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โดยใช้ระบบผู้เชี่ยวชาญสารสนเทศภูมิศาสตร์

นายฤทธิรงค์ จังโกฏิ

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SPATIAL PLANNING FOR SECURED LANDFILL USING AN EXPERT GEOGRAPHIC INFORMATION SYSTEM

Mr. Rittirong Junggoth

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy Program in Environmental Management
(Interdisciplinary Program)
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ฤทธิรงค์ จังโกฏิ: การวางแผนเชิงพื้นที่สำหรับการฝังกลบอย่างปลอดภัยโดยใช้ระบบผู้เชี่ยวชาญสารสนเทศภูมิศาสตร์ (SPATIAL PLANNING FOR SECURED LANDFILL USING AN EXPERT GEOGRAPHIC INFORMATION SYSTEM) อ.ที่ปรึกษา: รศ.ดร.วันเพ็ญ วิโรจนกูฏ, อ.ที่ปรึกษาร่วม: ผศ.ดร.สมศักดิ์ พิทักษานุรัตน์, อ.ที่ปรึกษาร่วม: ผศ.ดร.เควิน แอล เคน, 175 หน้า.

การศึกษานี้มีวัตถุประสงค์เพื่อพัฒนาระบบผู้เชี่ยวชาญสารสนเทศภูมิศาสตร์ ที่มีชื่อว่า EGIS ในการวิเคราะห์หาพื้นที่ฝังกลบของเสียอันตรายโดยพัฒนาการทำงานร่วมกันระหว่างระบบผู้เชี่ยวชาญ (ES) ระบบสารสนเทศภูมิศาสตร์ (GIS) กระบวนการลำดับชั้นเชิงวิเคราะห์ (AHP) และแบบจำลองน้ำใต้ดินวิชวลมอดโฟลว์ ซึ่งระบบสารสนเทศภูมิศาสตร์ทำหน้าที่ในการวิเคราะห์ข้อมูลเชิงพื้นที่ ระบบผู้เชี่ยวชาญทำหน้าที่ในการเก็บและประมวลผลความรู้ด้านการวิเคราะห์หาพื้นที่ฝังกลบของเสียอันตราย ใช้กระบวนการลำดับชั้นเชิงวิเคราะห์ในการจัดลำดับความสำคัญของพื้นที่ที่ได้รับการคัดเลือกเพื่อระบุพื้นที่ที่มีความเหมาะสม และใช้แบบจำลองน้ำใต้ดินวิชวลมอดโฟลว์คาดการณ์ผลกระทบต่อน้ำใต้ดินที่อาจเกิดขึ้นจากการฝังกลบของเสียอันตรายในพื้นที่ดังกล่าว ระบบ EGIS ที่พัฒนาขึ้นนี้ได้นำมาใช้เพื่อหาพื้นที่ฝังกลบของเสียอันตรายในจังหวัดขอนแก่น ประเทศไทย ทั้งนี้ก่อนการวิเคราะห์ด้วยระบบสารสนเทศภูมิศาสตร์ ได้ทำการสร้างเงื่อนไขสำหรับพื้นที่ฝังกลบของเสียอันตรายแบบปลอดภัยจำนวน 23 เงื่อนไข โดยประมวลจากเงื่อนไขของ องค์การพิทักษ์สิ่งแวดล้อมแห่งสหรัฐอเมริกา กระทรวงอุตสาหกรรม และกรมควบคุมมลพิษ จากเงื่อนไขดังกล่าวเมื่อผู้ใช้นำเข้าข้อมูลของจังหวัดขอนแก่น ระบบผู้เชี่ยวชาญได้คัดเลือกเงื่อนไขสำหรับจังหวัดขอนแก่น จำนวน 16 เงื่อนไขเพื่อนำเข้าในระบบสารสนเทศภูมิศาสตร์ ผลของการวิเคราะห์ด้วยระบบสารสนเทศภูมิศาสตร์ พบว่าพื้นที่ที่ได้รับการคัดเลือกมีจำนวน 11 แห่ง จากนั้นจัดลำดับความสำคัญของพื้นที่ดังกล่าวด้วยกระบวนการลำดับชั้นเชิงวิเคราะห์ซึ่งมีปัจจัยที่ใช้ในการพิจารณาจำนวน 15 ปัจจัย ประกอบด้วย ปัจจัยที่ได้จากการพิจารณาเงื่อนไขที่ได้รับการคัดเลือกข้างต้น และปัจจัยเพิ่มเติมทางด้านสังคมอีก 2 ปัจจัย ผลจากการการศึกษาพบว่าพื้นที่ 5 อันดับแรกได้แก่ พื้นที่หมายเลข 3 (ตำบลโพธิ์ไชย กิ่งอำเภอโคกโพธิ์ไชย พื้นที่หมายเลข 2 (ตำบลโนนสะอาด อำเภอแวงใหญ่) พื้นที่หมายเลข 1 (ตำบลท่าวัด อำเภอแวงน้อย) พื้นที่หมายเลข 11 (ตำบลหัวนาคำ อำเภอกระนวน) และ พื้นที่หมายเลข 4 (ตำบลภูเหล็ก อำเภอบ้านไผ่) โดยมีค่าคะแนน 0.322, 0.307, 0.226, 0.203 และ 0.188 ตามลำดับ เมื่อพิจารณาผลที่ได้ร่วมกับข้อมูลจากการศึกษาภาคสนาม พบว่าพื้นที่หมายเลข 4 มีความเหมาะสมสำหรับการเป็นพื้นที่ฝังกลบของเสียอันตราย นอกจากนี้โมเดลที่พัฒนาขึ้นในระบบสารสนเทศภูมิศาสตร์สามารถแสดงให้เห็นข้อมูลชั้นใต้ดินของพื้นที่ที่มีความเหมาะสม และสามารถเตรียมข้อมูลนำเข้าสำหรับโปรแกรมวิชวลมอดโฟลว์ ซึ่งผลจากการจำลองโปรแกรมตามเงื่อนไขที่กำหนด พบว่าหลังจากการรั่วซึมของพื้นที่ฝังกลบในระยะเวลา 7,300 วัน (20 ปี) สารตะกั่วจากการรั่วซึมเคลื่อนที่ไปไม่ถึงบ่อน้ำบาดาลในพื้นที่ใกล้เคียง

สาขาวิชา การจัดการสิ่งแวดล้อม | ลายมือชื่อนิสิต..........
ปีการศึกษา 2550 | ลายมือชื่ออาจารย์ที่ปรึกษา..........
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม..........
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KEY WORD: GOEGRAPHIC INFORMATION SYSTEM/ EXPERT SYSTEM/ ANALYTIC HIERACHY PROCESSS/ SECURED LANDFILL

RITTIRONG JUNGGOTH: SPATIAL PLANNING FOR SECURED LANDFILL USING AN EXPERT GEOGRAPHIC INFORMATION SYSTEM. THESIS ADVISOR: ASSOC. PROF. WANPEN WIROJANAGUD, Ph.D., THESIS CO-ADVISOR: ASST. PROF. SOMSAK PITAKSANURAT, Dr. Tech., THESIS CO-ADVISOR: ASST. PROF. KEVIN L. KANE, Ph.D., 175 pp.

