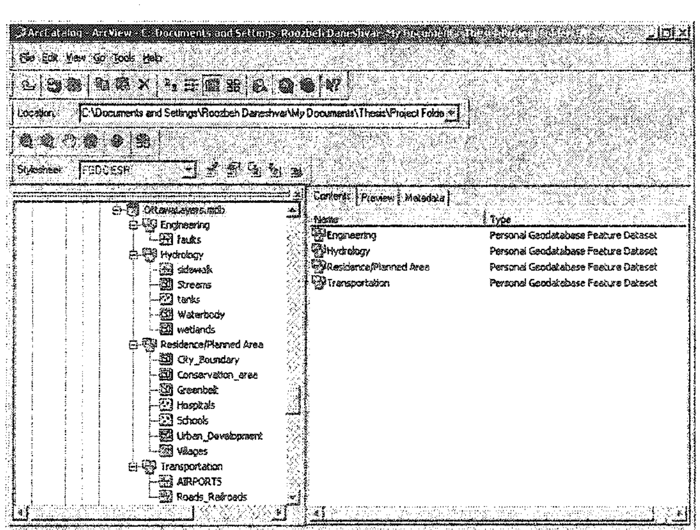


Figure 5.7 "OttawaLayers" Personal Geodatabase, Feature-Datasets and Layers

A series of layers (or pointers) can be created to point the original data and serve as shortcuts to them. That way a single copy of the original data are maintained as a backup but accessed from within the project folder on the local machine. This lets user access the data from within the project folder without creating duplicate datasets and this is particularly useful when accessing data over a network.

In the present case study, the original database containing all required data, was collected from different sources and saved on the local drive. In addition, they are copied into a personal geodatabase for further use. Hence, making pointers for them is not a necessary step and therefore, it can be skipped. For the sake of demonstration, however, the following steps show how to create pointers in the "City_layer" folder that point the original database.

1. Right-click on the "City_Layer" folder and select the "New" and click "Layer"
2. Specify the name and location of the original layer in the "Create New Layer" dialog box

In a similar fashion, a pointer layer can be created for each original layer and used for the analysis. Figure 5.8 shows layers created in the "City_layers" folder that point the original data.

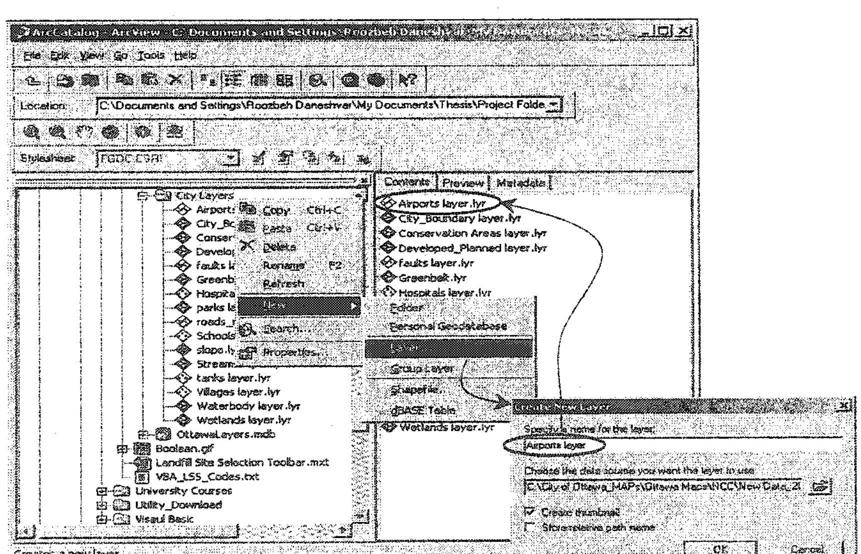


Figure 5.8 Pointer Layers Created in the "City Layer" Folder

5.2.2.4. Reviewing Data in the ArcCatalog

ArcCatalog lets user quickly preview the features and attributes in each individual dataset. The right side of the ArcCatalog window displays the name of the layer, along with its type and three tabs, Contents, Preview and Metadata.

The following steps show how to review the projection of a layer.

1. Click "Metadata" tab
2. Select "Spatial" tab in the metadata panel

This window gives the information about the horizontal coordinate system as shown in Figure 5.9.

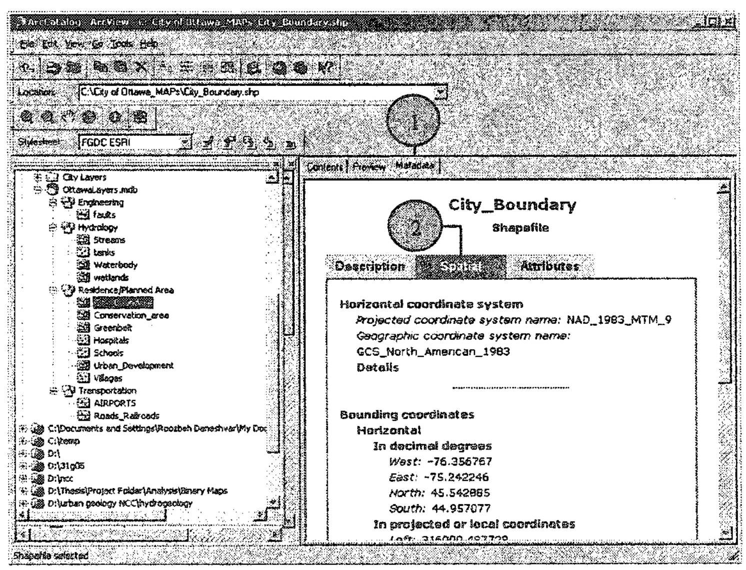


Figure 5.9 Spatial Metadata Review in the ArcCatalog Application

Data obtained from the "Map Library" database at the University of Ottawa, have NAD_1983_MTM_9 projection. However, other data collected for this case study, have different projections and hence had to be converted to the latter projection. This task can be carried out in the following section.

5.2.3. MAP PREPARATION FOR THE CASE STUDY

Based on the user's review in the ArcCatalog application, it is determined which layers are currently usable or needs additional processing for analysis. Common tasks involved in preparing data for analysis are integrating the layers regarding to their coordinate systems and assembling them such as "Merging" or "Clipping" if required. Tools available in the "Map Preparation" menu on the LSS toolbar perform these tasks.

5.2.3.1. Defining and Matching the Coordinate Systems Using ArcToolbox Application

Unless GIS data are in the same coordinate system, they may not display or overlay correctly. Data for the present case study come from several different sources and they have either different or even undefined coordinate systems. Their projection, therefore, must be defined to an appropriate coordinate system for the Ottawa area. It is also recommended to have them in the same coordinate system. Therefore, two different procedures can be implemented, (1) defining a coordinate system and (2) projecting a layer.

Defining a coordinate system simply means telling the ArcGIS what projection the dataset uses and what units the coordinates are stored in. When the projection of data is unknown it must be defined using its metadata and projection specification.

When projecting a dataset, on the other hand, ArcGIS actually creates a new dataset with the coordinates transformed from the existing coordinate units to a new coordinate system. User defines the input dataset and the coordinate system to project into, and ArcGIS creates the new dataset. In order to project a shapefile layer, the new output coordinate system must be known via three alternatives: (1) Using a predefined coordinate system stored as a .prj file, (2) Matching the coordinate system of an existing dataset by specifying the name of the dataset, or (3) Interactively specifying a projection and a datum and their associated parameters (Corey, 1999).

ArcGIS provides many predefined coordinate systems to use, stored as .prj files. The files include all the coordinate system parameters including the map projection type and parameters, measurement units.

In the present case study, both projecting and defining coordinate-system techniques are applied. Projection of the layers obtained from NRC database, must be defined according to their metadata specifications. Then, they are projected to a new coordinate system, which is common between data.

Since the process of these two tasks is similar, as an example, the procedure of projecting the "Rivers" layer is explained below.

One way to project the "Rivers" layer is matching the coordinate system of an existing dataset by specifying the name of the dataset. "Define Projection Wizard" available in the ArcToolbox can get the coordinate system parameters from "City boundary" layer that contains the appropriate projection with the following properties:

- Grid Coordinate System: Modified Transverse Mercator (MTM)
- Projection: Modified 3 Degree Transverse Mercator, Zone 9
- Horizontal Geodetic Datum: NAD83
- Units: meters and Square meters
- Spheroid: GRS80 "6378137.0 m" "6356752.314 m"
- Central Meridian: -76.5
- Easting/Northing Unit: meters
- False Easting: 304800.0
- False Northing: 0
- Latitude of Origin: 0

The following steps get through the process of defining the projection of "Rivers" layer and creating a new "Rivers" layer in the referred coordinate system.

1. Click launch ArcToolbox button in the "Map Preparation" menu as shown in Figure 5.10

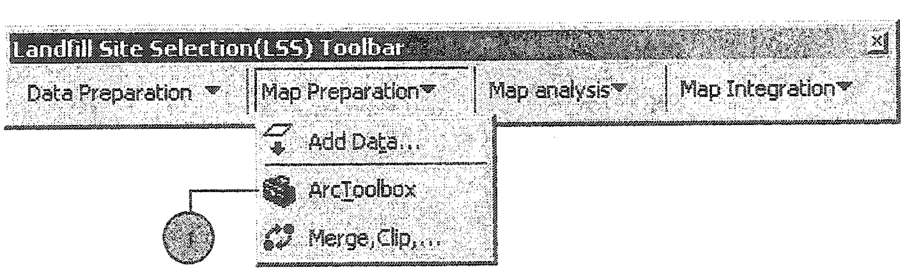


Figure 5.10 "ArcToolbox" button in the "Map Preparation" Menu

2. Double-click "Data Management Tools" in the ArcToolbox tree; double-click "Projections" then double-click "Define Projection Wizard", as shown in Figure 5.11.

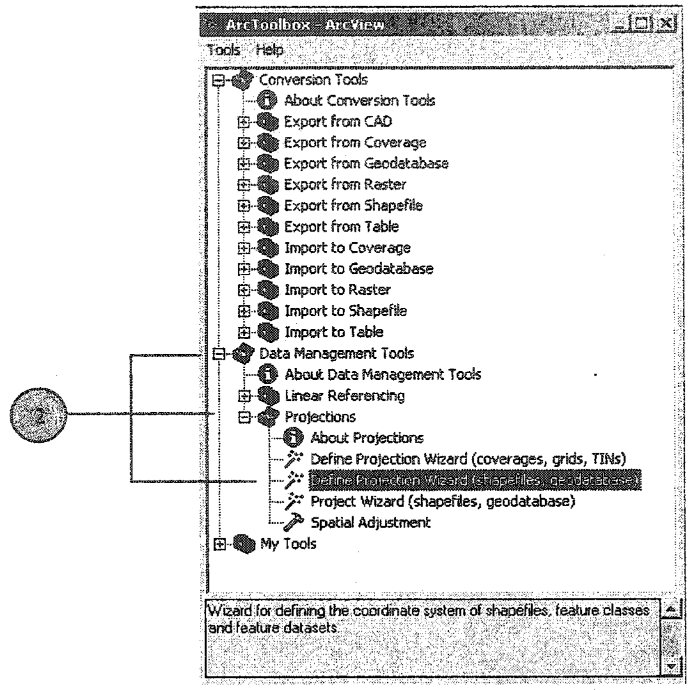


Figure 5.11 "Define Projection Wizard" in the ArcToolbox Application

3. Click "Open" button to point the "Rivers" layer in the "City_Layer" subfolder of the "LSS Project" folder, as shown in Figure 5.12

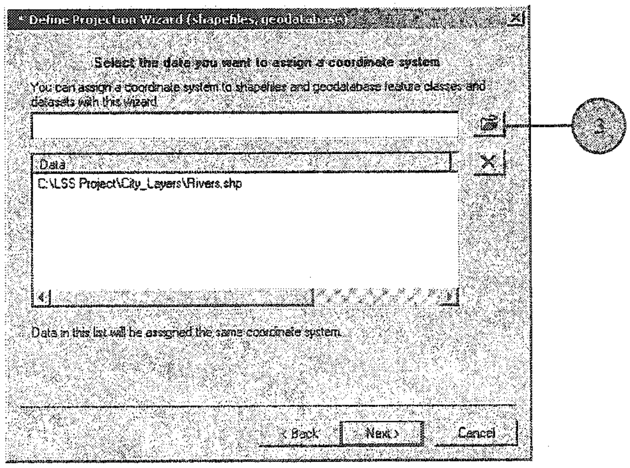


Figure 5.12 Selecting "Rivers" Layer from the "City_Layer" subfolder

4. Click "Select Coordinate System" button

5. Click "Import" button and point the "City boundary" layer. Information from this layer are retrieved as shown in Figure 5.13
6. Click "Ok"

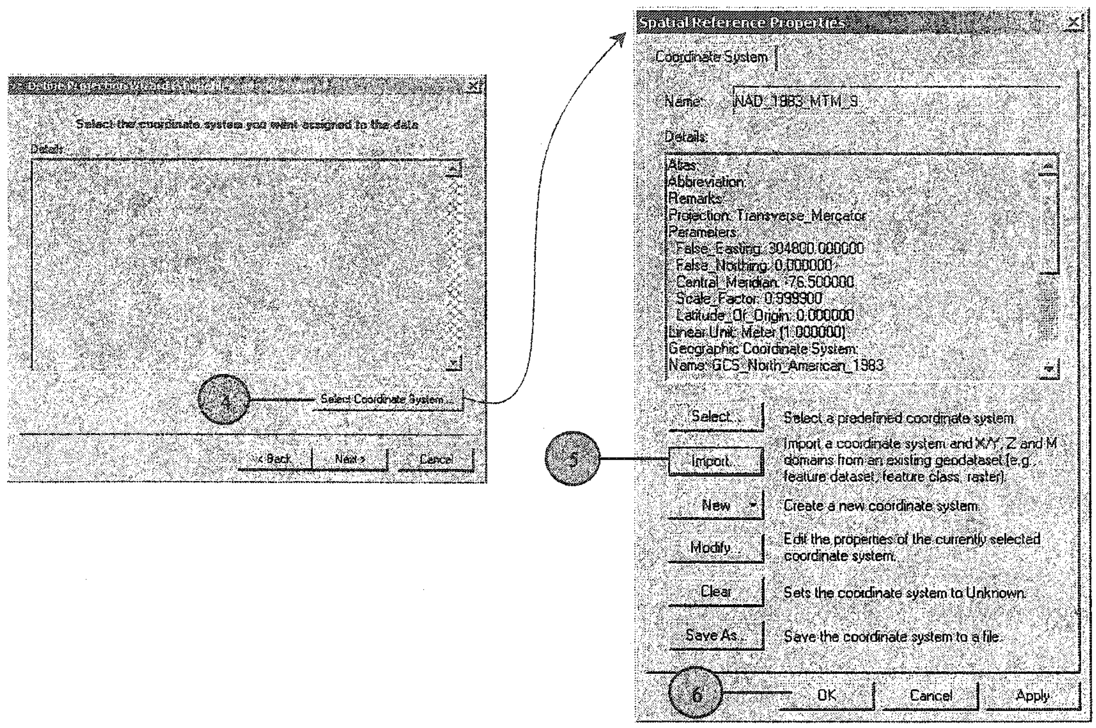


Figure 5.13 Projection Properties Retrieved From the Selected Layer

7. A summary of the selected projection is displayed as shown in Figure 5.14. Click "Finish" to end the process.

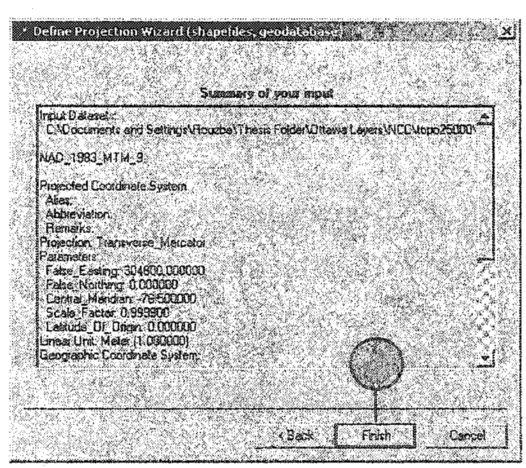


Figure 5.14 Properties of the Selected Projection

In a similar fashion, coordinate system or projection of all layers is also defined and matched to NAD_1983_MTM_9 projection.

5.2.3.2. Merging Layers

Sometimes data are in two or more adjacent datasets, either because of the way the data were created or the way they are stored. Therefore they need to be merged to make the analysis easier to perform. In the present case study, "wetlands" and "water bodies" shapefile layers have been originally stored as tiles of several adjacent layers and need to be merged into a single layer to cover the whole area of the case study and become a more suitable layer during the analysis. The following steps describe the process of merging "wetlands" layers into a single layer.

1. Click "Merge, Clip..." button in the "Map Preparation" menu as shown in Figure 5.15

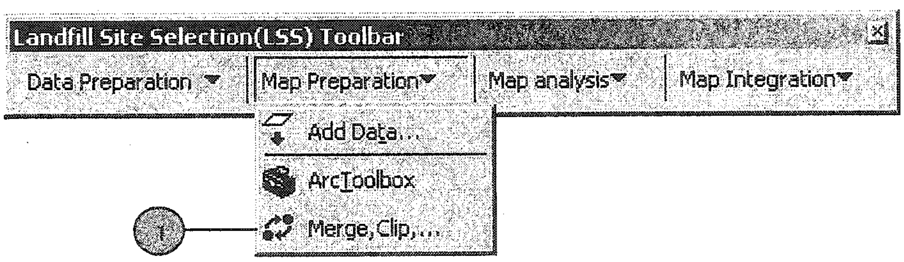


Figure 5.15 "Merge, Clip" button in the "Map Preparation" Menu

2. The Geoprocessing Wizard lets user combine features and datasets in several ways. In this case, choose "Merge layers together" as shown in Figure 5.16
3. Click "Next"

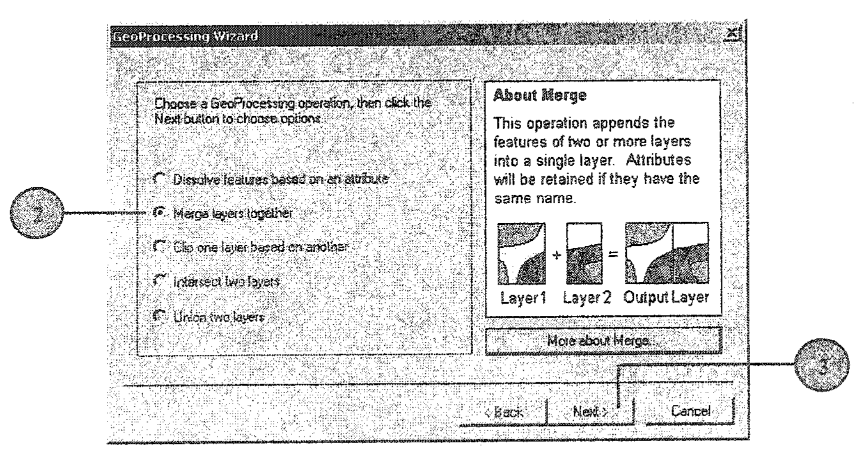


Figure 5.16 Selecting the "Merge layers together" Button

4. Select "wetland-03" to "wetland-08" layers which must be merged by checking the boxes next to them as shown in Figure 5.17
5. Put the joined layer in the "Analysis" folder. To do so, Click Browse button next to the "specify the output" text box and navigate to the "C:\LSS project\Analysis" folder. Specify "WtlM" as a name for the joined layer. The "M" suffix implies the "Merged" action
6. Click "Finish" to merge the layers.