This study aims at developing an Expert Geographic Information System for secured landfill sites analysis called as EGIS. The EGIS is a package tool of an integrated Geographic Information System (GIS), Expert System (ES), Analytic Hierarchy Process (AHP), and Visual MODFLOW model. GIS represents a spatial data, ES represents a knowledge base about secured landfill siting, AHP applies for ranking of candidate sites, and the Visual MODFLOW model is used as a tool for predicting the possible groundwater impacts from the landfill site. The developed EGIS was applied to identify the preferred site for secured landfill in Khon Kaen province, Thailand. Prior to applying GIS, criteria for secured landfill were formulated by compiling criteria of US.EPA, MOInd and PCD. The formulated criteria are consisted of 23 criteria. The selected criteria for Khon Kaen Province inputted by users through ES, 16 criteria were used as the input to GIS model. The result of GIS models analysis showed that there were eleven candidate sites for secure landfill. The candidate sites were then ranked as top five sites by using AHP method based on fifteen factors considered from the selected criteria including 2 social factors. The top five candidate sites with AHP ratio of 0.322, 0.307, 0.226, 0.203 and 0.188 for site 3 (Tambon Pho chai, King Amphoe Kok Pho Chai), site 2 (Tambon Non Sa-at, Amphoe Wang Yai), site 1 (Tambon Tawad, Amphoe Wang Noi), site 11 (Tambon Hau Na Kham, Amphoe Kranuan), and site 4 (Tambon Phulek, Amphoe Banphai), respectively. Then compiling with the information of field investigation, site 4 was evaluated as the preferred site for secured landfill. In addition, GIS model is able to visualize subsurface information of the preferred site and to produce the necessary information for the Visual MODFLOW model's input files. Under the designated condition, model simulation predicted that the lead contaminant from the preferred site would not reach any well within 7,300 days (20 years) after leaking. The study result showed that the development and application of EGIS was achievable.

Field of Study: Environmental Management Student's Signature:..........................

Academic Year: 2007 Advisor's Signature:........................

Co-advisor's Signature...................

Co-advisor's Signature:....................

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NOMENCLATURES

AHP	=	Analytic Hierarchy Process
C.R.	=	Consistency Ratio
EGIS	=	Expert Geographic Information System
ES	=	Expert System
GIS	=	Geographic Information System
MOInd	=	Ministry of Interior
NRD2c census	=	National Rural Development Committee bi-annual village database
PCD	=	Pollution Control Department
RCRA	=	Resource Conservation and Recovery Act
TDS	=	Total Dissolved Solids
U.S.EPA	=	United States Environmental Protection Agency

CHAPTER I

INTRODUCTION

1.1 Background and motivation

The Pollution Control Department (2005) under the Thai Ministry of Natural Resources and Environment estimates the amount of hazardous waste generated in Thailand in year 2004 at about 1,810,000 tones per year. Of such total generation, 1,405,000 tones (77.6%) and 405,000 tones (22.4%) are produced from industries and communities, respectively. Most of the community hazardous waste is co-disposed with the solid waste at the municipality disposal sites. Only 50 percent of the industrial hazardous waste is treated by licensed centralized treatment facilities. The remainder is managed using a combination of low cost and often less regulated practices. Therefore, these wastes are potentially hazardous to the environment, living organisms and human beings. There are only 10 licensed hazardous waste treatment and disposal service companies in Thailand and 7 of these companies use cement incinerators and 3 companies use secured landfills to dispose the hazardous waste (the Department of Industrial Works, 2003). Five of these service companies are located in Saraburi Province and the others are located in Bangkok, Lampang, Nakhon Si Thummarat, Rayong, and Sa Keao Province (Thailand consists of 76 provinces).

Since there are only 10 licensed hazardous waste treatment and disposal service companies, most of the community hazardous waste isn't disposed in the proper way and only 50 percent of the industrial hazardous waste is treated and disposed in an environmental safe way, there is an urgent need for identifying appropriate and environmentally sound sites for new secured landfills for treatment and disposal of hazardous waste. However, siting of secured landfill has become increasingly difficult because communities typically respond to plans to build a secured landfill or the others hazardous waste disposal facilities with the view of "Not in My Back Yards (NIMBYs)" or "Locally Unwanted Land Uses (LULUs). This means that in general, a new facility for treating or disposing hazardous waste is desirable, but at the same time every community refuses to accept the facility (Minehart and Neeman, 2002). There are two basic approaches to facility siting: open and closed. Closed siting approach often fails because social and political considerations are not given adequate attention, not because of environmental or technical mistakes. While the open approach supports more effective public involvement, and shares decision-making power (Kuhn and Ballard, 1998). In order to achieve the open approach, the appropriate tool for siting analysis should be applied in the siting procedures. In addition, this tool should be effective and easy to use for general public, planners, and decision makers. Geographic Information System (GIS) and Multi-criteria Decision Analysis (MCDA) such as Analytic Hierarchy Process (AHP) have been used in a number of studies in site selection (for example, Lindquist, 1991; Siddiqui et al., 1996; Koa et al., 1997; Lin and Koa, 1998; Badri, 1999; Badri et al., 2001; Chuang, 2001; Themistoklis et al., 2003). However, the research dealing with the integration between GIS and MCDA as a public participation tool is still needed (Higgs, 2006). Siting of secured landfills should carefully consider various factors and regulation. Spatial planning is a method, which combines environmental factors, engineering factors and socio-economic factors to select suitable sites for secured landfills. Based on spatial planning, the candidate sites are identified by analyzing GIS map layers and data according to the siting criteria. After the candidate sites have been identified, the techniques of AHP could be applied to rank the candidate sites of secured landfills. Additionally, the Visual MODFLOW model could be used as a tool for monitoring and predicting the groundwater impacts from the sites, since the major environment concern with secured landfill is groundwater contamination associated with infiltration of leachate (Misra and Pandey, 2005). Even though the GIS, MCDA, ES and Visual MODFLOW model are useful for siting analysis there has been no attempt to integrate all of them for the comprehensive analysis of secured landfill sites. Therefore, this study developed a comprehensive tool to facilitate the analysis of secured landfill sites. It integrates ES, GIS, AHP and Visual MODFLOW model into a packaged tool, called an Expert Geographic Information System. The GIS represented spatial data, ES represented a knowledge base about secured landfill siting including spatial planning, AHP was applied for ranking of candidate sites, Visual MODFLOW model was used to assess the possible groundwater impacts from the preferred site, and a user interface was developed to allow users to revise the intermediate decisions by examining the consequences and make this tool a user-friendly graphic system The developed system was used to identify the suitable sites for secured landfill in Khon Kaen Province located in the Northeast region of Thailand where there is no licensed hazardous waste disposal site in the region.

1.2 Objectives

The main objective of this study is to identify the suitable sites for secured landfill in Khon Kaen Province by applying spatial planning and using an expert Geographic Information System (EGIS). It can be divided to three specific objectives which are:

1. To establish criteria for secured landfill siting
2. To develop a package tool of EGIS for secured landfill site analysis by applying spatial planning and integrating GIS, Expert System (ES), Analytic Hierarchy Process (AHP), and Visual MODFLOW model
3. To apply the EGIS for identifying suitable sites of secured landfill in Khon Kaen Province

1.3 Hypothesis

The EGIS will be a valuable tool for secured landfill analysis.

1.4 Scope of Study

1. Formulating criteria of secured landfills by compiling the criteria from U.S.EPA., Ministry of Industry and Pollution Control Department.
2. Developing EGIS for analysis of secured landfill site. It is consisted of:
   - 2.1 Developing ES on Visual Basic Language
   - 2.2 Developing GIS models in ArcGIS 9 for running GIS analysis to identify candidate sites of secured landfill.
   - 2.3 Integrating GIS, ES, AHP, and Visual MODFLOW using Visual Basic Language.
3. Applying EGIS to identify the suitable sites for secured landfill in Khon Kaen Province, Thailand.

1.5 Expected results

1. An effective tool for analysis of secured landfill sites.
2. Appropriate secured landfill sites for Khon Kaen Province.

CHAPTER II

LITERATURE REVIEWS

2.1 Siting of secured landfills

The typical hazardous waste management system consists of components for the collection, transportation, treatment and disposal of waste. The most common application treatment methodologies for hazardous waste are incineration, neutralization, precipitation, various separation processes, and secured landfills (Beer, 1984). The treatment technologies convert the waste into a more innocuous form, or immobilize toxic components, or reduce the quantity of the waste. Disposal of the waste is the final process and a key issue in overall hazardous waste management programs (Millano, 1996). There are several methods used for ultimate disposal of hazardous waste such as incineration, immobilization, landfill, off-shore and under ground storage. The landfill option is the one which is used in many countries, and major portion of wastes is disposed of through this rustic method. It is also technologically considered as an unsophisticated disposal method (Visvanathan, 1996). A landfill is a disposal facility where the hazardous wastes are placed and stored in the soil. A landfill site for hazardous waste disposal, which is known as the secured landfill, must be properly designed and operated to protect public health and environment (Batston et al., 1989). Site selections plays an important role in hazardous waste management processes in order to assure that the proposed location for waste facilities are based on environmental, social and economic concerns. The component of the siting process can be subdivided into: establishment of technical criteria, identification of a site, technical review of application, impact identification, approval of a site application and regulatory oversight (Craig and Lash, 1994).

2.1.1 Siting of hazardous waste management facilities of the U.S. Environmental Protection Agency

U.S.EPA. (1997) published the manual of sensitive environments and the siting of hazardous waste management facilities according to the Resource Conservation and Recovery Act (RCRA). The environmentally sensitive locations addressed in this publication are:

- Flood plain: facilities should avoid building in floodplains.

- Wetlands: facilities should not be located in wetlands.
- Ground water: facilities should not be located over high-value groundwater or areas where the underground conditions are complex and not understood.
- Earthquake zones: facilities are banned within 200 feet of a Holocene fault, faults that have been active within the last 10,000 years.
- Karst terrian: facilities should avoid locating in “active” karst areas.
- Unstable terrian: it is possible to build a safe facility on unstable terrain; however, construction and operating costs would increase considerably.
- Unfavorable weather conditions: facilities that burn hazardous wastes should avoid locating where unfavorable weather conditions exist.
- Incompatible land use: facilities should avoid locating near sensitive populations or in densely populated areas.

2.1.2 Laws and guidelines criteria for siting of secured landfills in Thailand

In Thailand, there are only rather broadly defined laws and guidelines criteria for siting of secured landfills which are:

(1) The regulation No.2 of Ministry of Industry (A.D. 1992), referring to the Factory Act A.D.1992. This regulation determined criteria for the location of the factory type 3 (secured landfills are defined as the factory type 3) as follows:

The factory type 3 can not be located in the areas of:

- housing estates and commercial building
- within 100 meters of public places such as temples, schools, historical sites, hospitals, government offices and conservation areas

(2) Siting Criteria of hazardous Waste Disposal Facilities from Pollution Control Department’s Guideline

Hazardous waste disposal facilities shall be located in the following areas:

- Distance from major Highway should be more than 100 meters but less than 10 kilometers
- Distance from communities or residential areas should be more than 3 kilometers
- Distance from river or water resources should be more than 300 meters and not be located in watershed areas
- Groundwater table should be deeper more than 1.5 meters from he surface
- Not be located in flood-prone areas, low permeability soils
- Not be located in religious or historic sites or conservation areas
- Not be located in mining areas and should be far from fracture areas of more than 100 meters

(3) Siting Criteria of landfill facilities from the Pollution Control Department's Guideline of Municipal Solid Waste Management.

Site Selection shall exclude the following areas:

- Within watershed areas class 1 and class 2 as defined under the Cabinet Resolution on May 28, B.E.2538 in setting up the watershed Classification
- Within 1-kilometer from the property boundary of any ancient monuments as defined under the Ancient Monuments, Relics, Antiques and Nation Museum Act
- Within 5-kilometer distance from the property boundary of any licenced and operating airport runway
- Within 700 meters of an existing potable water well or existing community water treatment plant
- With 300 meters of any natural or man-made body of water, including wetlands, except bodies of water

contained completely within the property boundary of the disposal site

- In an area where geological formations or other subsurface features will not provide support for the solid waste
- Unless in the high land area. In an area subject to frequent and periodic flooding unless flood protection measures are in place
- Unless in an area where the normal water table is sufficiently low. In high water level area unless special design is provided
- Unless in a stretch of sufficiently large area which can be landfilled at least 20 years.

Thailand is divided into 6 regions; North, East, North East, West, Central, and South. The regions have different environmental characteristics in geology, hydrology, topography, etc., Therefore, the siting criteria should be used flexibly to help make better decisions for siting analysis. Thus the siting criteria in this study were divided into two levels, the first level was screening criteria and the second level was additional criteria. The screening criteria came from relevant laws, regulations, and guidelines and could be used in any regions of country in siting selection processes. The additional criteria were flexible and cover environment, economic and social aspects. The additional criteria were used as factors in the site ranking process.

2.2 Spatial planning

There are many definitions of spatial planning. However, the most well known definition is from the European Commission which describes spatial planning as "methods used largely by the public sector to influence the future distribution of activities in space. It is undertaken with the aims of creating a more rational territorial organization of land uses and the linkages between them, to balance demands for development with the need to protect the environment, and to achieve social and economic objectives. Spatial planning embraces measures to co-ordinate the spatial impacts of other sector policies, to achieve a more even distribution of economic development between regions than would otherwise be created by market forces, and to regulate the conversion of land and property uses" (The European Spatial Planning Observatory Network, 2004).

Spatial planning covers traditional land use planning. It is concerned with the physical aspects of location and land use, but it integrates others policies for development and takes into account economic, social and environment aspects (Planning Officers' Society, 2005). The aim of spatial planning is to achieve sustainable development. Denmark is a European country that has been successful in applying spatial in the planning system through Denmark's Planning Act. The Danish planning system is based on the principle of framework control, in which plans on lower levels must not contradict planning decisions on higher levels. There are 4 levels in the planning system which are national planning, regional planning, municipal planning, and local planning (Kevin, 2002). The Danish concept of spatial planning consists of the following steps:

1. General policies, planning objectives and laws
2. Spatial analysis and criteria for spatial priorities – Sector plans
3. Balancing of sector plans - Final designation of areas for use or protection
4. Regulatory framework directed specifically towards the designated areas

The GIS has been used as a valuable tool for planning in Denmark. The Danish concept of spatial planning and the relationship between spatial planning, data, geographical information and information systems are shown in Figure 2.1.