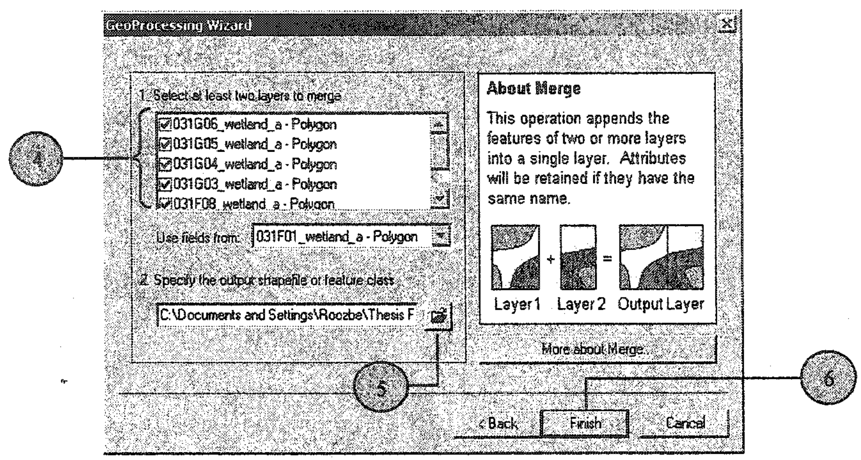


Figure 5.17 Finalize Merging

"Water bodies" layers are also merged using a similar technique and saved in the "C:\LSS project\Analysis" folder with "WbdM" new name.

5.2.3.3. <u>Clipping Layers</u>

Since the extent of the layers exceeds the boundary of the study area, they need to be cut out using the "City boundary" layer as a "cookie cutter". For example, the original road layer covers the area beyond the city boundary; however, for this project only the segment of roads that fall inside this boundary is of interest to us. The "cookie cutter" or clip layer must contain a polygon feature layer such as "City_boundary" shapefile.

The following steps get through the process of clipping the "Roads" layer as an example.

1. Click "Merge, Clip..." button in the "Map Preparation" menu as shown in Figure 5.15

2. In the Geoprocessing Wizard, choose " Clip one layer based on another" as shown in Figure 5.18
3. Click "Next" to display the next screen

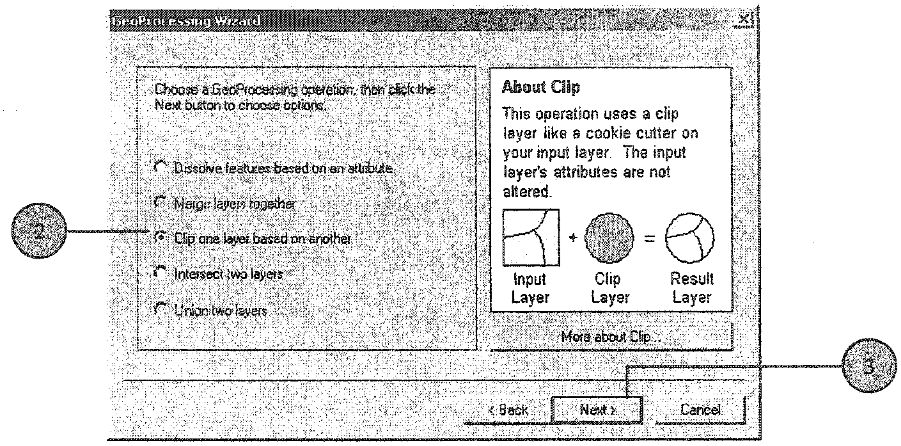


Figure 5.18 Selecting the "Clip one layer based on another" Button

4. Select "Roads" layer as an input layer to clip and "City_boundary" as a polygon clip layer as shown in Figure 5.19

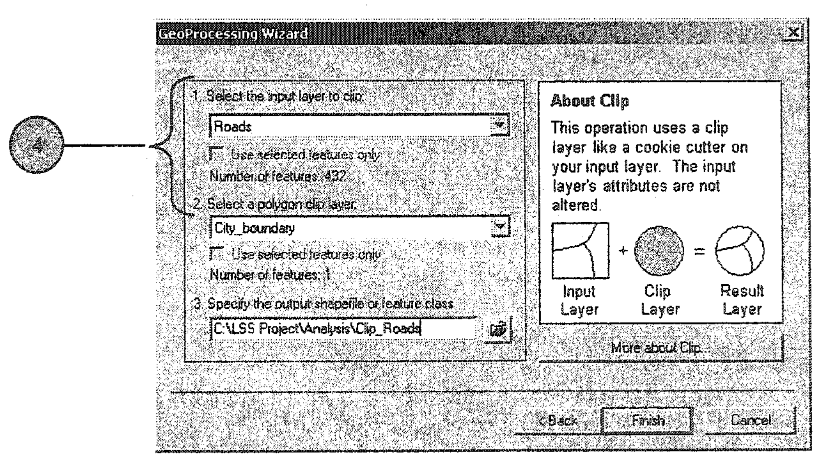
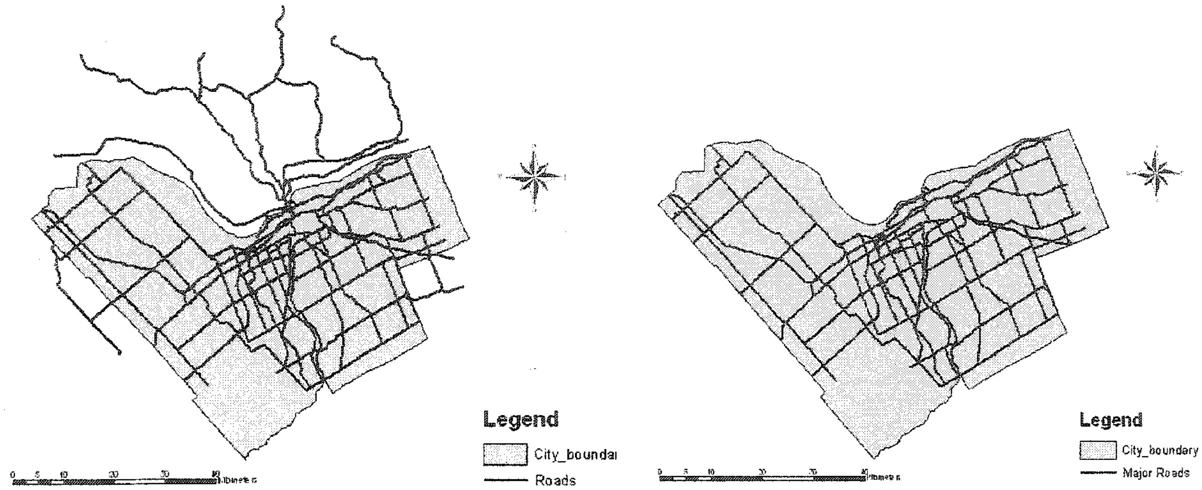


Figure 5.19 Specifying the Input, Clip Layer and Output Specifications

5. Specify "C:\LSS Project\Analysis" as a location and "RodC" as a new name for the output layer. The "C" suffix implies the "Clipped" action
6. Click "Finish" to complete the process.

Figure 5.20 illustrates the "Clip" function applied to the "Roads" layer.



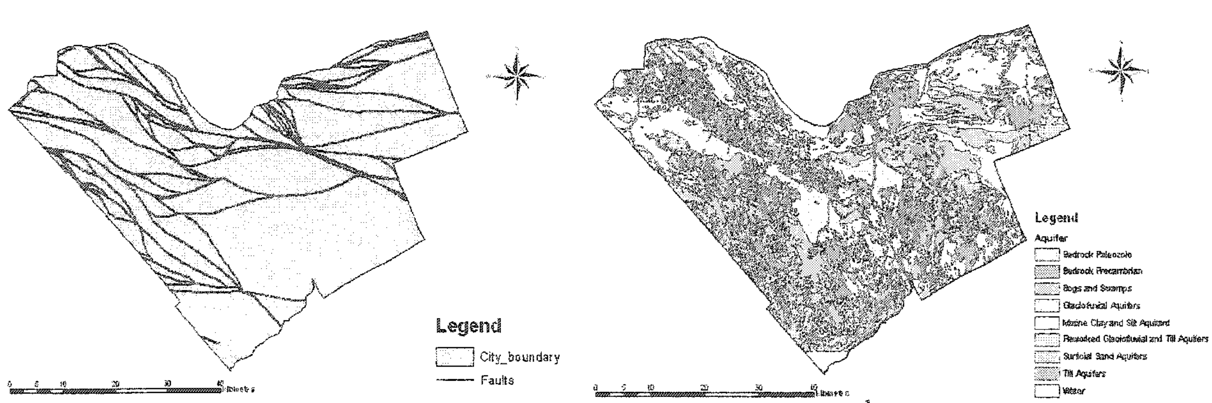
a. b.

Figure 5.20 (a) "Roads" Layer Before and (b) After Getting Clipped

In a similar way, layers get clipped and saved in the "C:\LSS Project\Analysis" folder and assigned the following names:

- "ArpC" for Airports layer
- "AqfC" for Aquifer layer
- "FltC" for Faults layer
- "LnsC" for Landslides layer
- "RvrC" for Rivers layer
- "WtlMC" for Wetlands layer
- "WbdMC" for Water bodies layer

Figure 5.21 shows "AqfC" and "FltC" layers.



a. b.

Figure 5.21 (a) Clipped "Aquifer" Layer and (b) Clipped Faults Layer

5.2.4. MAP ANALYSIS

"Map analysis" is the third element on LSS toolbar and contains all necessary tools for making slope map, buffering and eventually making binary and scored maps that are essential components for "Map Integration". The following steps get through the process of Map analysis.

5.2.4.1. Setting up the Analysis Environment

Before preparing and analyzing maps, the analysis environment must be identified. This step involves specifying "Working Directory", "Analysis Mask", "Extent" and "Cell size" of the outputs.

For the present case study, these properties are specified. The procedure follows.

1. Click "Options" button in the "Map analysis" dropdown menu as shown in Figure 5.22

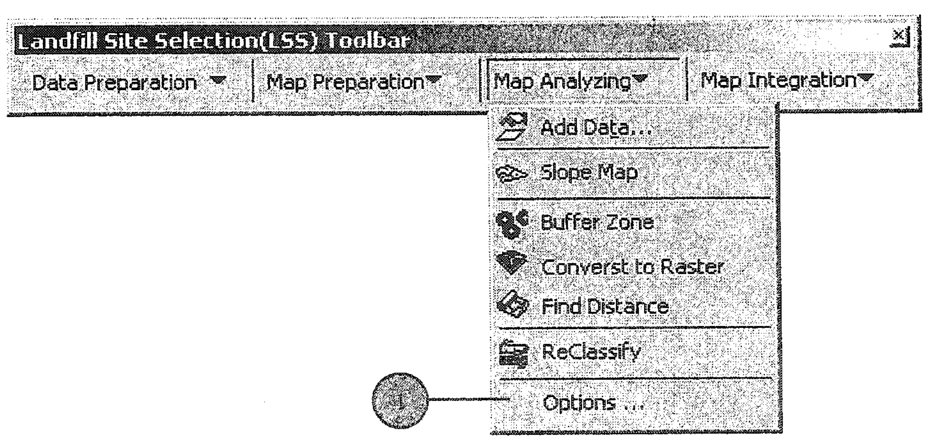


Figure 5.22 "Options" button in the "Map analysis" Menu

2. Click "General" tab and type "C:\temp" as "Working directory" and specify "BndR" raster layer as a mask or cutter for the analysis as shown in Figure 5.23.

   Note "BndR" is a raster format of "City_boundary" shapefile

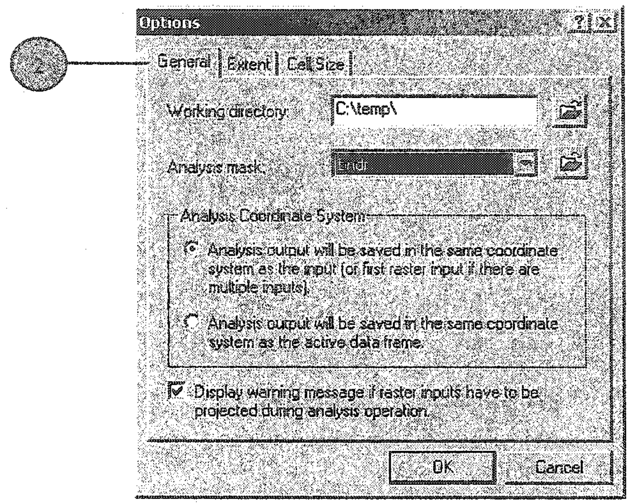


Figure 5.23 "General" Tab in the "Options" Dialog Box

3. Click "Extent" tab and select "Same as Layer City_boundary" as an analysis extent as shown in Figure 5.24

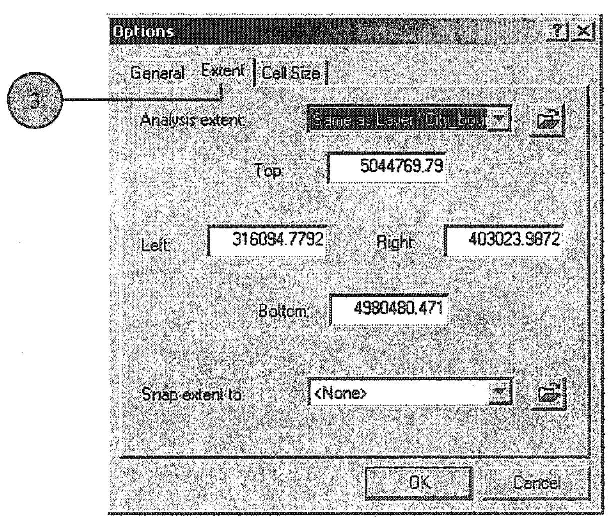


Figure 5.24 "Extent" Tab in the "Options" Dialog Box

4. Click "Cell Size" tab and select "Maximum of Inputs" as an analysis cell size for the outputs as shown in Figure 5.25

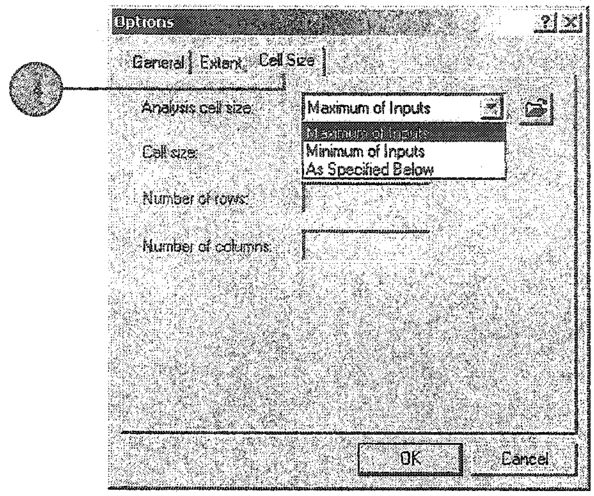


Figure 5.25 "Cell Size" Tab in the "Options" Dialog Box

5.2.4.2. <u>Creating Slope map</u>

Since the region being studied is a relatively flat area, there is no need to generate the slope map; however, for the sake of demonstration, the process of creating a slope map with the "Slope Map" function from the digital elevation model (DEM) of the area is illustrated in the following section.

1. Click "Slope Map" button in the "Map analysis" menu as shown in Figure 5.26.

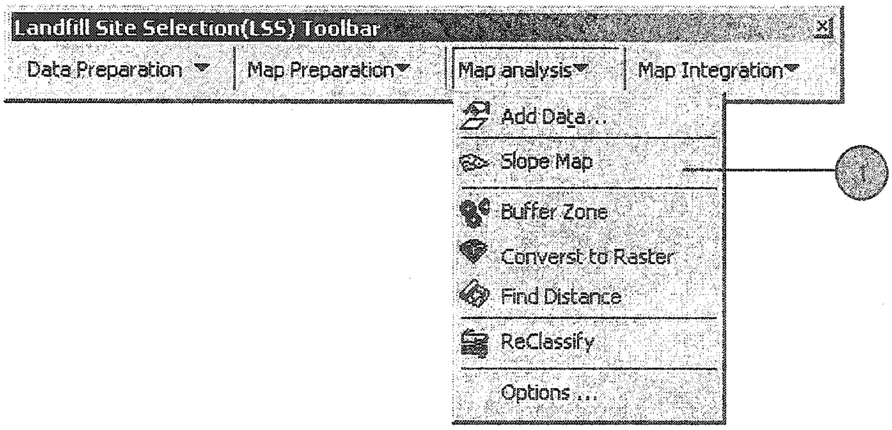


Figure 5.26 "Slope Map" Button in the "Map analysis" Menu

2. Click button next to "Input surface" dropdown menu and locate the City_Layer personal geodatabase where the "DEM" layer is available as shown in Figure 5.27

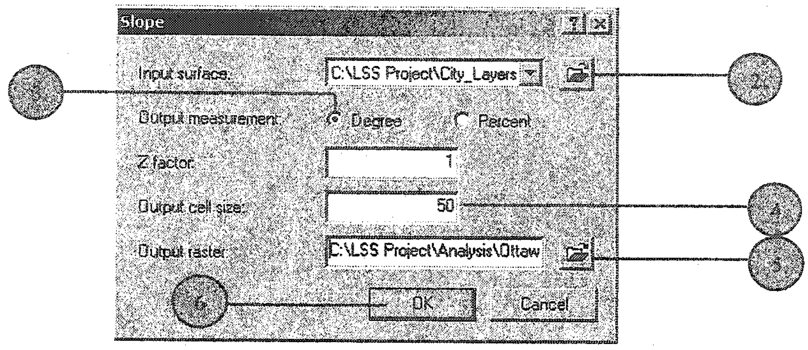


Figure 5.27 Specifying the Input Surface and the Output Specifications

3. The output can be in degrees or percentages. Choose "Degree" as the output measurement unit. The Z-factor is the number to adjust the input surface z units to another unit of measure. Since units in this case are the same, choose the default value of z (i.e. Z = 1)
4. Choose 50 as the output cell size
5. Select "Slope" as the name and "C:\LSS Project\Analysis" folder as the location for the output
6. Click "Ok".

The generated slope map can also be clipped to the extent of the study area with the method explained earlier and saved in the "C:\LSS Project\Analysis" folder with a new name of "SlopeC".