In Thailand, the spatial planning function falls largely within the Department of Public Works and Town & Country Planning, Ministry of Interior. Based on the Town Planning Act, B.E. 2518 [A.D. 1975], the Department responsible for physical plans in many levels such as Regional Plan, Provincial Structure Plan, Comprehensive Plan, Sub-District Plan, Specific Plan, Special Area Plan.

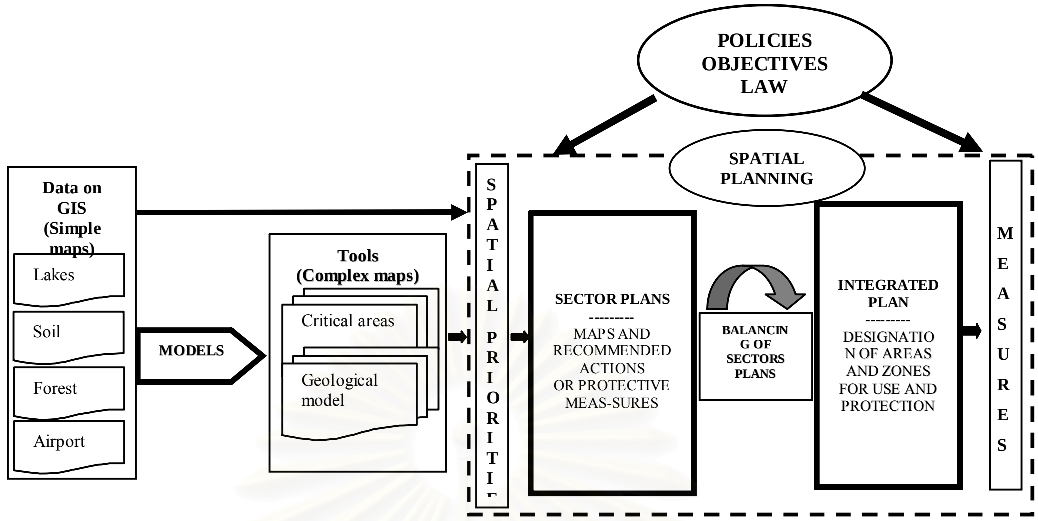

Figure 2.1 Spatial planning Concept (Kevin, 2002).

2.3. Geographic Information System (GIS) and site selection

GIS is a technology that manages, analyzes, and disseminates geographic knowledge (Environmental Systems Research Institute, 2005). It is used to view and analyze data from a geographic perspective. Lindquist (1991) identified the advantages of applying GIS to assist landfill siting as: (1) an objective exclusion process based on a set of defined criteria; (2) a capability to handling complicated geographic data; (3) flexible in implementing “what if” analysis, and (4) display and graphical representation of results. An example of GIS application in landfill siting process was studied by Siddiqui et al. (1996) using GIS and the Analytic Hierarchy Process (AHP) decision-making procedure to aid in preliminary landfill site selection. A similar study was conducted by Themistoklis et al., (2003). In this study, a GIS was used to identify the candidate landfill sites according to 10 criteria and the candidate sites were ranked by using the AHP. Koa et al., (1997) developed the network geographic information system for landfill siting by providing a raster-based GIS on the network to allow the general public to access the siting system. Lin and Koa (1998) also developed the spatial model integrating with a GIS to facilitate landfill siting analysis. However, the model was so far not physically integrated with a GIS.

2.4 Expert Systems (ES)

In general, ES also called a knowledge-based system (KBS) is a computer program which comprises software technology that can replicate certain aspects of expertise and can manipulate both qualitative and quantitative knowledge. This technology offers planners new ways of organizing, formalizing, and manipulating context-specific knowledge and problems (Masri and Moore 1993). It differs from conventional programs in the way it is structured. A conventional program is structured in a procedural way and needs a complete set of data to provide a unique a solution to a problem, while ES is conceptual in nature, can run on an incomplete set of data, and provides many solutions to a problem each with a varying degree of uncertainty (Lukasheh et al., 2001). The basic components of expert systems included: (1) user interface which allows the user to communicate with the system, providing necessary data to the system; (2) inference engine, which solves given problems using input data from the user and knowledge from the knowledge base, through its own reasoning methods; and (3) knowledge base, which contains the knowledge obtained from a domain expert, including facts and rules (Kim et al., 1990). Figure 2.2 shows the basic components of expert system.

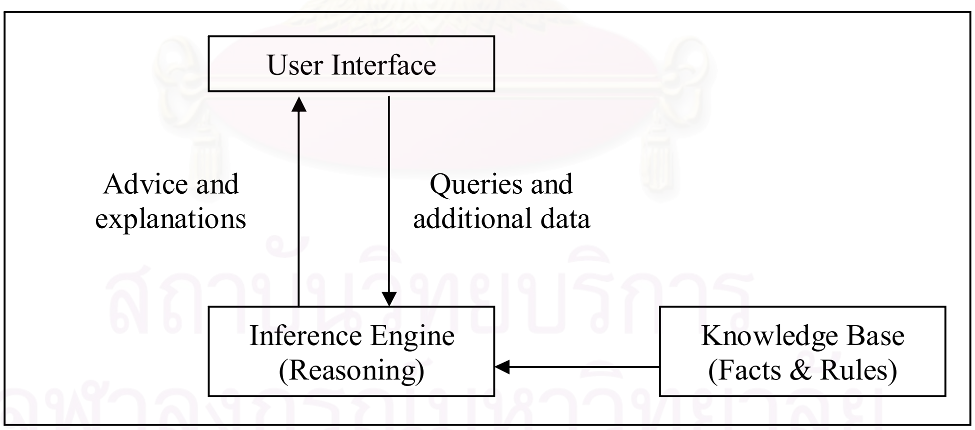

Figure 2.2 Basic components of expert system (Kim et al., 1990).

Expert systems related to site selection were found in the literature review such as:

Theo et al. (1995) investigated the use of expert system technology for the development of a knowledge-based Decision Support System (DSS) for the planning of retail and service facilities. The conclusion of this study was that ES techniques make it possible to incorporate expert knowledge for complementing existing algebraic and algorithmic models in a Decision Support System (DSS).

Khalid et al. (2003) used Component Object Model (COM) technology in designing a decision support system for industrial site selection. In this research GIS, ES, and AHP were successfully integrated using COM Technology. The integrated system could benefit developers, consultants, and planners.

Wann (2005) developed an expert decision support system (EDSS) to aid planners in determining the most appropriate waste incinerator sites. This study described that the decision support systems are not intended to replace the decision maker in solving the problem: they are constructed to help the user to make responsible and clearly documented decisions, which use the potential available as much as possible.