5.2.4.3. <u>Buffering</u>

Some of the location criteria prohibit landfills of being located inside or within a certain distance from specific features. The areas delineated by these criteria become the unacceptable and acceptable areas for the landfill, respectively. These criteria are known as constraints and determined by experts, planners and engineers involved in the project.

In the present case study, landfill is restricted of being constructed within a certain distance of the (1) Airports, (2) Rivers, (3) Water bodies, (4) Roads, (5) Faults, (6) Conservation Area, (7) Urban development area, (8) Villages, (9) Hospitals, and (10)

Schools. Buffer zone must be created around each of these objects to distinguish the acceptable and unacceptable areas. Since the buffering process is similar for all layers, the following steps demonstrate an example of making a buffer zone of 3 kilometer around the "ArpC (Airports)" layer.

1. Click "Add Data" button in the "Map analysis" menu as shown in Figure 5.28. Point the "C:\LSS Project\Analysis" folder where the "ArpC" layer is available

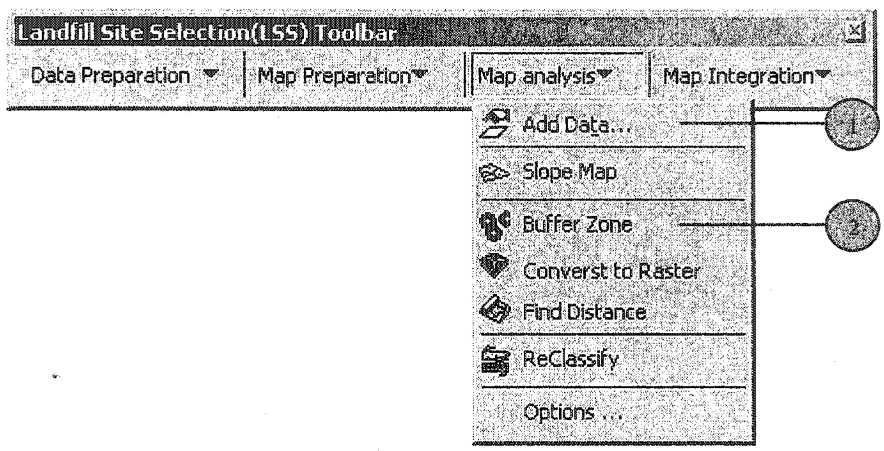


Figure 5.28 Adding the "Airports" Layer from the Geodatabase

2. Click "Buffer Zone" button available in "Map analysis" dropdown list.
3. Select "The features of a layer" option. Click dropdown arrow, and click "ArpC" as shown in Figure 5.29
4. Click "Next" to display the next screen

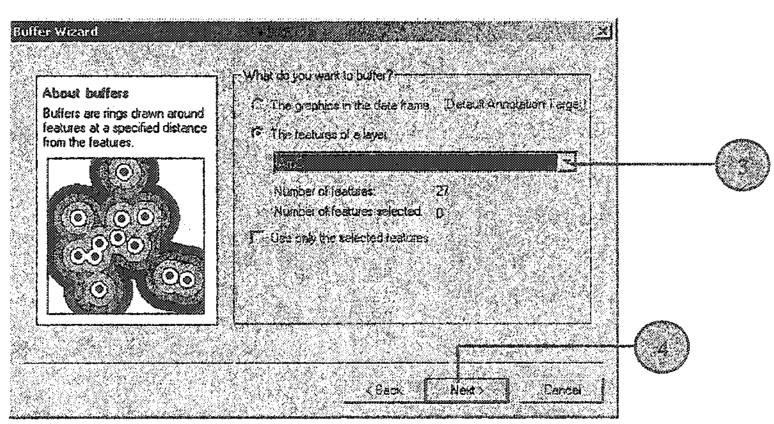


Figure 5.29 Selecting the Input Layer for Buffering

5. Select the "At a specified distance" option and type 3000m in the text box. Make sure that the selected unit in the "Distance units" dropdown menu is set as "Meters" as shown in Figure 5.30
6. Click "Next"

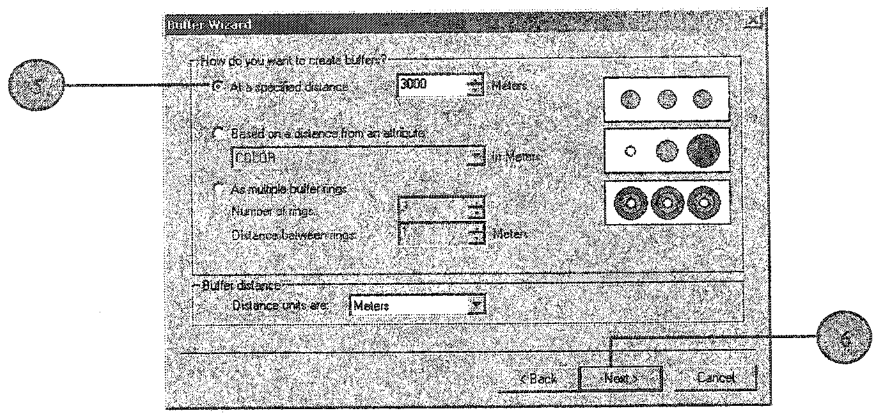


Figure 5.30 Specifying the Distance and Units for Buffering

7. Click "Yes" to dissolve the barriers between buffers as shown in Figure 5.31 Hence, barriers will create a single buffer around the airports
8. In the text box, select the option to save the buffer "In a new layer". Type "C:\LSS Project\Analysis" as the path and "ArpCB" as the layer name. The "B" suffix implies the "Buffering" action
9. Click "Finish" to complete the process.

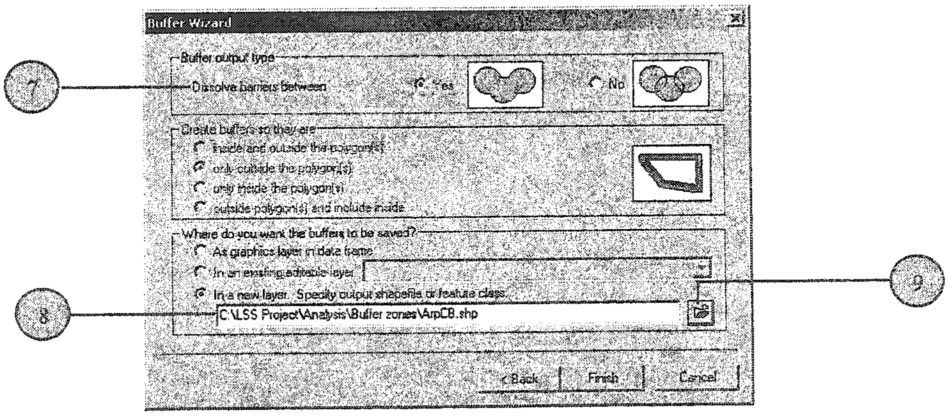
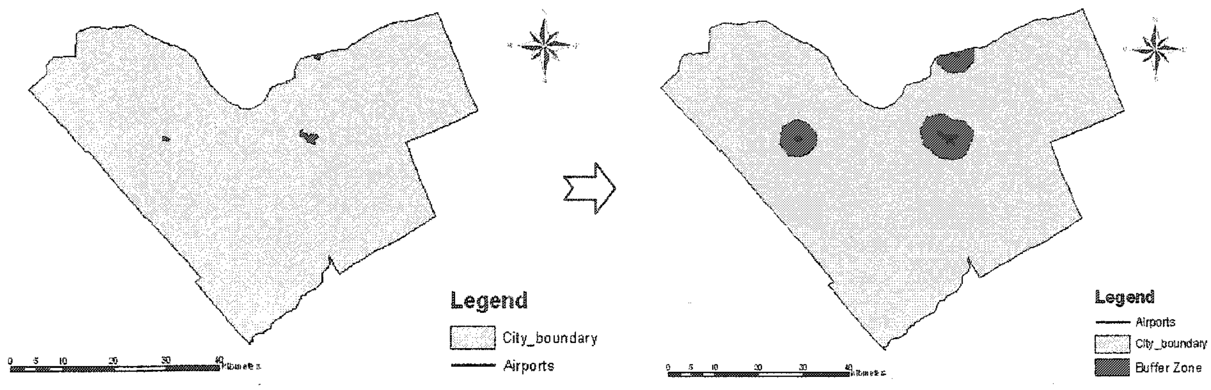


Figure 5.31 Specifying the Buffer Output Type

Figure 5.32 illustrates "Buffering" function applied to the "Airports" layer.



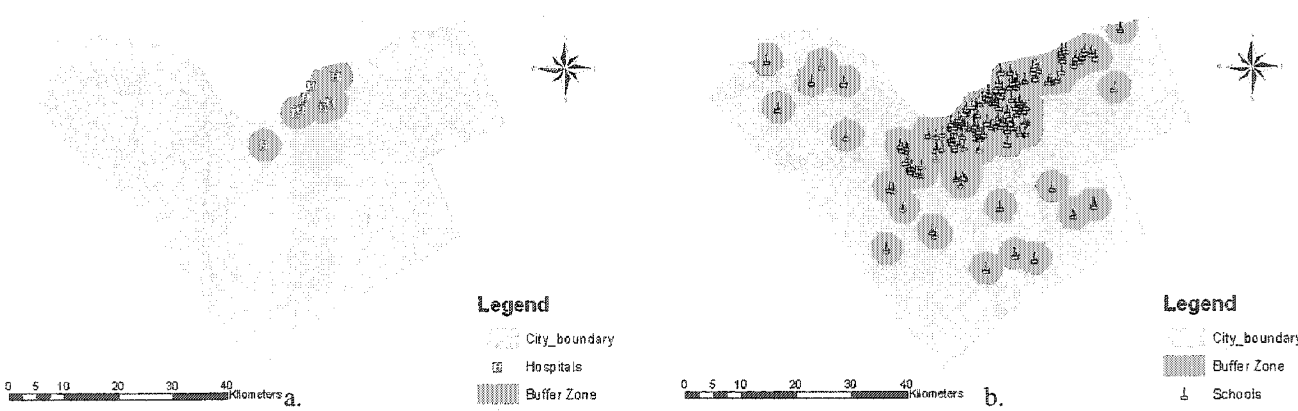
a. b.

Figure 5.32 "Airports" Layer Before (a) and After (b) Buffering

In a similar fashion, buffer zone maps for other layers are also generated and stored in the "C:\LSS Project\Analysis" folder with the following new names:

- "FltCB" for Faults layer
- "RodCB" for Roads layer
- "RvrCB" for Rivers layer
- "WbdMCB" for Water bodies layer
- "HspB" for Hospitals layer
- "SchB" for Schools layer
- "VllB" for Villages layer
- "CnsB" for Conservation area layer
- "UbdB" for Urban development area layer

Figure 5.33 displays "HspB" and "SchB" layers.



a. b.

Figure 5.33 "Hospitals" Buffer Zone Layer (a) and "Schools" Buffer Zone Layer (b)

5.2.4.4. Converting to Raster

All original layers in shapefile format must be converted to raster data format. Additionally, outputs resulted from "Buffering" function require this conversion as well. This is a necessary task to make layers ready for map integration process.

As an example, the process of converting "ArpCB (Airports)" layer to raster data is described in the following steps and can be applied to other layers by using the same method.

1. Click "Convert to Raster" button available in "Map analysis" dropdown list as shown in Figure 5.34

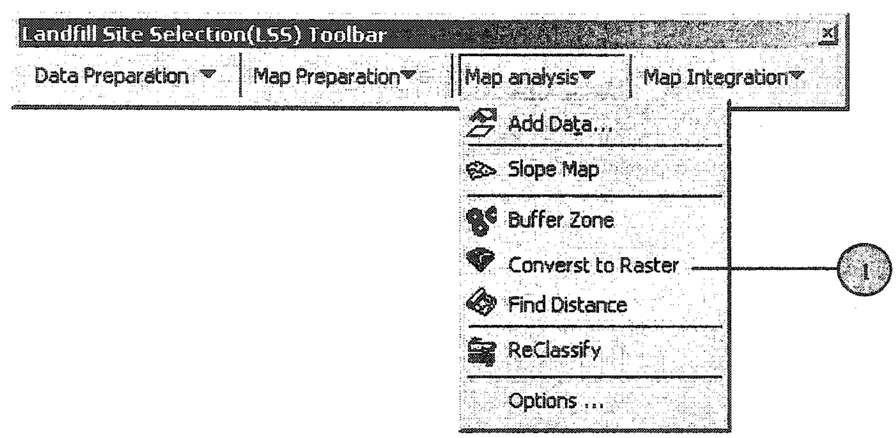


Figure 5.34 "Convert to Raster" button in the" Map analysis" Menu

2. Click Input features dropdown arrow and point the "ArpCB" in the C:\LSS Project\Analysis folder that needs to be converted to a raster as shown in Figure 5.35

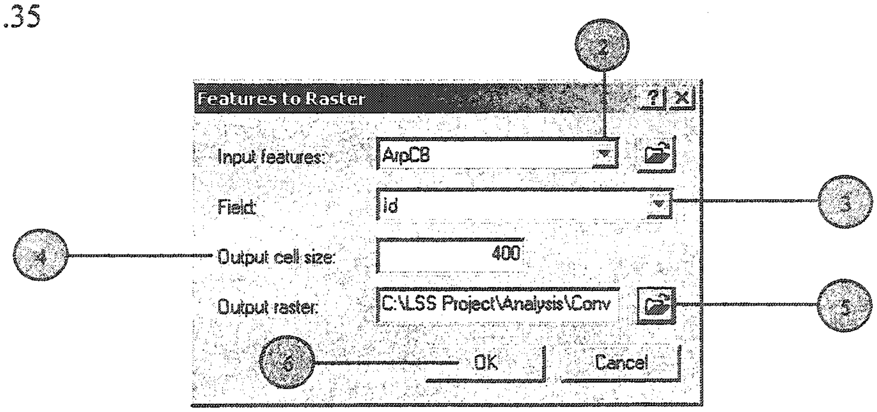


Figure 5.35 "Feature to Raster" Dialog Box in the "Map analysis" Menu

3. Click "Field" dropdown arrow and select "Id" as a field you want to copy to the Output Raster
4. When converting feature data to a raster, a cell size must be specified for the output raster. Note the larger raster will require longer processing times. Type 400 as an output cell size for this case
5. Locate "C:\LSS Folder\Analysis" as an output folder and type "ArpCBR" as a new layer name. The "R" suffix implies the "Raster" conversion.
6. Click "Ok".

All buffer layers and original polygon layers are also converted to raster with a similar method and saved in the "C:\LSS Project\Analysis" folder with the following new names:

- "ArpCR" for Airports layer
- "AqfCR" for Aquifer layer
- "BndR" for City boundary layer
- "CnsBR" for Conservation area buffer zone layer
- "CnsR" for Conservation are layer
- "FltCBR" for Faults buffer zone layer
- "FltCR" for Faults layer
- "GrbR" for Greenbelt layer
- "HspBR" for Hospitals buffer zone layer
- "LnsCR" for Landslides layer
- "RodCBR" for Roads layer
- "RvrCBR" for Rivers buffer zone layer
- "RvrR" for Rivers layer
- "UbdBR" for Urban development buffer zone layer
- "UbdR" for Urban development area layer
- "VllBR" for Villages buffer zone layer
- "WbdCBR" for Water bodies buffer zone layer
- "WbdR" for Water bodies layer
- "WtlMCR" for Wetlands layer
- "SchBR" for Schools buffer zone layer

Note "BndR" layer, which is a raster version of "City_boundary" layer, is used as a "mask" when setting the "Options" in "Map analysis", to limit the raster-based analysis processes to the extent of the study area.

5.2.4.5. Find Distance

Unlike the constraints, sometimes it is preferred the landfill be close or far from a certain object. In the present case study, for example, it is preferable to locate the landfill close to roads or far from rivers. Therefore, a map displaying the distance to a particular object is required for each criterion. This process involves calculating the straight-line distance from any location to the nearest source using "Find Distance" function available in the "Map analysis" menu. Distance maps (proximity maps) created in this way will be used for further analysis to create scored maps and perform map overlay.

The following steps demonstrate an example of how to make a distance map for the "RvrC (Rivers)" layer.

1. Click "Find Distance" button available in "Map analysis" dropdown menu as shown in Figure 5.36

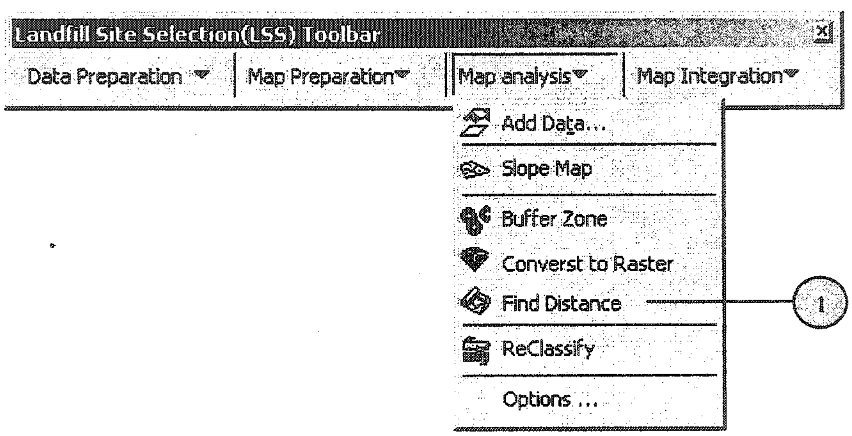


Figure 5.36 "Find Distance" button in the "Map analysis" Menu

2. Click button next to "Distance to" dropdown menu and locate the "C:\LSS Project\Analysis" where the "RvrC" layer is available as shown in Figure 5.37

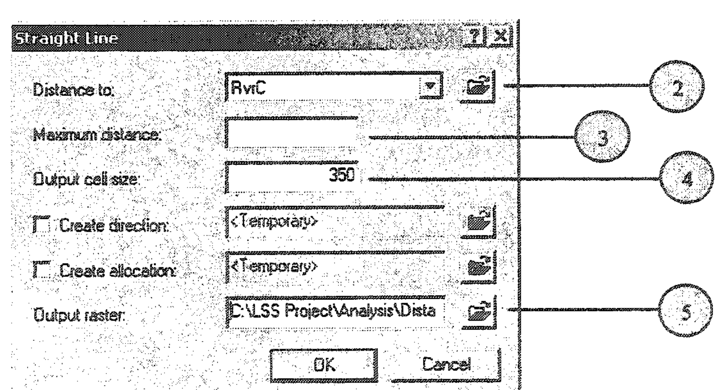
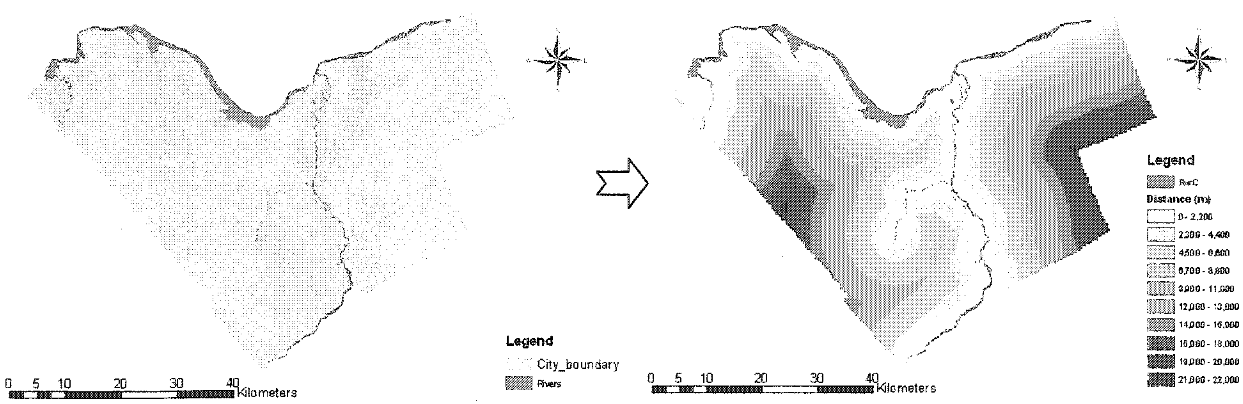


Figure 5.37 "Straight Line" Dialog Box in "Map analysis" Menu

3. Optionally, the maximum distance that will not be considered when the extent of the analysis is set in the "Options" tool
4. Specify 350 for the Output cell size
5. Locate "C:\LSS Project\Analysis" as the folder and type "RvrCD" as the name for the result. The "D" suffix implies applying "Distance Map" function.
6. Click "Ok".