2.5 Analytic Hierarchy Process (AHP)

The AHP was developed by Thomas L. Saaty in 1980. It is a method for ranking decision alternatives based on how well each alternative meets the decision maker's criteria. The AHP can be used to measure the relative degree of importance of each requirement by comparing each pair of requirements to indicate how much more important one member of each pair is than the other (Chuang, 2001). AHP has been applied to a wide variety of decisions such as planning and development, selecting a best alternative, resource allocations, benefit-cost analysis, etc. Some examples of AHP application in site selection are as follows: Badri (1999) combined AHP and goal programming for global facility location. He claimed that the methodology could help the facility planning personnel to formulate location strategies. Badri et al. (2001) presented a method of selecting sites for the safe application of animal waste by combining GIS and AHP. In this study, the factors affecting the suitability of a site for animal waste application were selected and digital data sets were clipped to the size of the delineated sub-catchments boundary producing input factors. Then, these input factors were weighted using AHP to find the suitable sites. The process of the AHP is shown in the next chapter.

2.6 Visual MODFLOW model

The major environmental concern with a secured landfill is ground water contamination associated with infiltration of leachate (Misra and Pandey, 2005). In order to protect ground water from leachate, USEPA has proposed Double Liners and Leachate Collection and Removal System (LCRS). However, in worse case such as the leakage of liners, the contamination should be predicted. The Modular Three-Dimensional Finite-Difference Ground Water Flow (MODFLOW) is perhaps the most popular groundwater flow model used by government agencies and consulting firms (Peter, 1993). MODFLOW is a computer program that simulates three-dimensional ground-water flow through a porous medium by using a finite-difference method (Harbaugh et al, 2000). It was originally documented by McDonald and Harbaugh in 1984. Visual MODFLOW model was developed by Waterloo Hydrologic Inc. The advantages of this program are: easily dimension the model domain and select unit, conveniently assign model properties and boundary conditions, run the model simulations, calibrate the model using manual or automated techniques, and visualize the results using 2D or 3D graphics (Waterloo Hydrologic, 2002). The partial-differential equation of ground-water flow used in MODFLOW is as follows (McDonald and Arlen, 1988):

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t}$$

Where,

K_{xx}, K_{yy}, and K_{zz} = hydraulic conductivity along the x, y, and z coordinate axes (m/s)

h = potentiometric head (m)

W = volumetric flux per unit volume (s^{-1})

S_S = specific storage of the porous material (m^{-1})

t = time (s).

CHAPTER III

MATERIALS AND METHODOLOGY

3.1 Materials

3.1.1 Computer hardware and software

1) Personal computer Intel? Celeron? M, 1.30 GHz, 512 MB of RAM, Hard disk 60 GB.

2) ArcGIS 9 (Environmental Systems Research Institute, ESRI)

3) Microsoft Visual Basic 6.0

4) Microsoft Excel 2003

5) Visual MODFLOW version 2.8.1.71 (Waterloo Hydrogeologic software)

3.1.2 Relevant data

1) Geographic data from Regional Environmental Office 10 and Department of Groundwater Resources, Ministry of Environment and Natural Resources

2) Geological and Hydrogeological data from the Department Groundwater Resources

3) Meteorological data from Thai Meteorological Department

4) National Rural Development Committee bi-annual village census database (NRD2c) from Community Development Department, Community Development Department (CDD) under Ministry of Interior

3.2 Methodology

The steps of development of EGIS and application are summarized in Figure 3.1 and described as follows.

3.2.1 Formulating criteria of secured landfills

Criteria of secured landfills were established by compiling the criteria from U.S.EPA., Ministry of Industry and Pollution Control Department. The criteria are consisted of relevant laws, regulations, and technical guidelines. The criteria of each agency were formulated as the matrix table. The criteria that are not the same were selected. For the same criteria, the strictest one was selected. The output of this step is the formulated criteria.

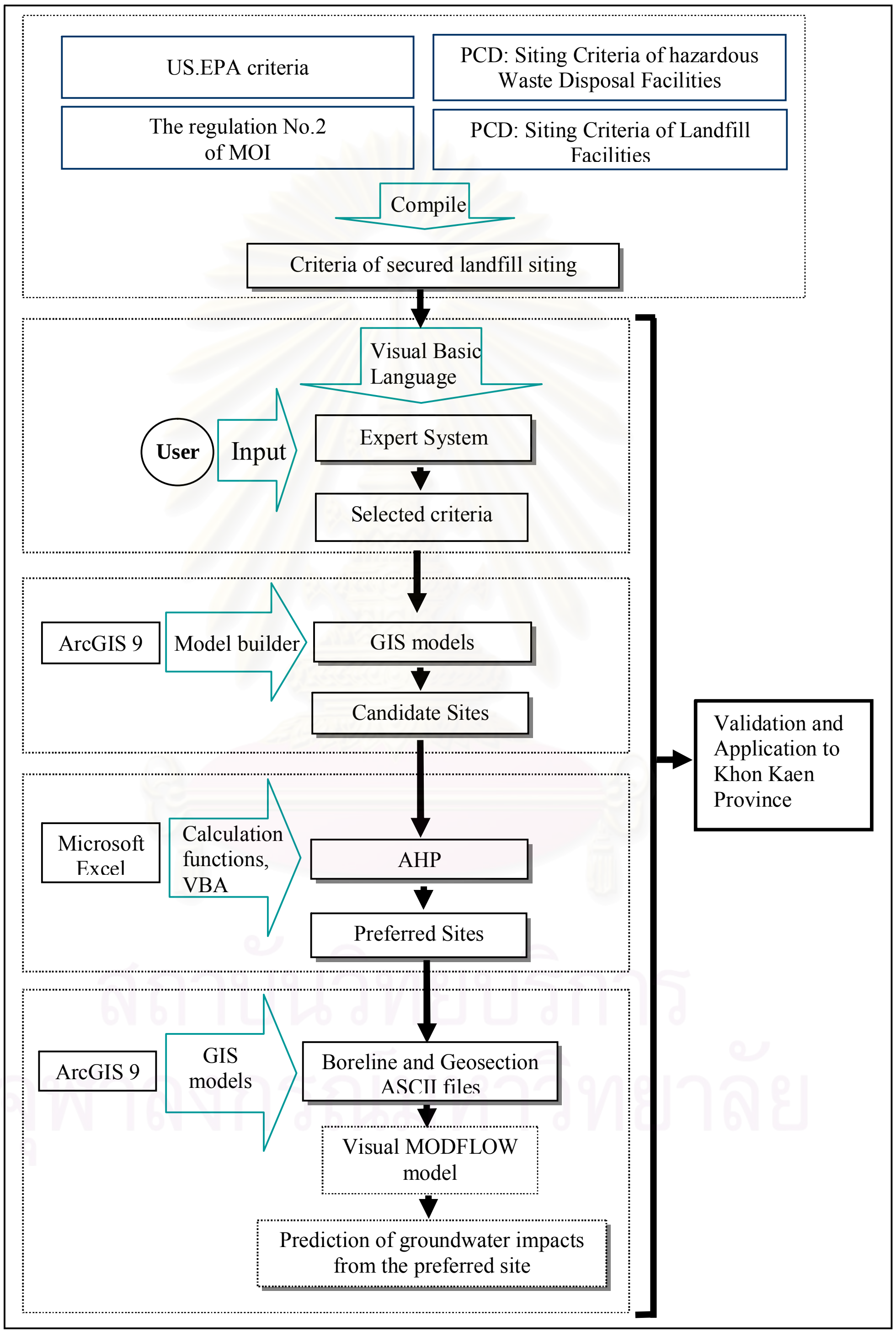

Figure 3.1 Steps of development of EGIS and application.

3.2.2 Development of EGIS for analysis of secured landfill site

EGIS was developed for analysis of secured landfill site by integrating GIS, ES, AHP, and Visual MODFLOW (Figure 3.2) as subsequently described below. In addition, the EGIS user interface was developed to allow users to interact with either system through graphic menu-based tools

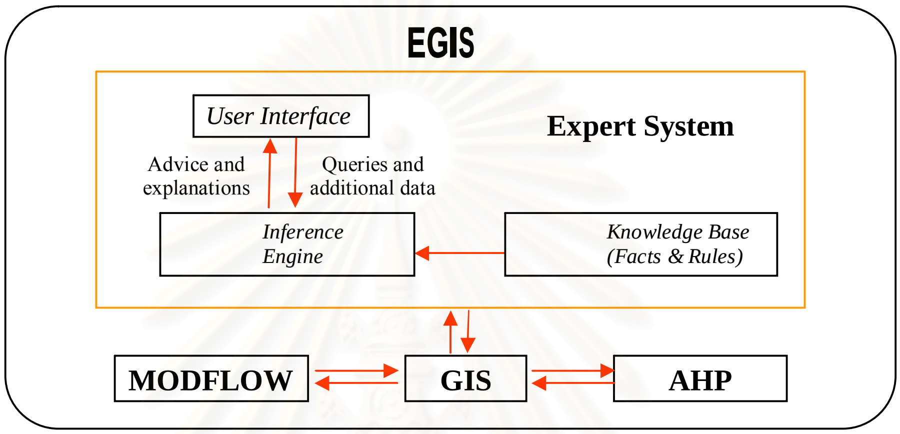

Figure 3.2 Components of EGIS.

3.2.2.1 Development of Expert System for criteria selection of secured landfill

The ES for selecting criteria of secured landfill was developed by using Microsoft Visual Basic 6.0. The "If – Then" rule was applied in coding of the ES. The system has the capability to provide the information and suggestions about siting criteria of secured landfill formulated as stated in 3.2.1. It allows the users to input the GIS data of the siting criteria that are available in hand. In addition, the ES provides the suggestion about GIS data and their sources for the users to obtain. The outputs of this step are screened criteria used in the GIS analysis.

3.2.2.2 Development of GIS models

GIS models were developed in ArcGIS 9 for running GIS analysis.

The GIS models have the capability to:

- allow users to import GIS data layers for siting analysis.
- provide default value of buffer distance.
- allow users to create buffer distance by themselves.
- screen out unsuitable areas.

- identify potential areas.
- identify candidate sites by calculating the suitable size of the secured landfill site based on the quantity of hazardous waste in the study areas.
- identify characteristics of candidate sites.
- import the National Rural Development Committee bi-annual village census database (NRD2c Data) - originating from comprehensive surveys conducted by Community Development Department (CDD) under Ministry of Interior.
- identify NRD2c data of each candidate site.

The output of this step is the candidate sites and characteristics of such candidate sites.

3.2.2.3 Development of AHP

AHP was developed by Microsoft Excel. The system has capability to:

- import the required information from output files (.dbf files) of GIS analysis for implementing to AHP.
- allow users to weigh the criteria for candidate sites ranking by themselves.
- rank candidate sites by implementing AHP- The factors applied for ranking candidate sites were the considered criteria in the process of potential areas identification, and population and unemployment rate from NRD2c data. The population and unemployment rate of communities surrounding candidate sites was used to estimate a number of people that could be potentially affected by the sites. Population figures would possibly give a negative impact by adverse consequence of the sites, while unemployment would be a positive impact in terms of potential job opportunities to the communities.
- present a preferred site's map in 2 and 3 dimensions

In this step, Microsoft-Excel and Visual Basic for Application (VBA) were employed to develop an Excel application to implement the AHP technique. The characteristics of candidate sites analyzed by running GIS models was reported and used as ranking factors in AHP analysis. After ranking the candidate sites, the preferred site was visualized in GIS.

The process of AHP in this study comprises the following steps (Saaty, 1980 and Badiru and Cheung, 2002):

1) Developing the hierarchical structure for the decision problem.

The top level of the hierarchy is the overall objective of the decision problem and the competing alternatives are at the bottom of the hierarchy. The attributes of alternatives such as selection criteria and factors, on which the final objective depends, are listed between the top and the bottom of the hierarchy. The number of levels in the hierarchy depends on the complexity of the problem.

2) Determining the relative weights of each alternative with respect to the characteristics and sub-characteristics in the hierarchy

After the hierarchy has been constructed, the users must undertake a subjective prioritization procedure to determine the weight of each element at each level of the hierarchy. Pairwise comparisons are performed at each level to determine the relative importance of each element at that level with respect to each element at the next-higher level in the hierarchy.

2.1) Determine the relative weights of each attribute with respect to the objective.

2.1.1 Develop Matrix of Pairwise Comparison of attributes. The matrix of pairwise comparisons can take the following form:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix}$$

The attribute of the matrix A (m by m matrix) in the i^{th} row and j^{th} column is denoted by a_{ij}. The a_{ij} values represent the relative degree of importance of attribute i over attribute j. The possible assessment value of a_{ij} with the corresponding interpretation is shown below:

Attribute i and j are equally important, insert 1

Attribute i is weakly more important than attribute j, insert 3

Attribute i is strongly more important than attribute j, insert 5

Attribute i is demonstrably or very strongly more important than attribute j, insert 7

Attribute i is absolutely more important than attribute j, insert 9

Intermediate numbers (2, 4, 6, and 8) are used as appropriate to indicate intermediate levels of importance. For all i and j, it is necessary that a_{ji} = 1 and a_{ij} = $1/a_{ji}$.

2.1.2 Compute normalized relative weights of attributes. The entries of the matrix of pairwise comparisons are then normalized by dividing each entry in a column by the sum of all the entries in that column. This yields a new matrix A_w, in which the sum of the entries in each column is 1.

$$A_w = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}} \\ \vdots & \vdots & \cdots & \vdots \\ \vdots & \vdots & \cdots & \vdots \\ \frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}} \end{bmatrix}$$

Compute w_i as the average of the entries in row i of A_w to yield column vector W.

$$W = \begin{bmatrix} w_1 \\ \vdots \\ \vdots \\ w_m \end{bmatrix} = \begin{bmatrix} \dfrac{\frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} + \cdots + \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}}}{n} \\ \vdots \quad\quad \vdots \quad\quad \cdots \quad\quad \vdots \\ \vdots \quad\quad \vdots \quad\quad \cdots \quad\quad \vdots \\ \dfrac{\frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} + \cdots + \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}}}{n} \end{bmatrix}$$

Where, w_1 represents the normalized average rating associated with each attribute. These averages represent the relative weight of the attributes that are being evaluated. The attribute which has highest value of w_1 is considered to be the most important factor in the selection of a decision aid for productivity improvement.