Figure 5.38 illustrates "Straight Line" function applied to the "Rivers" layer.



a. b.

Figure 5.38 (a) "Rivers" Layer Before and (b) After Making a Distance Map

Unlike buffering, the result of the "Straight Line" function is a raster data in which every cell represents the distance to the nearest source. For example, in the distance map (b), darker areas have higher pixel values showing areas with farther distance from rivers.

In a similar manner, a distance map for each layer is generated and stored in the "C:\LSS Project\Analysis" folder with the new names as follows:

- "ArpCD" for Airports layer
- "CnsD" for Conservation area layer
- "FltCD" for Faults layer
- "HspD" for Hospitals layer
- "RodCD" for Roads layer
- "RvrCD" for Rivers layer
- "SchD" for Schools layer
- "UbdD" for Urban development layer
- "VllD" for Villages layer
- "WbdMCD" for Water bodies layer

Figure 5.39 shows "HspD" and "VllD" layers.

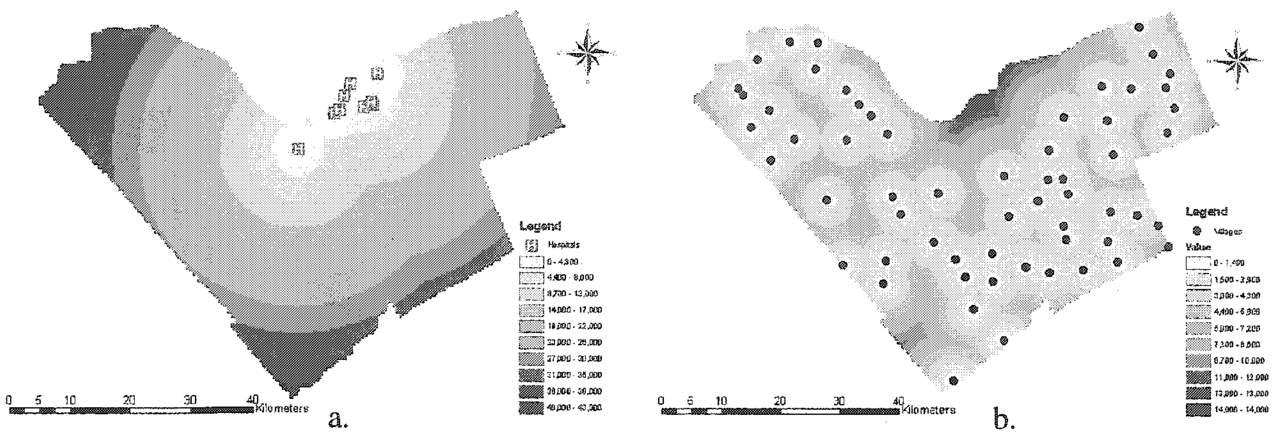


Figure 5.39 "Hospitals" Proximity Layer (a) and "Villages" Proximity Layer (b)

5.2.4.6. <u>Reclassification</u>

By reclassifying the output layers resulting from "Buffering" and "Find Distance" functions, "Binary" and "Scored" maps can be created, respectively. This is an essential step for layers prior to the integration process.

"Reclassify" button available in the "Map analysis" menu enables the user to perform the reclassification task.

In the present case, all layers except "Aquifer" are converted to the "Binary" maps. As an example, the following steps go through the process of creating a "Binary" map for the "ArpCBR (Airports)" layer.

1. Make sure "BndR" (i.e. City boundary raster layer) has been defined as a "Mask" and "Extent" of the analysis in the "Options" dialog box.
   Click "Map analysis" dropdown list; click "ReClassify" as shown in Figure 5.40.
2. Click "Input raster" dropdown arrow and point the "ArpCBR" layer located in the "C:\LSS Project\Analysis" folder as shown in Figure 5.41

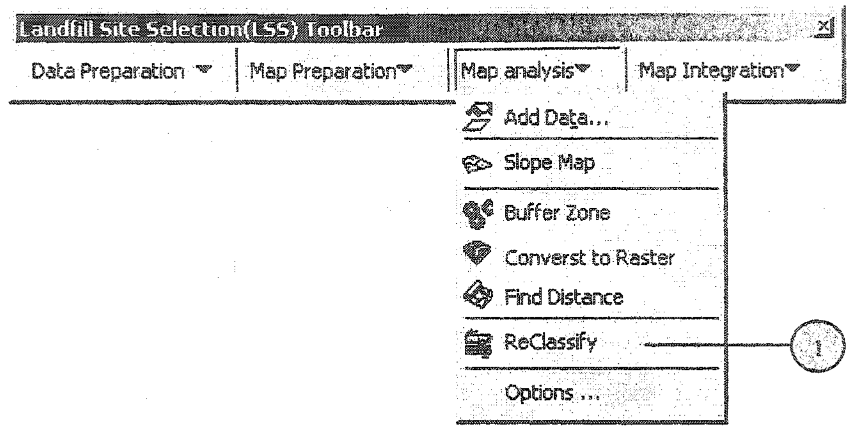


Figure 5.40 "ReClassify" button in the" Map analysis" Menu

2. Click "Input raster" dropdown arrow and point the "ArpCBR" layer located in the "C:\LSS Project\Analysis" folder as shown in Figure 5.41
3. Click "Reclass field" dropdown arrow and Click "Value" field
4. Click "Classify" button to display the next screen

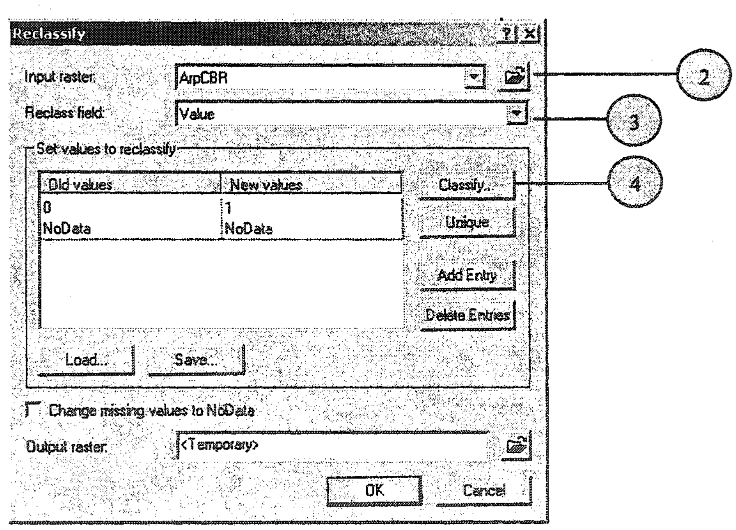


Figure 5.41 Locating the Input Raster and Reclass Field

5. Click "Method" dropdown menu and choose "Equal Interval" as shown in Figure 5.42
6. Click "Class" dropdown list and select "2" classes
7. Click "Ok"

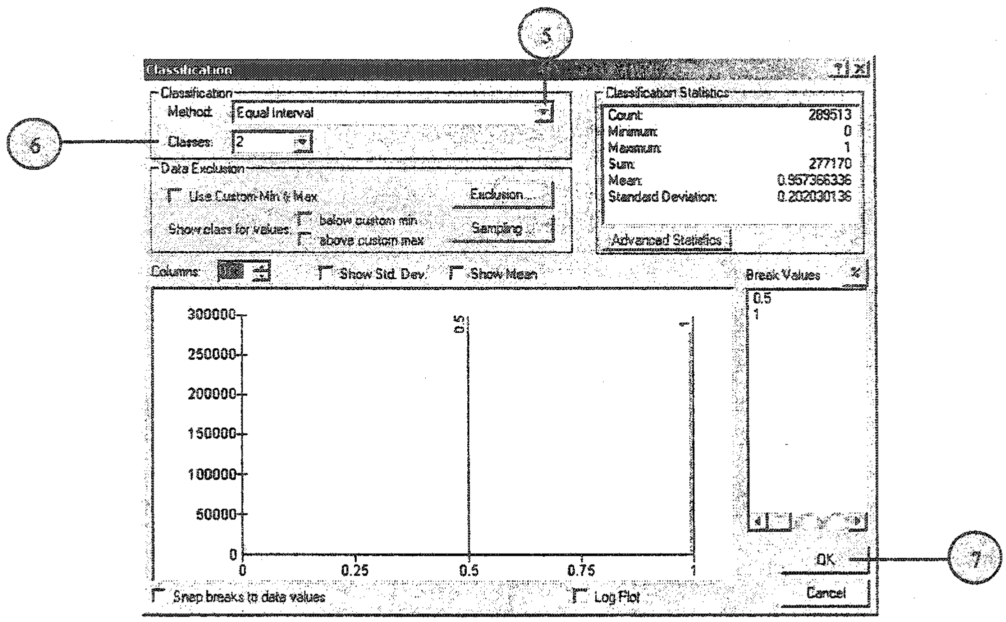


Figure 5.42 Specifying the Method and Number of Classes

5. Modify the "New Values" to "0" and "1" as shown in Figure 5.43
6. Type "C:\LSS Project\Analysis" as the folder and "ArpCBR_Bin" as the name for the output binary map

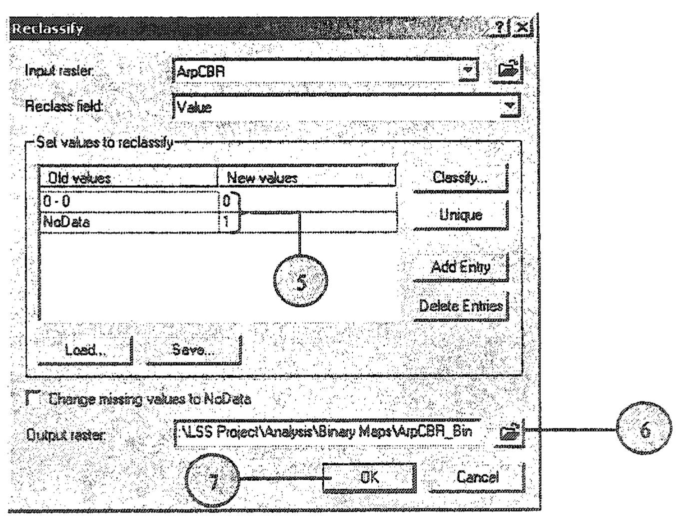


Figure 5.43 Creating Two Classes: (a) Class 0 and (b) Class 1

7. Click "Ok" to complete the Reclassification.

"ArpCBR_Bin" layer is now a "Binary" map with two classes "0" and "1". Area with pixel value equal to zero implies unacceptable area, and area with pixel value equal to one means acceptable area for siting a new landfill.

The following maps are also reclassified and converted to the "Binary" maps with a similar manner. They are saved in the "C:\LSS Folder\Analysis" folder. The "Bin" suffix implies "Binary" maps.

- "CnsR_Bin" for Conservation are layer
- "FltCBR_Bin" for Faults layer
- "GrbR_Bin" for Greenbelt area
- "HspBR_Bin" for Hospitals layer
- "LnsCR_Bin" for Landslides area
- "RvrCR_Bin" for Rivers layer
- "RvrCBR_Bin" for Rivers buffer zone area
- "RodCBR_Bin" for Roads layer
- "SchBR_Bin" for Schools layer
- "UbdR_Bin" for Urban development area
- "UbdBR_Bin" for Urban development buffer zone area
- "VllBR_Bin" for Villages layer
- "WbdMCR_Bin" for the Water bodies layer
- "WbdMCBR_Bin" for Water bodies buffer zone layer
- "WtlMCR_Bin" for Wetlands area

Figure 5.44 shows "GrbR_Bin" and "RodCBR_Bin" layers.

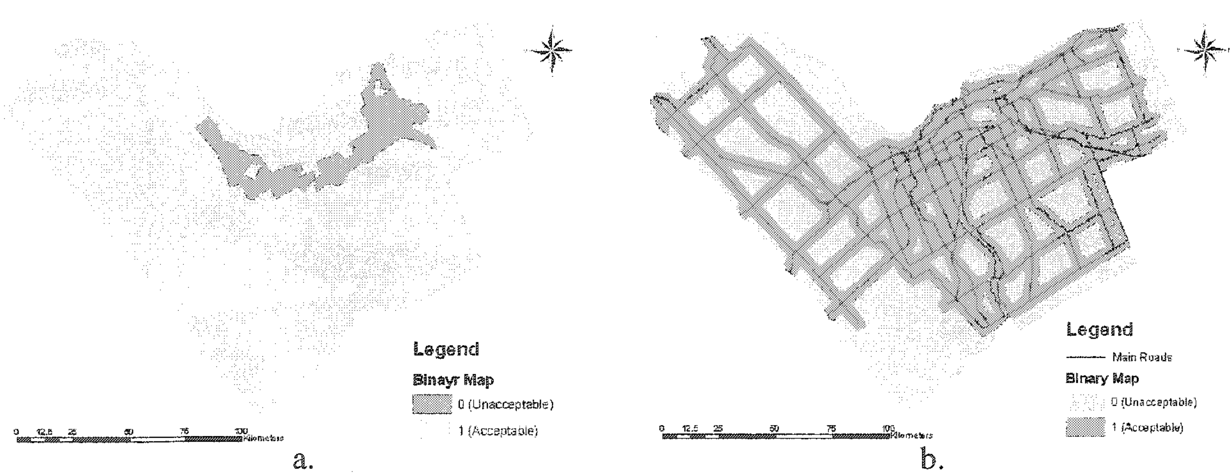


Figure 5.44 (a) "Greenbelt" Binary Layer and (b) "Roads" Binary Layer

By using "Reclassify" function, "Scored" maps can also be created. In order to perform this task, distance maps are reclassified and ranked on a common scale between all layers.

In this study, classes receive scores ranging from 1 to 10. In reality, however, suitability scales and class intervals are determined by experts and engineers involved in the project to find the best scenario.

The outputs resulting from this ranking are referred to as "Scored" or "Ranked" maps and will be used in the map integration process.

As an example in this case, since it is preferred to locate the landfill within 1100 meters from major roads, the value of 10 is assigned to the first class with 1100 meters interval. The remaining classes will then be assigned values in sequence until the furthest class receives the value of 1. Figure 5.45 shows scores assigned to each class of the "RodCD" layer.

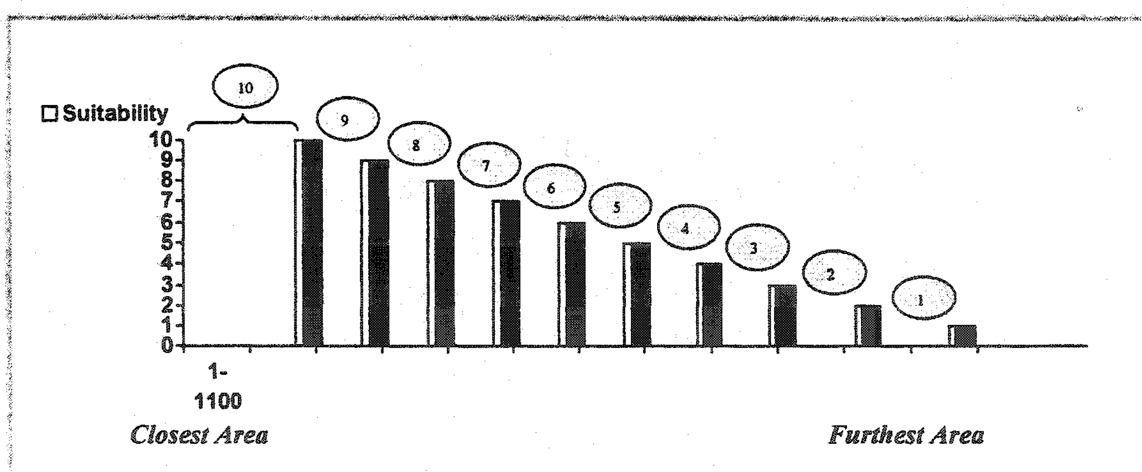


Figure 5.45 Scoring the "RodCD" Layer

The following steps describe the process of ranking the "RodCD" layer.

1. Click "ReClassify" button in "Map analysis" dropdown menu as shown in Figure 5.37
2. Click "Input raster" dropdown arrow and locate the "RodCD" layer available in the "C:\LSS Project\Analysis" folder
3. Click "Reclass field" dropdown arrow and Click "Value" field as shown in Figure 5.46

4. Click “Classify” button to display the next screen

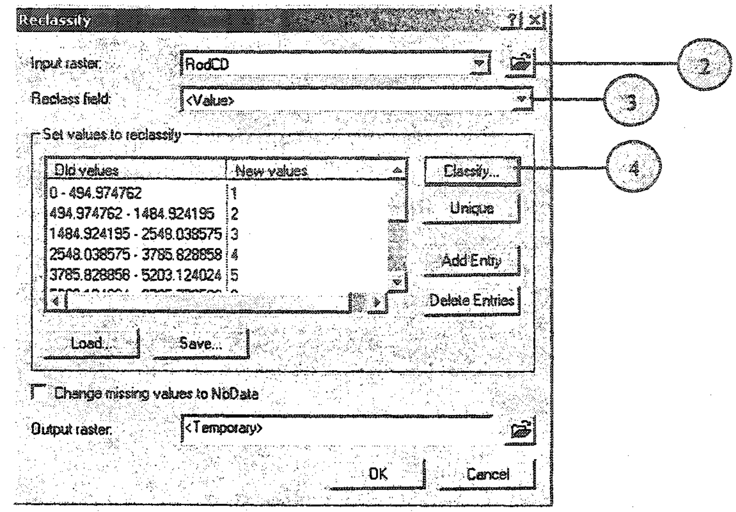


Figure 5.46 Locating the Input Raster and Reclass Field

5. Click “Method” dropdown arrow and choose “Manual” classification method as shown in Figure 5.44
6. Adjust the class intervals and set 1100m for the first interval. Note the adjustment can be performed by either moving bars by mouse (6a) or typing new values (6b), as shown in Figure 5.47

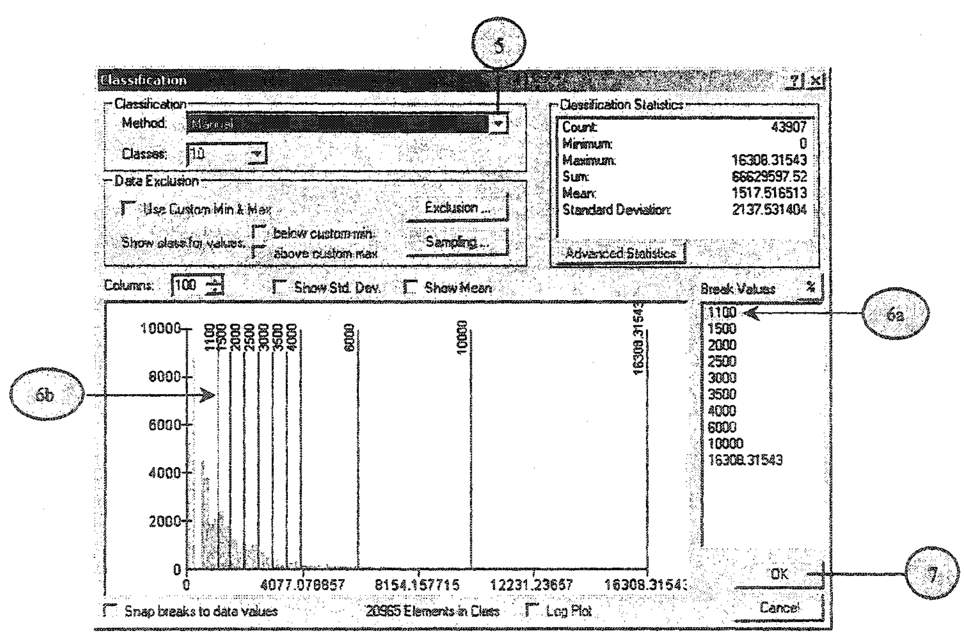


Figure 5.47 Adjusting the Class Intervals

7. Click "Ok"
8. Modify the "New Values" from "10" to "1" as shown in Figure 5.48
9. Type "C:\LSS Project\Analysis" and "RodCD_Scr" for the output location and name respectively.
10. Click "Ok" to complete the ranking task.

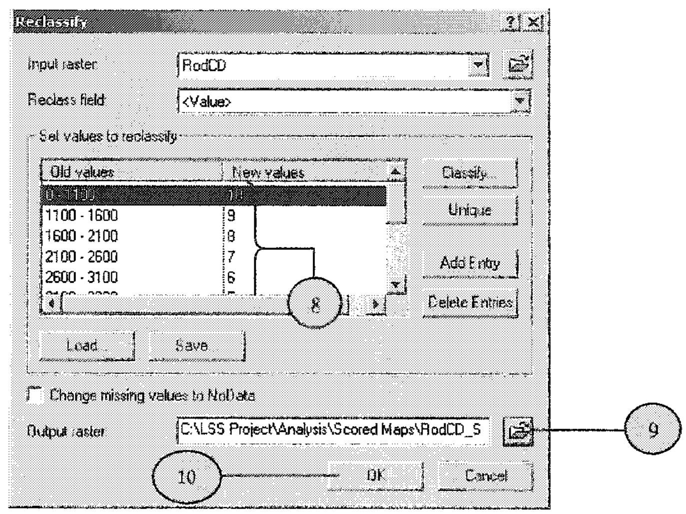


Figure 5.48 Assigning New Values to "RodCD" Layer

Figure 5.49 displays "UbdD_Scr" and "WbdMCD_Scr" layers.

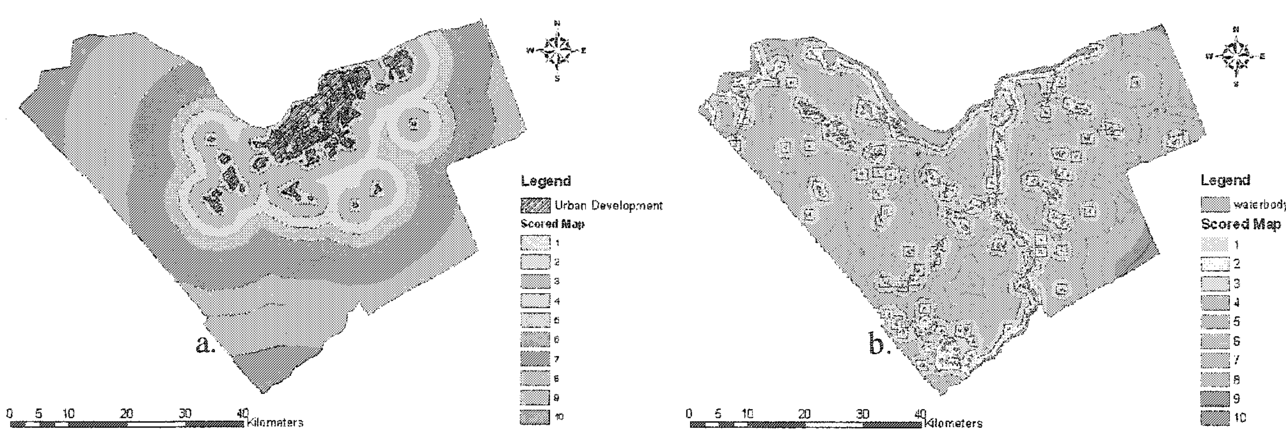


Figure 5.49 (a) "Urban development" Scored Layer and (b) "Water Bodies" Scored Layer

The following scored maps are created from the distance maps with the similar routine and saved in the "C:\LSS Folder\Analysis" folder. The "Scr" suffix implies "Scored" maps.

- AqfCR_Scr
- ArpCD_Scr
- CnsD_Scr
- FltCD_Scr
- HspD_Scr
- RvrCD_Scr
- SchD_Scr
- UbdD_Scr
- VllD_Scr
- WbdMCD_Scr

Note "AqfCD_Scr" scored layer is built in a different way. Since there is no distance map for this layer, classes are given scores according to the aquifer types and their characteristics. For instance, aquifers with a low permeability and low travel time (e.g. Bedrock Precambrain and Marine Clay and Silt Aquitard) receive higher scores. Travel time reflects the time it takes for substances to travel from the source through intervening layers to an aquifer and it is based on the thickness and hydraulic conductivity. Scoring procedure for this particular map was performed through consulting with an expert. Figure 5.50 shows the "AqfCD_Scr" scored layer.

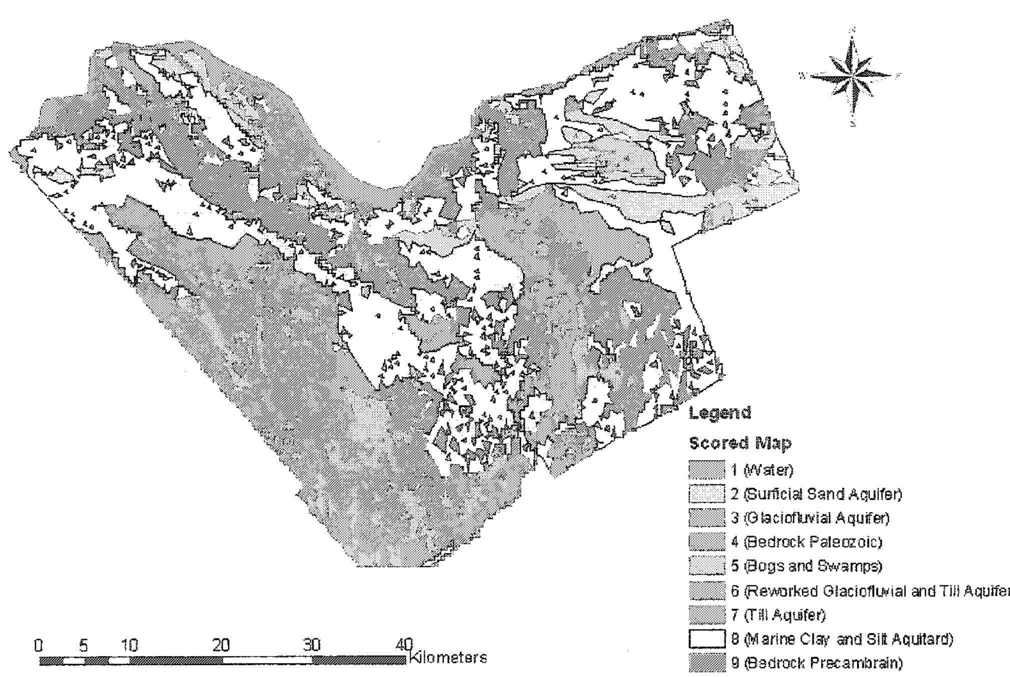


Figure 5.50 "Aquifer" Scored Layer

Table 5.1 and 5.2 summarize the map preparation and map analysis processes for the present case study. New name of a layer is obtained by adding a suffix representing the initial letter(s) of the function applied.

Table 5.1 Map Preparation Process

Layer Name	*Short name*	MAP PREPARATION *Define & Project Coordinate system*	*Merged (M)*	*Clipped (C)*
1. Airports	Arp	--	--	(x)
2. Aquifers	Aqf	(x)[a]	--	(x)
3. City boundary	Bnd	--	--	--
4. Conservation area	Cns	--	--	--
5. Faults	Flt	(x)	--	(x)
6. Greenbelt	Grb	--	--	--
7. Hospital	Hsp	--	--	--
8. Land slides	Lnd	(x)	--	(x)
9. Rivers	Rvr	(x)	--	(x)
10. Roads	Rod	--	--	(x)
11. Schools	Sch	--	--	--
12. Urban development	Ubd	--	--	--
13. Villages	Vll	--	--	--
14. Water bodies	Wbd	(x)	(x)	(x)
15. Wetlands	Wtl	(x)	(x)	(x)

[a] x's indicate considered process in each case

Table 5.2 Map analyses Process

Layer Name	MAP ANALYSIS *Buffer (B)*	*Raster(R)*	*Distance (D)*	*New name*
1. Airports	(x)	(x)	(x)	ArpCBR, ArpCD
2. Aquifers	--	(x)	--	AqfCR
3. City boundary	--	(x)	--	
4. Conservation area	(x)	(x)	(x)	CnsR, CnsD, CnsBR
5. Faults	(x)	(x)	(x)	FltCBR, FltCD
6. Greenbelt	--	(x)	--	GrbR
7. Hospital	(x)	(x)	(x)	HspBR, HspD
8. Land slides	--	(x)	--	LnsCR
9. Rivers	(x)	(x)	(x)	RvrCR, RvrCBR, RvrCD
10. Roads	(x)	(x)	(x)	RodCBR, RodCD
11. Schools	(x)	(x)	(x)	SchBR, SchD
12. Urban development	(x)	(x)	(x)	UbdR, UbdBR, UbdD
13. Villages	(x)	(x)	(x)	VllBR, VllD
14. Water bodies	(x)	(x)	(x)	WbdMCR, WbdMCBR, WbdMCD
15. Wetlands	--	(x)	--	WtlMCR

Table 5.2 (cont.) Map analyses Process

Layer Name	MAP ANALYSIS – Reclassified: Binary (Bin)	Scored (Scr)
1. Airports	ArpCBR_Bin	ArpCD_Scr
2. Aquifer	--	AqfCR_Scr
3. City boundary	BndR	--
4. Conservation area	CnsR_Bin, CnsBR_Bin	CnsD_Scr
5. Faults	FltCBR_Bin	FltCD_Scr
6. Greenbelt	GrbR_Bin	--
7. Hospitals	HspBR_Bin	HspD_Scr
8. Land Slides	LnsCR_Bin	--
9. Rivers	RvrCR_Bin, RvrCBR_Bin	RvrCD_Scr
10. Roads	RodCBR_Bin	RodCD_Scr
11. Schools	SchBR_Bin	SchD_Scr
12. Urban development	UbdR_Bin, UbdBR_Bin	UbdD_Scr
13. Villages	VllBR_Bin	VllD_Scr
14. Water bodies	WbdMCR_Bin, WbdMCBR_Bin	WbdMCD_Scr
15. Wetlands	WtlMCR_Bin	--

5.2.5. *MAP INTEGRATION*

The forth step involves combining layers and obtain the results. Two new interfaces designed and developed in this study allow the user to apply "Boolean" and "Index Overlay" models to integrate "Binary" and "Scored" maps respectively. Map overlay process in the present case study is shown schematically in Figure 5.51.

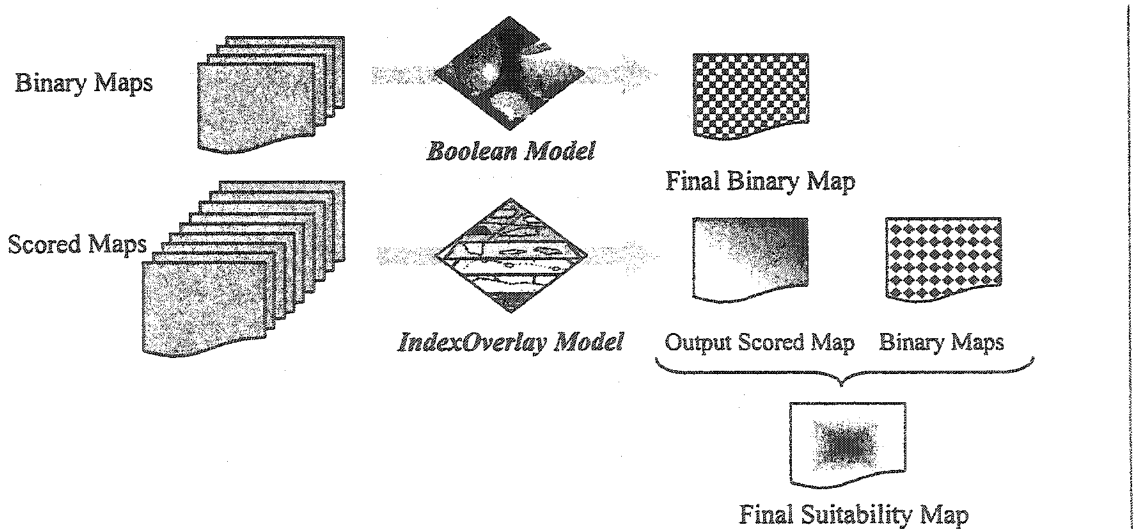


Figure 5.51 Map Integration Process

Each of the map integration models is described in the following sections.

5.2.5.1 Integrating Binary Maps Using Boolean Model

The following steps get through the process of combining binary maps created in the previous sections.

1. Click "Boolean Model" button in the "Map Integration" dropdown menu to open the first new interface as shown in Figure 5.52

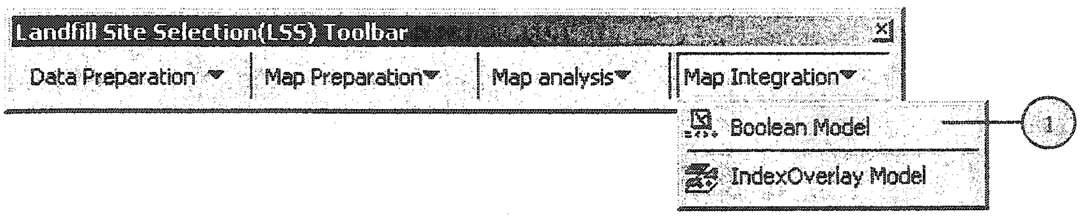


Figure 5.52 "Boolean Model" Button in the "Map Integration" Menu

2. Click "Data Frame" dropdown list, and select the data frame containing the "Binary" layers as shown in Figure 5.53

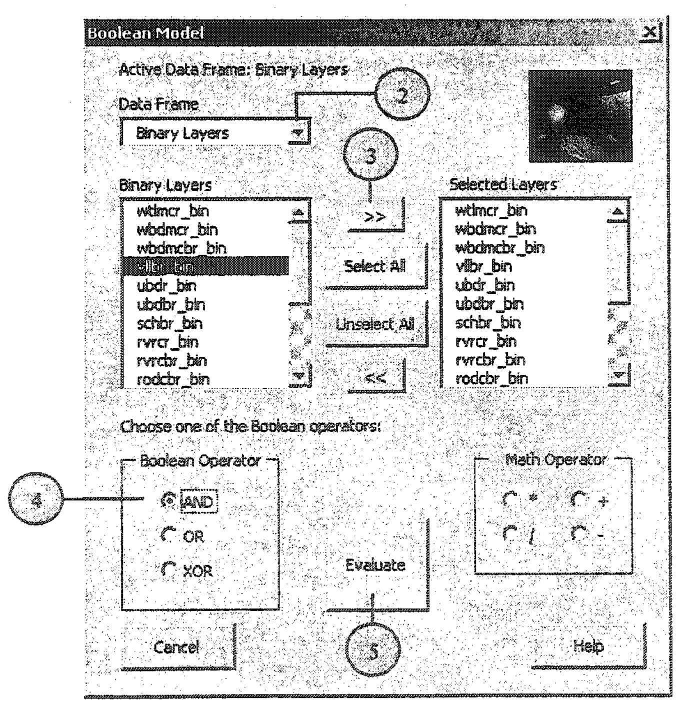


Figure 5.53 "Boolean Model" Dialog Box

3. Click layers with the suffix "Bin" and add them to the "Selected Layers" box
4. Choose "AND" Boolean operator
5. Click "Evaluate" to complete the integration task.

As shown in Figure 5.54, the output resulting from the "Boolean" model with "AND" operator, is also a "Binary" raster map with only two classes, 0 and 1, showing the acceptable and unacceptable areas for a new landfill site respectively.