2.1.3 Compute consistency ratio of pairwise comparison of attributes. Since the initial pairwise comparisons of the attributes are done based on subjective opinions of the people involved in the decision making, it is quite possible that some elements of bias and inconsistency will be present in the evaluations. Satty (1980) proposed a procedure for calculating the consistency ratio (C.R.) to determine reasonable consistency and to minimize bias. The consistency ratio is calculated as follows:

Consistency ratio (C.R.) = C.I. / R.I.

Where

C.I. = $(\lambda_{max} - m)/(m-1)$

λ_{max} = the average consistency measure for all alternatives

$$= \frac{1}{m}\sum_{i=1}^{m}\frac{i^{th}\ entry\ in\ A \times W}{i^{th}\ entry\ in\ W}$$

m = number of element

R.I. = the appropriate random index of m, which is shown below:

m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

If C.R. is sufficiently small, the decision maker's comparisons are probably consistent enough to give useful estimates of the weights for the objective function. In general, a consistency ratio of 0.10 or less is considered acceptable.

2.2 Determine the relative weights of each alternative with respect to the attribute. After the relative weights of the attributes are obtained, the next step is to evaluate the alternatives on basis of the attributes. In this step, relative evaluation rating is obtained for each of alternative with respect to each attribute. The procedure for the pairwise comparisons of the alternatives is similar to the procedure for the attributes. Then each matrix is analyzed and normalized by using the procedure shown previously.

3) Compute overall desirability weight of each alternative.

The attribute weights in step 2.1 are then combined with the system weights to obtain the final AHP analysis by using the following equation:

$$\alpha_j = \sum_i (w_i k_i)$$

where, α_j = overall weighted evaluation for alternative *j*.

w_i = relative weight for attribute *i*.

k_i = evaluation rating for alternative *j* with respect to attribute *i*.

$w_i k_i$ = a measure representing the global weight of alternative *j* with respect to attribute *i*. The sum of the global weights associated with an alternative represents the overall weight α_j, of that alternative.

4) Make a final decision based on the results

The alternative which has the highest weighted ranking should be selected as the preferred alternative.

3.2.2.4 Implementation of MODFLOW

MODFLOW was implemented to assess the impact of leachate leak from the preferred site. GIS models were developed for preparing the input data to Visual MODFLOW model in ASCII format. The Visual MODFLOW Model could be accessed by users from the main menu of the system. The steps of inputting data into the Visual MODFLOW Model consisted of (1) generate a new model by assigning the number of row, column, layer and unit that use in the model; (2) edit grids and surface elevation; (3) add pumping wells and monitoring wells; (4) assign flow properties such as hydraulic conductivity, specific storage, specific yield and porosity; (5) assign flow boundary condition such as constant head boundary, recharge boundary and river boundary; (6) assign particle tracking; (7) set up the transport model by setting up the numerical engine for simulated groundwater flow and contaminant transport; (8) assign the contaminant transport properties such as distribution coefficient, dispersion coefficient; and (9) assign contaminant transport boundary conditions such as recharge concentration and constant concentration.

3.2.3 Validation and application of EGIS for secured landfill site in Khon Kaen Province

EGIS was applied to find the secured landfill in Khon Kaen Province. In this step, the EGIS had been accordingly validated. The system was individually validated by following testing. Firstly, ES was tested to check for the conformance of data input following the "If-Then" rule. Secondly, GIS models were tested to confirm the outputs of each model resulted as the designated conditions. Thirdly, the AHP was tested for the system that can provide the correct results calculated from the data input by the users. Moreover, the GIS models were also used to test for MODFLOW model. Since the validation was completed, the applications of EGIS for secured landfill sites analysis in Khon Kaen Province, Thailand was implemented as follows:

1) Screening out the unsuitable areas for secured landfill sites based on the screening criteria and GIS data inputted by users
2) Identifying potential areas for secured landfill sites
3) Identifying candidate sites for secured landfill
4) Ranking candidate sites by applying the technique of AHP
5) Predicting groundwater impacts from the preferred site by using Visual MODFLOW Model. The data requirements are water table, hydraulic conductivity, transmissivity, porosity, pumping well and observation wells, soil properties and distribution coefficient (K_d)
6) Presenting planning maps and a 3-Dimension map of a preferred secured landfill site
7) Presenting recommended measures of the preferred site.

The conceptual framework of this study is shown in Figure 3.3.

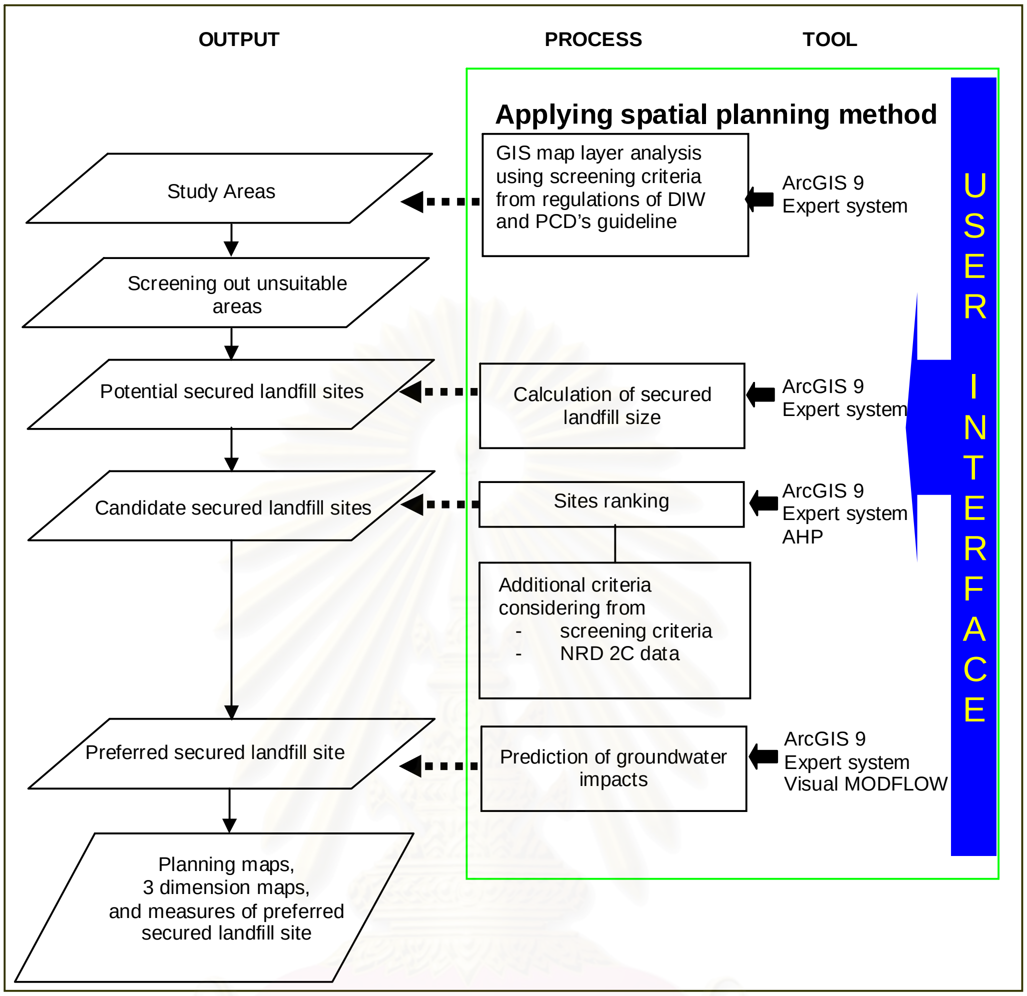

Figure 3.3 Conceptual framework of this study.