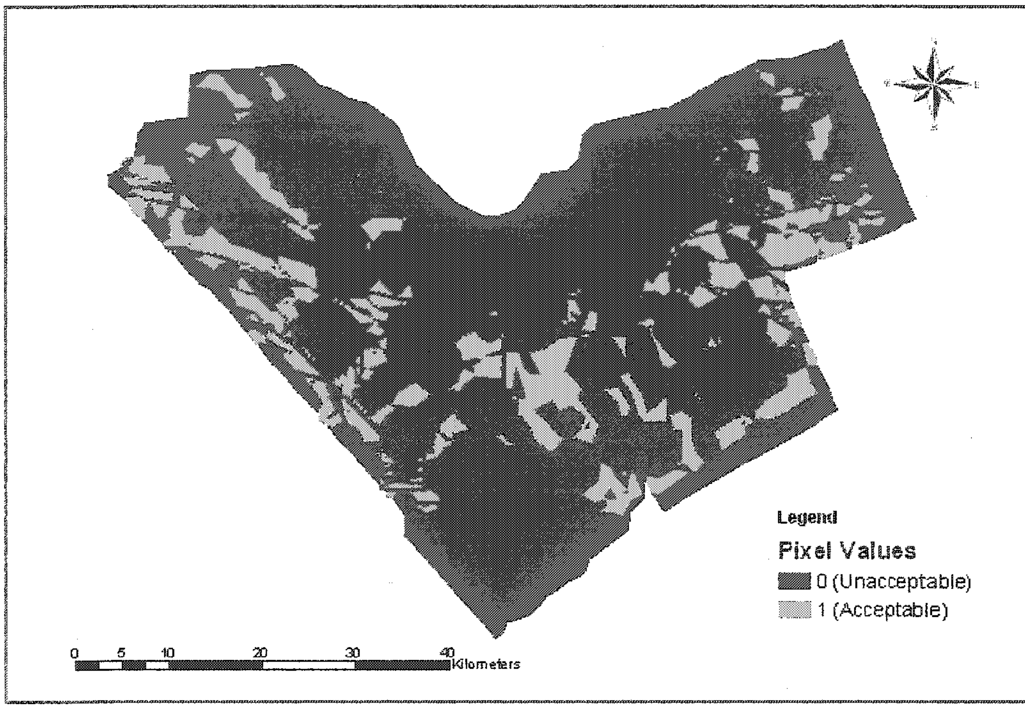


Figure 5.54 Final Binary Map

Relatively high percentage of the acceptable areas implies that insufficient constraints were applied in this example. Increase in constraints can result in significant decreases in the percentage of land available for landfilling.

The output map resulting from this model enables the planners to eliminate the strictly unacceptable areas and direct further investigations to the only remaining areas.

5.2.5.2 <u>Integrating Scored maps using Index Overlay model</u>

The following steps go through the process of combining scored maps created in the previous sections.

1. Click "Index Overlay Model" button in the "Map Integration" dropdown menu to open the second new interface as shown in Figure 5.55

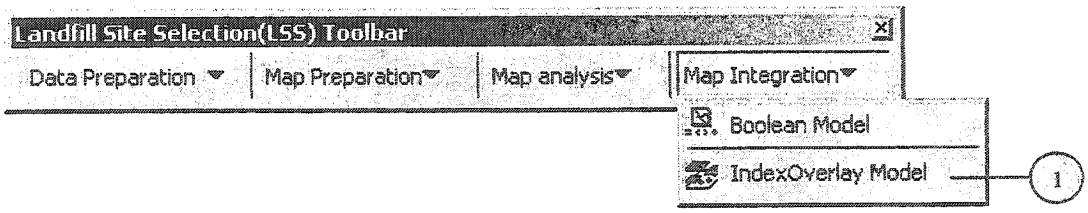


Figure 5.55 "IndexOverlay Model" Button in the "Map Integration" Menu

2. Click "Data Frame" dropdown list, and select the data frame containing "Scored" layers as shown in Figure 5.56

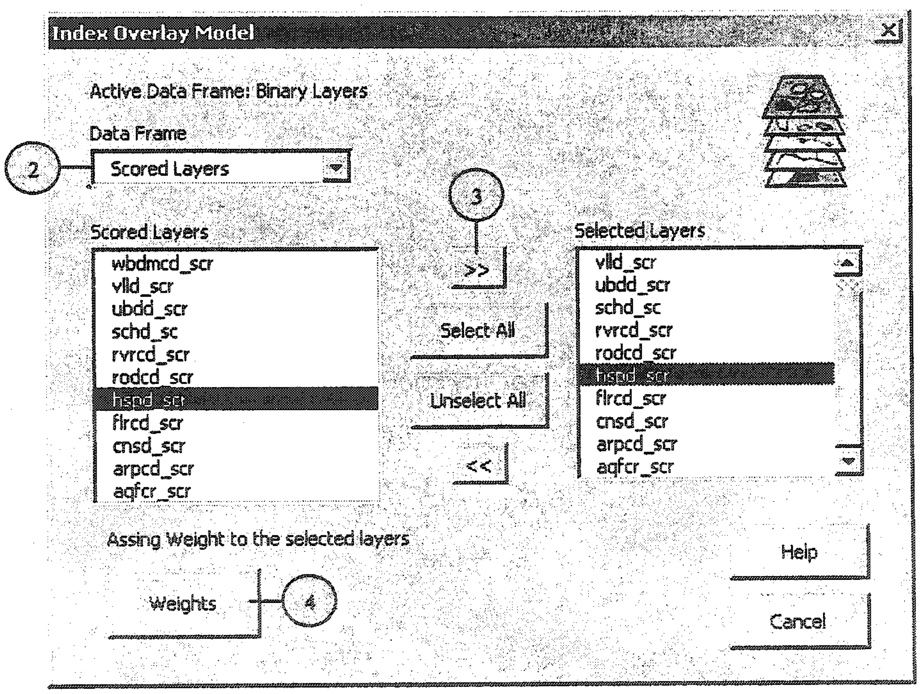


Figure 5.56 "Index Overlay Model" Dialog Box

3. Click layers with the suffix "Scr" and add them to the "Selected Layers" box
4. Click "Weights" button and assign weights tabulated in Table 5.3 to each scored layers. For example, Figure 5.57 shows a weight with the value of 8 that is assigned to the "ArpCD_Scr" "Scored" map.

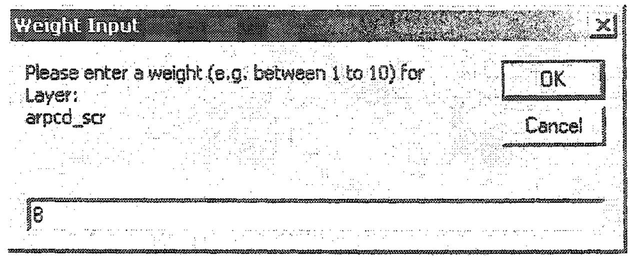


Figure 5.57 Weight Input Dialog Box

Table 5.3 Weight of the Layers

INDEX OVERLAY			
	Layers' Name	*Scored (Scr)*	*Weights*
1.	Airports	ArpCD_Scr	8
2.	Aquifer	AqfCR_Scr	10
3.	City boundary	--	
4.	Conservation area	CnsD_Scr	2
5.	Faults	FltCD_Scr	9
6.	Greenbelt	--	
7.	Hospitals	HspD_Scr	6
8.	Land Slides	--	
9.	Rivers	RvrCD_Scr	9
10.	Roads	RodCD_Scr	4
11.	Schools	SchD_Scr	6
12.	Urban development	UbdD_Scr	3
13.	Villages	VllD_Scr	7
14.	Water bodies	WbdMCD_Scr	9
15.	Wetlands	--	

"The usefulness of an index overlay model depends on the proper selection and interpretation of numeric scores and weights" (Robel *et al.*, 1993). Therefore, in reality, an appropriate weight should be set to ensure a good solution.

Determining the weights, in fact is quite controversial and subjective. Although there is no particular rule or process model involved for determining the weights, there are however, a few weighting and re-weighting models and decision-making methods proposed in the literature. For example, Siddiqui *et al.* (1996) introduced spatial – analytic hierarchy process (AHP) method, which involves pair-wise comparison. The paired comparison is a relative measurement of the dominance of one factor over another. Quite different scenarios can be produced by modifying the class scores and map weights.

The new developed Index Overlay interface allows the decision makers to repeat and refine the analysis with different weighting scheme and comparing the results until identifying a satisfactory solution. Kao and Lin (1996) explored the effect of different weights on the final siting solution. Discussion about sensitivity of the weights and systematically evaluated by some decision making methods is beyond the scope of the present study.

In general, the class scores and map weights can be adjusted to reflect the judgment of experts who are knowledgeable about the objective of the study in the domain of the application under consideration. For the present study, however, weights were determined heuristically and by reviewing the similar case studies and reports.

5. Click "Yes" in the next screen as shown in Figure 5.58 to complete the integration scored maps.

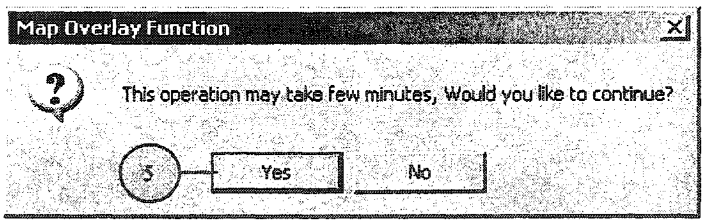


Figure 5.58 "Continue Process" Message Box

The output resulting from index overlay integration is a "Scored" raster map with different pixel value ranging from 0 to 10 representing low and high favorable areas respectively for a landfill site as shown in Figure 5.59.

The final map resulted from index overlay model, shows a continuous relative range of values indicating suitability of each location on the map; taking into account the criteria that have been put into the model. In this final map, areas with the higher pixel values represent higher suitability. The use of the index overlay model recovers significant areas discarded by the Boolean model and presents more

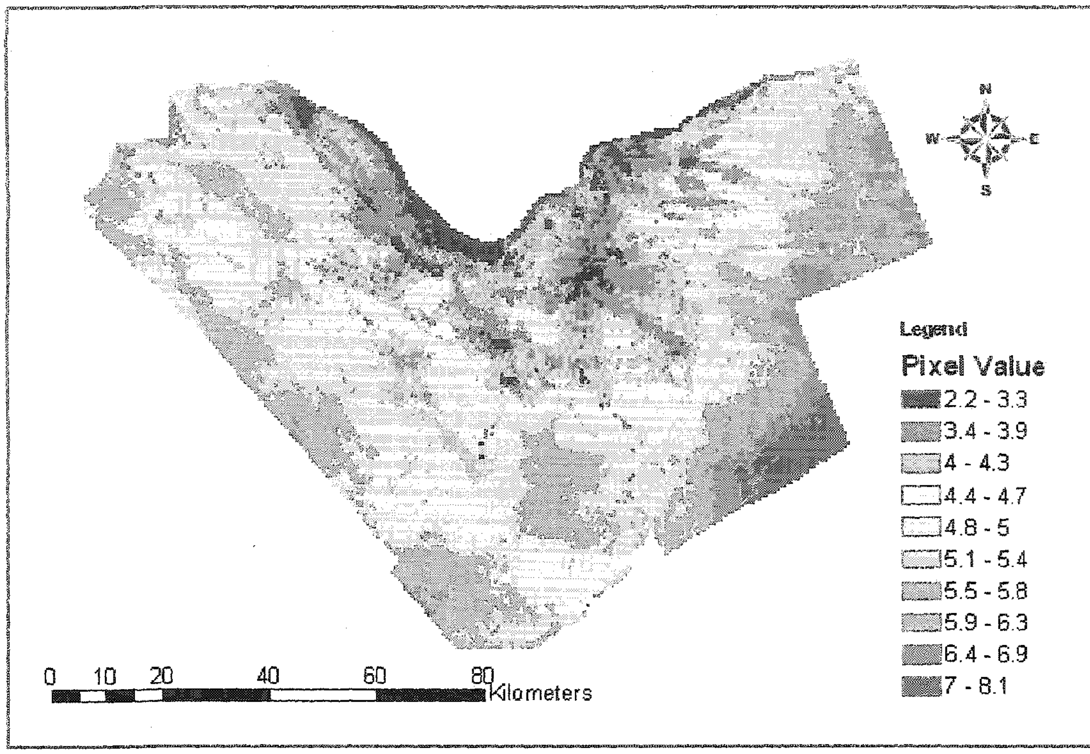


Figure 5.59 Output Scored Map

To make an effective use of the output scored map and narrow areas of interest for potential landfill sites to a more limited number of sites, areas delineated by the binary maps that reflect the constraints, are excluded from the Index overlay output map to remove the absolutely unacceptable areas. The final map resulting from this process will enable planners to obtain a suitability value for only the acceptable area on the map. One way for doing this is to apply the "*" (Times) operator and multiply two outputs resulting from Boolean and Index Overlay integration. The procedure follows:

1. Click "Boolean Model" button in the "Map Integration" dropdown menu as shown in Figure 5.46
2. Click "Data Frame" dropdown list, and select the data frame containing the output "Scored" and "Binary" maps as shown in Figure 5.60
3. Click "Output_Bin" and "Output_Scr" layers and add them to the "Selected Layers" box
4. Choose "Times" (*) operator

5. Click "Evaluate" to complete the task.

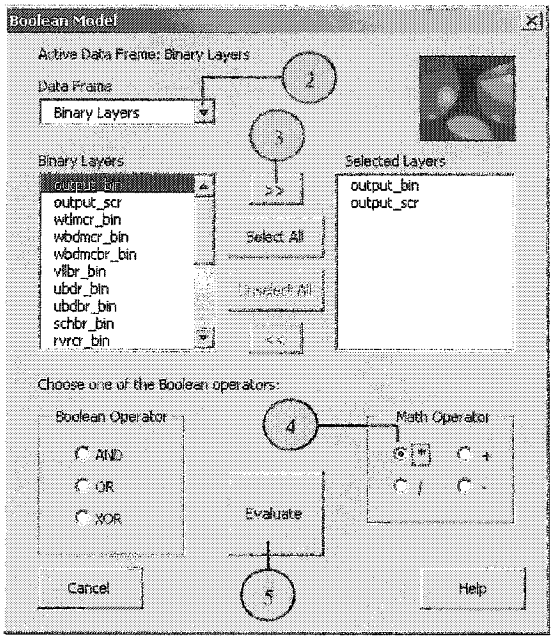


Figure 5.60 "Boolean Model" Dialog Box

As the result of this operation, areas with pixel value equal to zero will be eliminated from the output index overlay as shown in Figure 5.61.

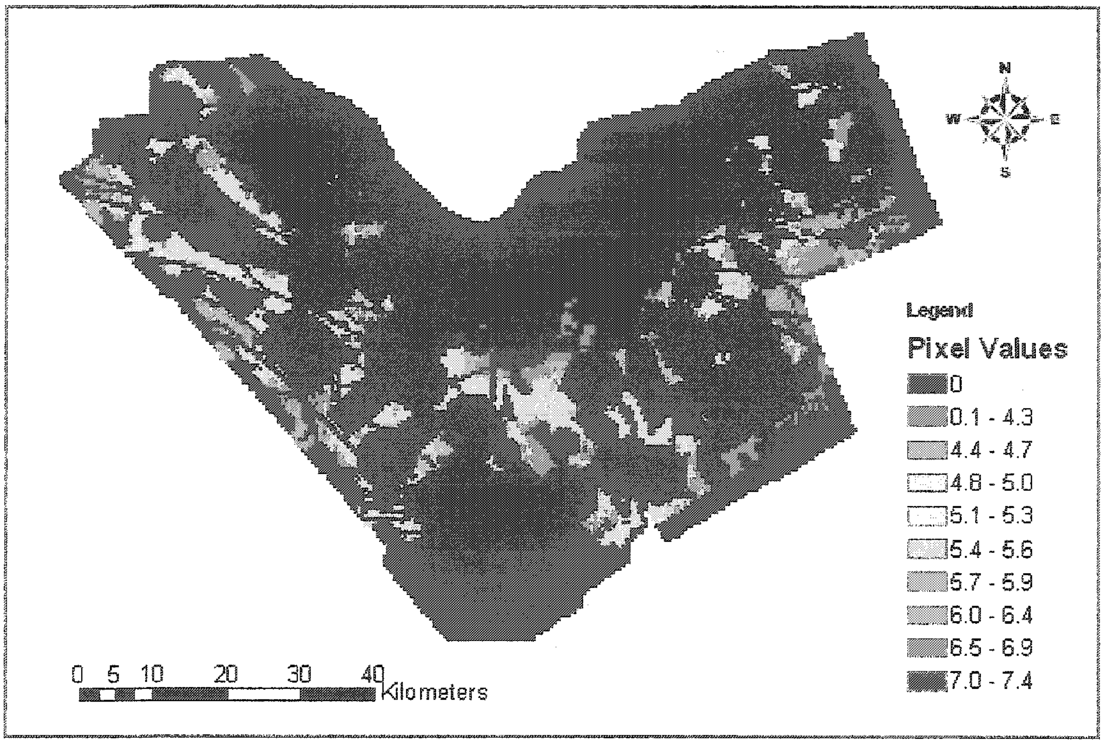


Figure 5.61 Final Suitability Map

The final suitability map would be therefore useful to demonstrate the remaining areas ranked based upon the degree of suitability for locating a new landfill. Because this map shows areas ranked according to the suitability, the decision as to where a landfill should be sited can now be made with a greater degree of flexibility.

The candidate sites can now be evaluated according to other constraints such as required space, cover material and population densities.

In order to determine the required landfill air space, information regarding to the current population, solid waste generation rates as well as waste quantities that the new landfill will receive during its operating life are vital.

For well-operated municipal landfills, a typical unit weight of about 5.4 KN/m^3 can be yielded (Oweis and Khera, 1998). Waste Generation for the City of Ottawa is 250,000 ton per year (personnel communication with the city of Ottawa).

It is assumed that the new landfills will be in operation for next 30 years and there is 2 percent increase in waste generation per year. By using spreadsheet calculation, the total waste that the new landfill will receive at the end of its operating life will be equal to 10,600,000 ton; therefore, the volume required is calculated as follows.

Unit weight $\gamma = 5.4\ KN/m^3$

Density $\rho = 5400\ (N/m^3) / 9.8\ (m/s^2) = 551\ kg/m^3 = 0.55\ ton/m^3$

$V = 10600000\ (ton) / 0.55\ (ton/m^3) = 19272727\ m^3$

By considering the typical height of the municipal landfills of about 30 meter, the required area for a new landfill site can be calculated as follows.

Required area $A = 19272727(m^3) / 30\ (m) = 642424\ m^2$

In addition it is desirable that the landfill be surrounded by a buffer zone of approximately 200m width to accommodate weighbridge, office and store civic amenity comprising receptacles for recyclable waste composting yard construction and demolition waste storage and possibly leachate and gas treatment plant. Thus the total area required is approximately 1 (km^2). Considering the final suitability map, areas with the highest score values (i.e. 7.0 – 7.4) were digitized and five polygons were created as shown in Figure 5.62.

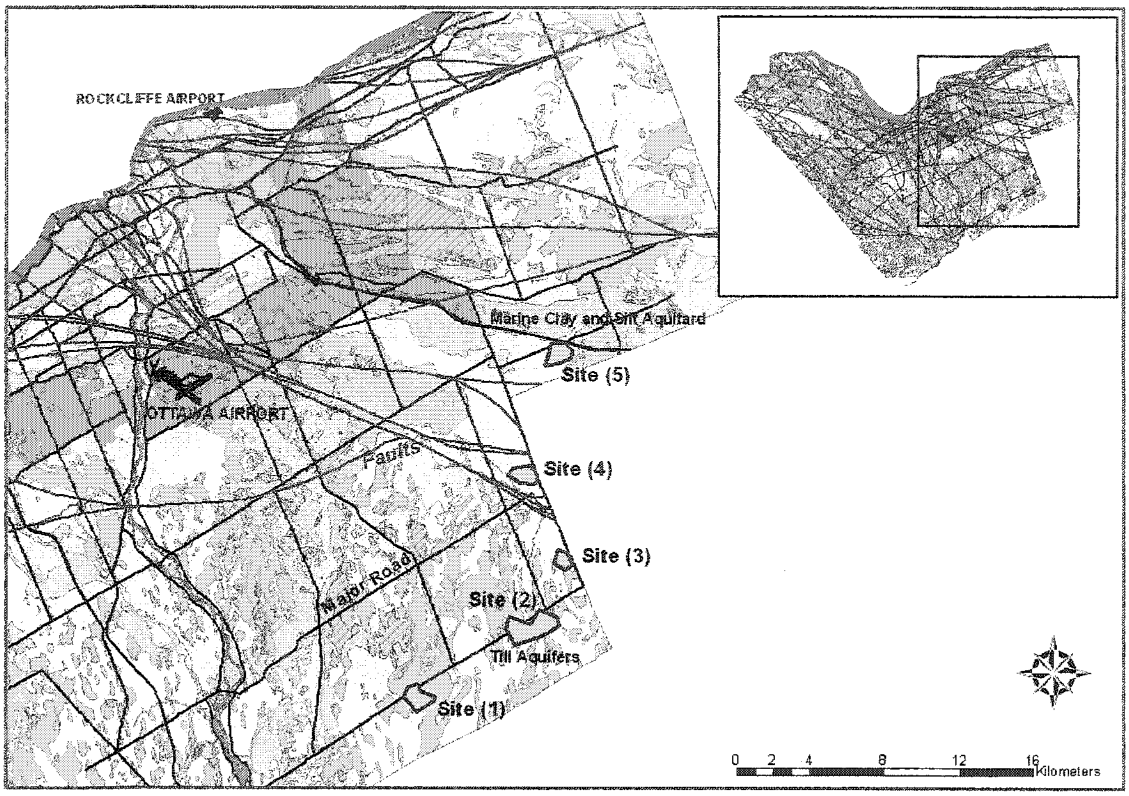


Figure 5.62 Potential Landfill Sites in Ottawa, Canada

By using two additional maps representing surficial soil type required for cover material and population density [Fig. 5.63], a list of potential sites is presented in Table 5.4.

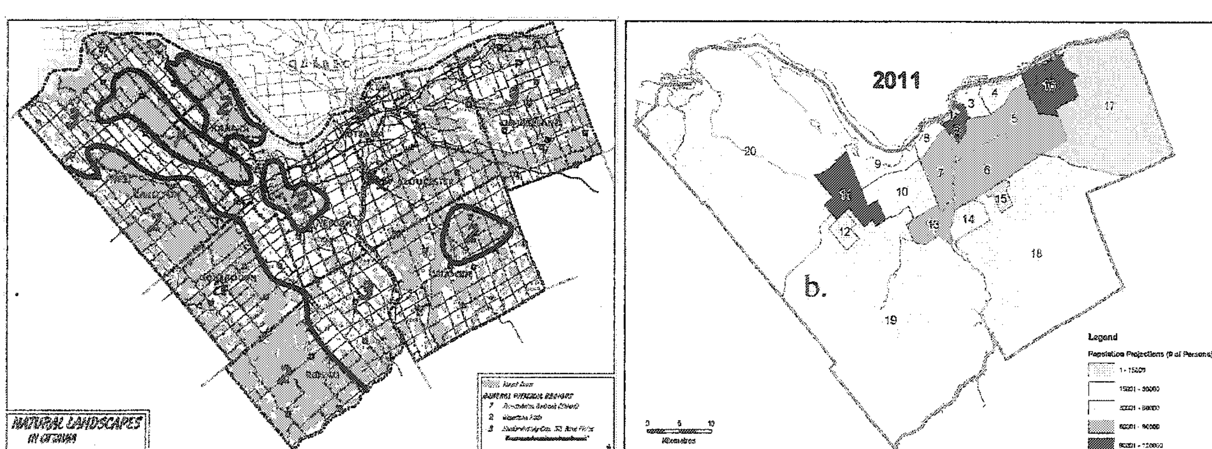


Figure 5.63 Surficial Soil Type (a) and Population Density (b) Maps (City of Ottawa, 2001)

Table 5.4 Potential Landfill Sites in Ottawa, Canada

Site	District Name	Area *(km^2)*	Soil	Population Density *(# of persons)*
1	OSGOOD	1.55	Clay, Till	15001-30000
2	OSGOOD	2.64	Clay, Till	15001-30000
3	OSGOOD	0.78	Clay, Till	15001-30000
4	OSGOOD	1.10	Limestone	15001-30000
5	CUMBERLAND	1.32	Clay, Till	1-15000

Site 3 does not meet the space requirement and should be eliminated. Site 1, 2 and 4 are located in a higher population density compared to site 5.

For the final site selection, further criteria including surrounding land development, political jurisdiction, exposure to the prevailing wind direction, public acceptance and land cost should also be considered for each of the remaining prime potential sites.

The feasibility report should then be developed concerning more detail investigation such as geological and hydrogeological studies over one or two prime potential landfill sites to select the best site. Finally, a report can be prepared for submittal to the appropriate approval agencies.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

7.1. CONCLUSIONS

In this study, a new landfill site selection (LSS) toolbar was developed within ArcMap v8.2, one of the most recent and popular GIS software using VBA language, to allow engineers and site planners with different GIS background to accomplish preliminary site selection procedure.

1. The LSS toolbar is comprised of four main menus: (1) Data Preparation, (2) Map Preparation, (3) Map Analyzing, and (4) Map Integration. The first three menus include a set of the existing built-in ArcMap tools required for: (i) storing, managing and organizing data, (ii) assembling and preparing layers, and (iii) creating binary and scored layers. Whereas the last menu that includes two new user-friendly interfaces developed in this study to facilitate map overlay task using *Boolean Logic* and *Index Overlay* models. Boolean and Index Overlay models enable the user to compare the results of map-overlay process and combine the outputs to screen areas of interest for the potential landfill sites to a more limited number.

   Boolean model allows the user to combine the binary maps that represent the constraints and eliminates the areas where locating new waste facilities are absolutely restricted. Index Overlay model permits the planners to rank the remaining area according to their degree of suitability, and therefore perform further investigations over a small number of prime potential landfill sites. This will result in saving of precious time and money.

   These new interfaces reduce the complexity of the existing tool in ArcMap significantly (i.e. Raster Calculator dialog box) and can be used for the academic purposes when integration methods and map-overlay models are studied.

2. The LSS toolbar makes landfill siting procedure systematic and automated, therefore; decision makers can refine their results by adding more criteria and maps and repeat the process with different weighting and scoring schemes easily. In addition, the LSS toolbar is easy to use and can be applied to any geographic area. Not only landfill site selection study, many other site selection studies for solid waste facilities such as land application of sludges, transfer stations, incinerators and recycling facilities can also be implemented with a similar procedure.

3. The operation of the new toolbar was successfully tested and verified by applying it to a case study in Ottawa, Canada using the available criteria, zoning-by laws and related layers and five potential sites were identified for a new landfill as a result. The selected sites will then be subject to further study and detail investigation in order to determine the best final site and obtain an approval prior to construction.

7.2. RECOMMENDATIONS

1. The level of effectiveness and reliability of the results depend upon selected rules, criteria and data availability for the region being studied. A systematic scoring criteria and weighing layers being combined can significantly impact obtaining a good solution. Hence, consulting with knowledgeable experts and engineers involved in the project and also encouraging public to participate in the evaluation task will enhance the outcome of the study in a real-world situation.

2. If a higher degree of security is required to protect the code from being accessed, one might consider a full-scale programming language such as Visual Basic (VB) or Visual C++ to develop the LSS toolbar in a form of a dynamic link library (DLL) or an executable file (EXE). These files can hold the entire code and be compiled into ArcMap.

3. The LSS toolbar can be expanded. More advanced integration models such as *Fuzzy Logic* will help the decision makers to have a more flexible tool to compare the results and make the decision.

4. Finally, as a more advanced tool, developing a "Network LSS Toolbar" is recommended. The main advantages of having this toolbar in network are: (1) accessing a comprehensive online database including regulations and criteria outlined in different countries for locating new waste facilities, (2) accessing the system without having the software platform on a local computer, (3) implementing landfill siting easily and efficiently, (4) allowing public to access the system and identifying the candidate sites by simply following the steps presented in an online help. All information is transferred, manipulated and overlaid via network and the output results can be reviewed closely and carefully using available online tools. Suggestions and feedbacks in regard to the final results can also be provided through this system that help to reduce the potential public misinterpretation and making a siting decision more acceptable.

APPENDIX A

Visual Basic Code for the "GetUserPassDlg" Macro

```
' This macro gets the username and password

Dim pGetUserPassDlg As IgetUserAndPasswordDialog
Dim BoolOk As Boolean
Set pGetUserPassDlg = New GetUserAndPasswordDialog
BoolOk = pGetUserPassDlg.DoModal("Log in ", "Login for Landfill Site Selection (LSS)
Application:", Application.hWnd)

If BoolOk Then
        If pGetUserPassDlg.UserName = "rdane042" And _
        pGetUserPassDlg.Password = "72053000" Then
        Call Greeting


        ElseIf pGetUserPassDlg. UserName = "" Or
        pGetUserPassDlg.UserName = "" Then
        MsgBox "Password and Username must be provided", vbOKCancel +
        vbExclamation, "Error"
        Call GetUserPassDlg
        Else
        MsgBox "Wrong username or password.", vbOKOnly + vbExclamation, "Error"
        Call GetUserPassDlg
        End If
Else
MsgBox "Cancelled"
End If
End Sub
```

APPENDIX B

Visual Basic Code for the "Greeting" Macro

```
Public Sub Greeting ()
' This macro shows a greeting page for landfill site selection application

frmGreeting.Show vbModeless
End Sub

Private Sub cmdContinue_Click()
        frmGreeting.Hide
        Call TemplateProject.CreateLSSToolbar
End Sub

Private Sub imgGreeting_Click()
        MsgBox " Landfill Site Selection Application" & vbCrLf & vbCrLf & _
        " University of Ottawa" & vbCrLf & _
        " Department of Civil Engineering", vbOKOnly + vbInformation, "Landfill Site
        Selection"
End Sub
```

APPENDIX C

Visual Basic Code for the "CreateLSSToolbar" Macro

```
Sub CreateLSSToolbar ()
' This macro creates the LSS toolbar and its components

'Optional
'Application Specifications
'Dim pWinPos As IWindowPosition
'Set pWinPos = Application
'pWinPos.Move 60, 60, 750, 600
'Application.Caption = "LandFill Site Selection Application"

'Get the commandbars collection
Dim pCmdBars As ICommandBars
Set pCmdBars = ThisDocument.CommandBars

'****************************************************************
'Create the new LSS toolbar
Dim pNewBar As ICommandBar
Set pNewBar = pCmdBars.Create("Landfill Site Selection(LSS)
Toolbar", esriCmdBarTypeToolbar)
pNewBar.Dock esriDockFloat

'Optional
'Place the LSS Toolbar at the top of the application below the standard toolbar
'pNewBar.Dock esriDockBottom, pCmdBars.Find (arcid.Standard_Toolbar)

'****************************************************************
'Create "Data Preparation" menu
Dim pDataPreparation As ICommandBar
Set pDataPreparation = pNewBar.CreateMenu ("Data Preparation")

' Add built-in tool to the "Data Preparation" menu
'1) Add "ArcCatalogue link"
pDataPreparation.Add arcid.Tools_Catalog

'****************************************************************
'Create "Map Preparation" menu
Dim pMapPreparation As ICommandBar
Set pMapPreparation = pNewBar.CreateMenu("Map Preparation")
Dim pMapPre As ICommandItem
Set pMapPre = pMapPreparation.Find("TemplateProject.Map Preparation")
pMapPre.Group = True
```

```
' Add built-in tools to the "Map Preparation" menu
'1) Add "Add Data"
pMapPreparation.Add arcid.File_AddData

'2) Add "ArcToolbox"
Dim pUID As New UID
pUID.Value = "{62730795-B876-11D1-9AB9-080009EC734B}"
pMapPreparation.Add pUID

'3) Add "GeoProcessing Wizard"
pMapPreparation.Add arcid.Query_GeoProcessingWizard

' Changing the "Add Data" icon
Dim pAddData As ICommandItem
Dim pGeoRef As ICommandItem
Set pAddData = pMapPreparation.Find(arcid.File_AddData)
pAddData.FaceID = frmAddDataIcon_1.Image1.Picture

' Changing the "ArcToolbox"
Dim pToolbox As ICommandItem
Set pToolbox = pMapPreparation.Find(pUID)
pToolbox.Group = True

' Changing the "GeoProcessing" icon and name
Set pGeoRef =  pMapPreparation.Find(arcid.Query_GeoProcessingWizard)
pGeoRef.FaceID = frmGeoRefIcon.Image1.Picture
pGeoRef.Style = esriCommandStyleIconAndText
pGeoRef.Caption = "Merge,Clip,..."

'**********************************************************
' Create "Map Analysis" menu
Dim pMapAnalysis As ICommandBar
Set pMapAnalysis = pNewBar.CreateMenu("Map Analysis")
Dim pMapAna As ICommandItem
Set pMapAna = pMapAnalysis.Find("TemplateProject.Map Analysis")
pMapAna.Group = True

' Add built-in tools to the "Map Analysis" menu
'1) Add "Add Data"
pMapAnalysis.Add arcid.File_AddData

'2) Add "Slope"
pMapAnalysis.Add arcid.Analysis_Slope

'3) Add "Buffer Zone"
pMapAnalysis.Add arcid.Query_BufferWizard
```

```
'4) Add "Conversion"
pMapAnalysis.Add arcid.Conversion_ToRaster

'5) Add "Distance"
pMapAnalysis.Add arcid.Analysis_EucDistance

'6) Add "Reclassify"
pMapAnalysis.Add arcid.Analysis_Reclass

'7) Add "Option"
pMapAnalysis.Add arcid.Analysis_Settings

' Changing the icons and names of "Map Analysis" components
Dim pAddData_2      As    ICommandItem
Dim pSlope          As    ICommandItem
Dim pBuffer         As    ICommandItem
Dim pConversion     As    ICommandItem
Dim pDistance       As    ICommandItem
Dim pReclass        As    ICommandItem
Dim pSetting        As    ICommandItem

Set pAddData_2 = pMapAnalysis.Find(arcid.File_AddData)
pAddData_2.FaceID = frmAddDataIcon_2.Image1.Picture

Set pSlope = pMapAnalysis.Find(arcid.Analysis_Slope)
pSlope.Style = esriCommandStyleIconAndText
pSlope.FaceID = frmSlopeIcon.Image1.Picture
pSlope.Group = True
pSlope.Caption = "Slope Map"

Set pBuffer = pMapAnalysis.Find(arcid.Query_BufferWizard)
pBuffer.Style = esriCommandStyleIconAndText
pBuffer.FaceID = frmBufferIcon.Image1.Picture
pBuffer.Group = True
pBuffer.Caption = "Buffer Zone"

Set pConversion =  pMapAnalysis.Find(arcid.Conversion_ToRaster)
pConversion.Style = esriCommandStyleIconAndText
pConversion.FaceID = frmConvertIcon.Image1.Picture
pConversion.Caption = "Converst to Raster"

Set pDistance = pMapAnalysis.Find(arcid.Analysis_EucDistance)
pDistance.Style = esriCommandStyleIconAndText
pDistance.FaceID = frmDistanceIcon.Image1.Picture
pDistance.Caption = "Find Distance"

Set pReclass = pMapAnalysis.Find(arcid.Analysis_Reclass)
```

```
pReclass.Style = esriCommandStyleIconAndText
pReclass.FaceID = frmReclassIcon.Image1.Picture
pReclass.Caption = "ReClassify"
pReclass.Group = True

Set pSetting = pMapAnalysis.Find(arcid.Analysis_Settings)
pSetting.Style = esriCommandStyleTextOnly
pSetting.Caption = "Options ..."
pSetting.Group = True

' ***********************************************************
' Create "Map Integration" menu
Dim pMapIntegration As ICommandBar
Set pMapIntegration = pNewBar.CreateMenu("Map Integration")

Dim pMapInt As ICommandItem
Set pMapInt = pMapIntegration.Find("TemplateProject.Map Integration")
pMapInt.Group = True

Dim pBoolean As ICommandItem
Dim pIndex As ICommandItem

' Add "Boolean Macro" User-form macro
Set pBoolean = pMapIntegration.CreateMacroItem("Boolean Model", 0,
"TemplateProject.LandfillSiteSelection.BooleanMacro")
' Change the icon of macro
pBoolean.FaceID = frmBooleanIcon.Image1.Picture

' Add "IndexMacro" User-form macro
Set pIndex = pMapIntegration.CreateMacroItem("IndexOverlay Model", 0,
"TemplateProject.LandfillSiteSelection.IndexMacro")
pIndex.Group = True
' Change the icon of macro
pIndex.FaceID = frmIndexIcon.Image1.Picture

End Sub
```

Note that all user-form names with the suffix “Icon” (e.g. frmGeoRefIcon) are responsible to hold the icon image of each command via their “Image” control and “Picture” property (i.e. Image1.Picture).

APPENDIX D

Visual Basic Code for the "Boolean User-form" Macro

```
' Declaration Module-level variables
Option Explicit
Private m_pMxDoc As IMxDocument
Private m_pMaps As IMaps
Private m_pMap As IMap
Private m_pEnumLayers As IEnumLayer
Private m_pLayer As ILayer

Private Sub cboMaps_Change ()
lboMapLayers. Clear

' Pull a map from the collection
Dim i As Integer
For i = 0 To m_pMaps. Count - 1
        Set m_pMap = m_pMaps. Item (i)
        If m_pMap. Name = cboMaps. Text Then
                Exit For
        End If
Next i

'Check if the map contains any layers
If m_pMap. LayerCount < 1 Then
        MsgBox "There is no Layer in this Data Frame ", vbInformation, "Binary Layers"
        Exit Sub
End If

' Add Layers of the selected map to the right List box
Set m_pEnumLayers = m_pMap. Layers
Set m_pLayer = m_pEnumLayers. Next
Do Until m_pLayer Is Nothing
        lboMapLayers. AddItem m_pLayer. Name
        Set m_pLayer = m_pEnumLayers. Next
Loop
End Sub

' Terminate the model
Private Sub cmdCancel_Click()
Unload Me
End Sub
```

```
' Enable "Select Layer" and "Select All" buttons when a layer is selected on the left
' list box
Private Sub lboMapLayers_Click ()
If lboMapLayers.Text <> " " Then
        cmdSelectLayer.Enabled = True
        cmdSelectAll.Enabled = True
End If
End Sub

' Enable "UnSelect Layer" and "UnSelect All" buttons when a layer is selected on
' the right List box
Private Sub lboMapSelectedLayers_Click()
If lboMapSelectedLayers.Text <> " " Then
        cmdUnSelectLayer.Enabled = True
        cmdUnselectAll.Enabled = True
End If
End Sub

' Add layers from left List box to right List box individually
Private Sub cmdSelectLayer_Click()
' Pull a map from the collection
Dim i As Integer
For i = 0 To m_pMaps.Count - 1
        Set m_pMap = m_pMaps.Item(i)
        If m_pMap.Name = cboMaps.Text Then
                Exit For
        End If
Next i

' Add Layers to the right List box
Dim j As Integer
For j = 0 To m_pMap.LayerCount - 1
        If lboMapLayers.Selected(j) = True Then
                lboMapSelectedLayers.AddItem m_pMap.Layer(j).Name
        End If
Next j
End Sub

' Remove layers from the right List box individually
Private Sub cmdUnSelectLayer_Click()
Dim i As Long
For i = 0 To lboMapSelectedLayers.ListCount - 1
If lboMapSelectedLayers.Selected(i) = True Then
        lboMapSelectedLayers.RemoveItem (i)
End If
Next i
```

```
' Unable the "UnSelect" & "UnSelect All" buttons upon voiding the Map Selected
' Layer list
If lboMapSelectedLayers.ListCount < 1 Then
        cmdUnSelectLayer.Enabled = False
        cmdUnselectAll.Enabled = False
End If
End Sub

' Select all layers from the left List box to the right List box
Private Sub cmdSelectAll_Click()
lboMapSelectedLayers.Clear
Dim j As Long
For j = 0 To m_pMap.LayerCount - 1
        lboMapSelectedLayers.AddItem lboMapLayers.List(j)
Next j
End Sub

' Remove all layers from the right List box
Private Sub cmdUnselectAll_Click()
lboMapSelectedLayers.Clear
cmdUnselectAll.Enabled = False
cmdUnSelectLayer.Enabled = False
End Sub

' Initialize User Form
Private Sub UserForm_Initialize()
' Reset all controls
cboMaps.Clear
lboMapLayers.Clear
lboMapSelectedLayers.Clear
optAND.Value = False
optOR.Value = False
optXOR.Value = False
optPlus.Value = False
optMinus.Value = False
optTimes.Value = False
optDivide.Value = False

Set m_pMxDoc = ThisDocument
Set m_pMaps = m_pMxDoc.Maps

' Add map names to the data frame combo list
Dim i As Integer
For i = 0 To m_pMaps.Count - 1
        cboMaps.AddItem m_pMaps.Item(i).Name
Next i
```

```
lblFocusMap.Caption = "Active Data Frame: " & m_pMxDoc.FocusMap.Name
End Sub

' Event procedure for "Evaluate" command button

Private Sub cmdEvaluate_Click()

' Check if any maps has been selected
If cboMaps.Text = "" Then
        MsgBox " Please select a data frame ", vbInformation, " Data Frame "
        Exit Sub
End If

' Check if any layers has been selected
If lboMapSelectedLayers.ListCount < 1 Then
        MsgBox " Please select layers ", vbInformation, " Selected Layer "
        Exit Sub
End If

' Check if at least two layers have been selected
If lboMapSelectedLayers.ListCount < 2 Then
        MsgBox " Please select two layers or more ", vbInformation, " Selected Layer "
        Exit Sub
End If

' Check if a Boolean operator has been selected
If (optAND.Value = False) And (optOR.Value = False) And (optXOR.Value = False) _
        And (optMinus.Value = False) And (optPlus.Value = False)
        And (optTimes.Value = False) And (optDivide.Value = False) Then
        MsgBox " Please select one of the Boolean Operators ", vbInformation, " Boolean
        Operator "
        Exit Sub
End If

' Pull a map from the collection
Dim i As Integer
For i = 0 To m_pMaps.Count - 1
Set m_pMap = m_pMaps.Item(i)
If m_pMap.Name = cboMaps.Text Then
Exit For
End If
Next i

' Check if the layer is RasterLayer
Dim j As Long
Dim m As Long
For j = 0 To m_pMap.LayerCount - 1
```

```
For m = 0 To lboMapSelectedLayers.ListCount - 1
        If lboMapSelectedLayers.List(m) = m_pMap.Layer(j).Name Then
                If Not TypeOf m_pMap.Layer(j) Is IRasterLayer Then
                        MsgBox "" & lboMapSelectedLayers.List(m) & _
                        " is not a Raster Layer"
                        Exit Sub
                End If
        End If
Next m
Next j

Dim pLayer As ILayer
Dim pLayer1 As ILayer

Dim pRLayer As IRasterLayer
Dim pRLayer1 As IRasterLayer

Dim pGeoDs As IGeoDataset
Dim pGeoDs1 As IGeoDataset

Dim pMathOp As IMathOp
Set pMathOp = New RasterMathOps

' Create a Spatial Operator
Dim pBitWiseOp As IBitWiseOp
Set pBitWiseOp = New RasterMathOps

' Store the first layer in the right List box
Dim s As Long
For s = 0 To m_pMap.LayerCount - 1
        If m_pMap.Layer(s).Name = lboMapSelectedLayers.List(0) Then
                Set pLayer = m_pMap.Layer(s)
                Set pRLayer = pLayer
                Set pGeoDs = pRLayer.Raster
                Exit For
        End If
Next s

' Loop through the rest of the layers in the right List box and apply selected Boolean
' operator over them

Dim k As Long
Dim q As Long

For k = 0 To m_pMap.LayerCount - 1
For q = 1 To lboMapSelectedLayers.ListCount - 1
If m_pMap.Layer (k).Name = lboMapSelectedLayers.List (q) Then
```

```
Set pLayer1  = m_pMap.Layer(k)
Set pRLayer1 = pLayer1
Set pGeoDs1  = pRLayer1.Raster

' Perform one of the "AND", "OR", "XOR", "*", "/", "+" or "-" operators
                If optAND.Value = True Then
                        Set pGeoDs = pBitWiseOp.And(pGeoDs, pGeoDs1)
                ElseIf optOR.Value = True Then
                        Set pGeoDs = pBitWiseOp.Or(pGeoDs, pGeoDs1)
                ElseIf optXOR.Value = True Then
                        Set pGeoDs = pBitWiseOp.XOr(pGeoDs, pGeoDs1)
                ElseIf optPlus.Value = True Then
                        Set pGeoDs = pMathOp.Plus(pGeoDs, pGeoDs1)
                ElseIf optMinus.Value = True Then
                        Set pGeoDs = pMathOp.Minus(pGeoDs, pGeoDs1)
                ElseIf optDivide.Value = True Then
                        Set pGeoDs = pMathOp.Divide(pGeoDs, pGeoDs1)
                Else
                        Set pGeoDs = pMathOp.Times(pGeoDs, pGeoDs1)
                End If
        End If
Next q
Next k

' Display the output map
Set pRLayer = New RasterLayer
pRLayer.CreateFromRaster pGeoDs
m_pMap.AddLayer pRLayer

frmBoolean.Hide
UserForm_Initialize
End Sub

' *****************************************************
' An alternative for getting the layers - Using IArray Interface
'Dim pLayerArray As IArray
'Dim pLayer As ILayer
' Function for the getting the layers

'Set pLayerArray = GetDocLayers()
'If pLayerArray Is Nothing Then Exit Sub
'If pLayerArray.Count < 1 Then Exit Sub

'Dim m As Long
'For m = 0 To pLayerArray.Count - 1
        'Set m_pLayer = pLayerArray.Element (m)
```

```
        'MsgBox " selected layer is " & m_pMap.Layer(m).Name
'Next

'GetDocLayers function for the proposed alternative
'Private Function GetDocLayers() As IArray

'Dim pMxDoc As IMxDocument
'Dim m_pMaps As IMaps
'Dim m_pMap As IMap
'Dim pLayers As IArray
'Dim pLayer As ILayer

'Set m_pMxDoc = ThisDocument
'Set m_pMaps  = m_pMxDoc.Maps
'Set pLayers  = New esriCore.Array

'Set GetDocLayers = New esriCore.Array

' Pull a map from the collection
'Dim i As Integer
'For i = 0 To m_pMaps.Count - 1
'        Set m_pMap = m_pMaps.Item(i)
'                If m_pMap.Name = cboMaps.Text Then
'                        Exit For
'                End If
'Next i
'Dim j As Integer
'For j = 0 To m_pMap.LayerCount - 1
'      pLayers.Add m_pMap.Layer(j)
'Next j
'Set GetDocLayers = pLayers
'End Function
```

Note declaration lines at the beginning of the code above; declare variables as Module-level, therefore they can be used throughout the code module. Module-level variables are not destroyed after the execution of a procedure and their values can be retained and referenced by any procedure inside the module.

APPENDIX E

Visual Basic Code for the "Index User-form" Macro

```
' Declaration Module-level variables
Option Explicit
Private m_pMxDoc As IMxDocument
Private m_pMaps As IMaps
Private m_pMap As IMap
Private m_pEnumLayers As IEnumLayer
Private m_pLayer As ILayer

Private Sub cboMaps_Change ()
lboMapLayers. Clear

' Pull a map from the collection
Dim i As Integer
For i = 0 To m_pMaps. Count - 1
        Set m_pMap = m_pMaps. Item(i)
        If m_pMap.Name = cboMaps.Text Then
                Exit For
        End If
Next i

' Check if the selected map has any layers
If m_pMap.LayerCount < 1 Then
        MsgBox "This Data Frame does not have any layers ", vbInformation, "Selected
        Layers "
        Exit Sub
End If

' Add Layers of the selected map to the right List box
Set m_pEnumLayers = m_pMap.Layers
Set m_pLayer = m_pEnumLayers.Next
Do Until m_pLayer Is Nothing
        lboMapLayers.AddItem m_pLayer.Name
        Set m_pLayer = m_pEnumLayers.Next
Loop
End Sub

Private Sub cmdSelectLayer_Click()
' Pull a map from the collection

Dim i As Integer
For i = 0 To m_pMaps.Count - 1
Set m_pMap = m_pMaps.Item(i)
```

```
        If m_pMap.Name = cboMaps.Text Then
                Exit For
        End If
Next i

' Add layers from the left List box to the right List box individually
Dim j As Integer
For j = 0 To m_pMap.LayerCount - 1
        If lboMapLayers.Selected(j) = True Then
                lboMapSelectedLayers.AddItem m_pMap.Layer(j).Name
        End If
Next j
End Sub

' Add all layers from the left List box to the right List box
Private Sub cmdSelectAll_Click()
lboMapSelectedLayers.Clear
Dim j As Long
For j = 0 To m_pMap.LayerCount - 1
        lboMapSelectedLayers.AddItem lboMapLayers.List(j)
Next j
End Sub

' Remove all layers from right List box
Private Sub cmdUnselectAll_Click()
lboMapSelectedLayers.Clear
cmdUnselectAll.Enabled = False
cmdUnSelectLayer.Enabled = False
End Sub

' Remove layers from the right List box individually
Private Sub cmdUnSelectLayer_Click ()
Dim i As Long
For i = 0 To lboMapSelectedLayers.ListCount - 1
        If lboMapSelectedLayers.Selected (i) = True Then
                lboMapSelectedLayers.RemoveItem (i)
        End If
Next i
If lboMapSelectedLayers.ListCount < 1 Then
        cmdUnSelectLayer.Enabled = False
        cmdUnselectAll.Enabled = False
End If
End Sub

' Active "Select" and "Select All" buttons upon clicking on a layer
Private Sub lboMapLayers_Click()
If lboMapLayers.Text <> " " Then
```

```
        cmdSelectLayer.Enabled = True
        cmdSelectAll.Enabled = True
End If
End Sub

' Active "UnSelect" and "UnSelect All" buttons upon clicking on a selected layer
Private Sub lboMapSelectedLayers_Click()
If lboMapSelectedLayers.Text <> " " Then
        cmdUnSelectLayer.Enabled = True
        cmdUnselectAll.Enabled = True
End If
End Sub

' Terminate the application
Private Sub cmdCancel_Click()
Unload Me
End Sub

' Initializing the form
Private Sub UserForm_Initialize()
' Reset all controls
cboMaps.Clear
lboMapLayers.Clear
lboMapSelectedLayers.Clear
Set m_pMxDoc = ThisDocument
Set m_pMaps = m_pMxDoc.Maps
' Fill the data frame combo list
Dim i As Integer
For i = 0 To m_pMaps.Count - 1
        cboMaps.AddItem m_pMaps.Item(i).Name
Next i
lblFocusMap.Caption = "Active Data Frame: " _
& m_pMxDoc.FocusMap.Name
End Sub

' ***********************************************************
' Event procedure for " Weights " command button

Private Sub cmdWeights_Click ()
' Check if any data frames has been selected
If cboMaps.Text = "" Then
        MsgBox " Please select a data frame ", vbInformation, " Data Frame "
        Exit Sub
End If

' Check if any layers has been selected
If lboMapSelectedLayers.ListCount < 1 Then
```

```
        MsgBox " Please select layers ", vbInformation, " Selected Layer "
        Exit Sub
End If

' Check if minimum two layers have been selected
If lboMapSelectedLayers.ListCount < 2 Then
        MsgBox " Please select two layers or more ", vbInformation, " Selected Layer "
        Exit Sub
End If

' Pull a map from combo box
Dim i As Integer
For i = 0 To m_pMaps.Count - 1
`       Set m_pMap = m_pMaps.Item (i)
        If m_pMap.Name = cboMaps.Text Then
                Exit For
        End If
Next i

' Check if the layer is RasterLayer
Dim j As Long
Dim m As Long
For j = 0 To m_pMap.LayerCount - 1
For m = 0 To lboMapSelectedLayers.ListCount - 1
        If lboMapSelectedLayers.List (m) = m_pMap.Layer (j).Name Then
                If Not TypeOf m_pMap.Layer (j) Is IRasterLayer Then
                        MsgBox "" & lboMapSelectedLayers.List (m) &_
                        " is not a Raster Layer"
                        Exit Sub
                End If
        End If
Next m
Next j

' Declare required variables
Dim pLayer0 As ILayer
Dim pLayer As ILayer

Dim pRLayer0 As IRasterLayer
Dim pRLayer As IRasterLayer

Dim pGeoDs0 As IGeoDataset
Dim pGeo0Weight As IGeoDataset

Dim pGeoDs1  As IGeoDataset
Dim pGeo1Weight As IGeoDataset
```

```
Dim pMathOp As IMathSupportOp
Set pMathOp = New RasterMathSupportOp

' Store the first scored layer of the right List box
Dim s As Long
Dim w0 As Variant

For s = 0 To m_pMap.LayerCount - 1
If m_pMap.Layer(s).Name = lboMapSelectedLayers.List (0) Then
        Set pLayer0 = m_pMap.Layer(s)
        Set pRLayer0 = pLayer0
        Set pGeoDs0 = pRLayer0.Raster

' Get the weight for the fist scored layer of the right List box
w0 = InputBox("Please enter a weight (e.g. between 1 to 10) for _ Layer:" & vbCrLf &
m_pMap.Layer(s).Name, "Weight Input")
' Check if the user click on "Cancel" button
If w0 = "" Then
        Exit Sub
End If

' Check if the weight is Numeric
Do While Not IsNumeric (w0)
MsgBox "Please enter only a number !", vbExclamation + vbOKOnly
w0 = InputBox("Please enter a weight (e.g. between 1 to 10) for _
Layer:" & vbCrLf & m_pMap.Layer(s).Name, "Weight Input")

' Check if the user click on "Cancel" button
If w0 = "" Then
        Exit Sub
End If

' Perform the operation
Set pGeo0Weight = CreateRaster (CDbl (w0))
Set pGeoDs0 = pMathOp.Times (CreateRaster (CDbl (w0)), pGeoDs0)
Exit For
End If
Next s

' Loop through the rest of the scored layers in the right List box
Dim k As Long
Dim q As Long
Dim w1 As Variant

For k = 0 To m_pMap.LayerCount - 1
For q = 1 To lboMapSelectedLayers.ListCount - 1
If m_pMap.Layer (k).Name = lboMapSelectedLayers.List (q) Then
```

```
Set pLayer = m_pMap.Layer (k)
Set pRLayer = pLayer
Set pGeoDs1 = pRLayer.Raster

w1 = InputBox ("Please enter a weight (e.g. between 1 to 10) for _
Layer:" & vbCrLf & m_pMap.Layer (k).Name, "Weight Input")

' Check if the user click on "Cancel" button
If w1 = "" Then
        Exit Sub
End If

' Check if the weight is Numeric
Do While Not IsNumeric (w1)
        MsgBox "Please enter only numbers!", vbExclamation + vbOKOnly
        w1 = InputBox ("Please enter a weight (e.g. between 1 to 10) for _
        Layer:" & vbCrLf & m_pMap.Layer (k).Name, "Weight Input")

        ' Check if the user click on "Cancel" button
        If w1 = "" Then
                Exit Sub
        End If
Loop

' Perform the operation
Set pGeo0Weight = pMathOp.Plus (pGeo0Weight, CreateRaster (CDbl (w1)))
Set pGeo0Weight = pMathOp.Float (pGeo0Weight)

        Set pGeoDs0 = pMathOp.Plus (pGeoDs0,
        pMathOp.Times(CreateRaster(CDbl(w1)), pGeoDs1))
SetpGeoDs0 = pMathOp.Float (pGeoDs0)

End If

Next q
Next k

' Closing the Index Overlay dialog box
frmIndex.Hide


' Check if the user wants to continue
        If MsgBox(" This operation may take few minutes, Would you like _ to continue?
                ", vbYesNo + vbQuestion, " Map Overlay Function ") = vbNo Then
                Exit Sub
        End If
```

```
' Perform the final operation
Set pGeoDs0 = pMathOp.Divide(pGeoDs0, pGeo0Weight)
Set pGeoDs0 = pMathOp.Float(pGeoDs0)

' Display the output map
Set pRLayer = New RasterLayer
pRLayer.CreateFromRaster pGeoDs0
m_pMxDoc.FocusMap.AddLayer pRLayer

UserForm_Initialize
End Sub
'*******************************************************
' This function creates a raster with pixel value equal to the weight provided by the
'  user

Function CreateRaster(m_Weight As Double) As IGeoDataset
Dim pRMakerOp As IRasterMakerOp
Set pRMakerOp = New RasterMakerOp

Dim pEnv As IRasterAnalysisEnvironment
Set pEnv = pRMakerOp

Dim pLayer As ILayer
Dim pRLayer As IRasterLayer
Dim pGeoDs As IGeoDataset

' Set cell size
pEnv.SetCellSize esriRasterEnvValue, 30

' Set output extent for the op
Dim pExt As IEnvelope
Set pExt = New Envelope

pEnv.SetExtent esriRasterEnvValue, m_pMxDoc.ActiveView.Extent

' Perform Spatial Operator
Dim pOutRaster As IGeoDataset
Set pOutRaster = pRMakerOp.MakeConstant(m_Weight, True)
Set CreateRaster = pOutRaster
End Function
```

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