In addition, EGIS was verified by implementing to the PCD criteria. The comparison was made for the output of secured landfill sites generated by PCD criteria and this study's criteria used for Khon Kaen Province. Then, the minimum criteria were determined by subtracting the full criteria of PCD out until the output were relatively resulted with the full PCD criteria. The minimum criteria are implied as the must criteria that the users need to have for secured landfill analysis.

3.2.4 Application of EGIS for analysis of secured landfill site in Mahasarakaham Province

This step was performed to indicate the EGIS can be implemented to other areas. After accomplishing the verification of EGIS for Khon Kaen Province, EGIS was applied to Mahasarakham Province.

CHAPTER IV

RESULTS AND DISCUSSIONS

This chapter presents the criteria formulated for secured landfills siting, EGIS for siting of secured landfill analysis, including the results of applying EGIS for Khon Kaen and Mahasarakham Provinces.

4.1 Criteria of secured landfills siting

The criteria of secured landfill and landfill siting designated by US.EPA, MOInd, and PCD as presented in Chapter 2 were tabulated in Table 4.1. All criteria in Table 4.1 were complied for formulation of criteria of secured landfill sites used in this study as shown in Table 4.2.

Table 4.1 Criteria of secured landfill and landfill siting.

Criteria	US.EPA	The regulation No.2 of MOInd	PCD: Siting criteria of hazardous waste disposal facilities	PCD: Siting Criteria of landfill facilities
Watershed areas class 1 and 2			√	√
Flood prone areas	√		√	√
River and water resources			√ 300 m	√ 300 m
Groundwater table			√ deeper <1.5 m	
Recharge areas	√			
High yields and high quality of groundwater	√			
Existing water wells				√ 700 m

Table 4.1 Criteria of secured landfill and landfill siting (continued).

Criteria	**US.EPA**	**The regulation No.2 of MOInd**	**PCD: Siting criteria of hazardous waste disposal facilities**	**PCD: Siting Criteria of landfill facilities**
Wastewater treatment plant				√ 700 m
Wetland	√			√ 300 m
High permeability soil			√	
Fractures areas			√ 100 m	
Unsuitable geological information				√
Mining areas			√	
Earthquake zone	√			
Karst terrain	√			
Unstable terrain	√			
Forest zone C		√ 100 m	√	√
National park		√ 100 m	√	√
Major highway			√ >100m < 10km	
Airport				√ 5 km
Communities and residential areas		√	√ 3 km	
Villages points			√ 3 km	
Religious areas		√ 100 m	√	
Historical sites or ancient monuments		√ 100 m		√ 1 km

Remark: *the figure after √ refers to buffer distance*

Table 4.2 Criteria of secured landfill sites used in this study.

No.	Screening criteria	Default values of buffer distance
1	**Environmental factors**	
	Water/Hydrology/Hydrogeology	
	- watershed areas class 1 and 2	
	- flood prone areas/ high risk areas of flood	
	- river and water resources	300 m
	- groundwater table depth	<1.5 m
	- recharge areas	
	- high yields and high quality of groundwater	
	- existing water wells	700 m
	- waste water treatment plant	700 m
	- wetland	300 m
	Soil/Geology	
	- high permeability soil	
	- fractures areas	100 m
	- unsuitable geological information	
	- earthquake zone	
	- karst terrain	
	- unstable terrain	
	- mining areas	
	Forest/Conservation areas	
	- forest zone C	
	- national park	
2	**Economic factors**	
	- major highway	> 100 m < 10 km
	- airport	5 km
3	**Social factors**	
	- communities and residential areas	3 km
	- religious areas	
	- historical sites or ancient monuments	1 km

4.2 EGIS for siting of secured landfill analysis

4.2.1 Development of the EGIS user interface

The user interface was developed to make the system easy to use mainly through the model's interface in ArcMAp, ArcCatalog and ArcScence. In AHP analysis, format controls were used to run macros for importing data and implementing AHP. In addition, a guideline of the system was provided for users.

4.2.2 ES for siting of secured landfill analysis

Twenty three criteria formulated in Table 4.2 were coded in the ES. The interface of ES was created to take input from users through the pop-up pages. The first page of ES is a welcome page (Figure 4.1). When users entered the system, they were asked to mark all the environmental sensitive areas in the study area (Figure 4.2) and to mark all GIS data they had in hand (Figure 4.3). In this step, the "If – Then" rule was applied in coding of the ES. The system operates by checking the 'If' part of each rule. If the conditions described in the 'If' part are matched, the system activate the 'Then' part of the rules. For example, if users marks the water well as an environmental sensitive area but do not mark the GIS layer of water well, the ES will recommend that users should have GIS layer of water well, and also suggests the available sources of this GIS data. Even though without such mentioned GIS layer, ES is still able to work. However, the output might not be completed as the criteria are not taken into the input process. For all the marked GIS layers, the ES identifies the screening criteria and their default value of buffer distance. Figure 4.4 shows an example of "If - Then" rule coded in ES.

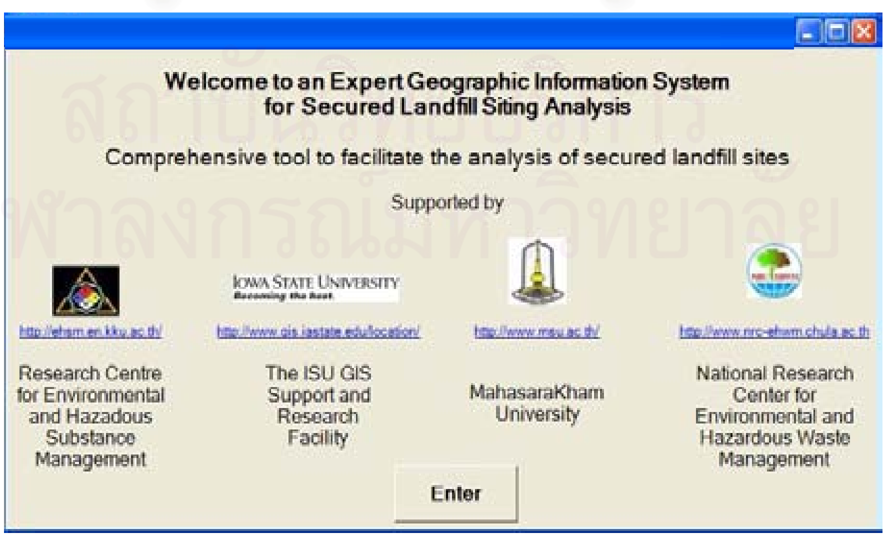

Figure 4.1 First page of the Expert System.

Figure 4.2 Expert System asking users to input the sensitive factors in their area.

Figure 4.3 Expert System asking users to input the GIS layers they have.

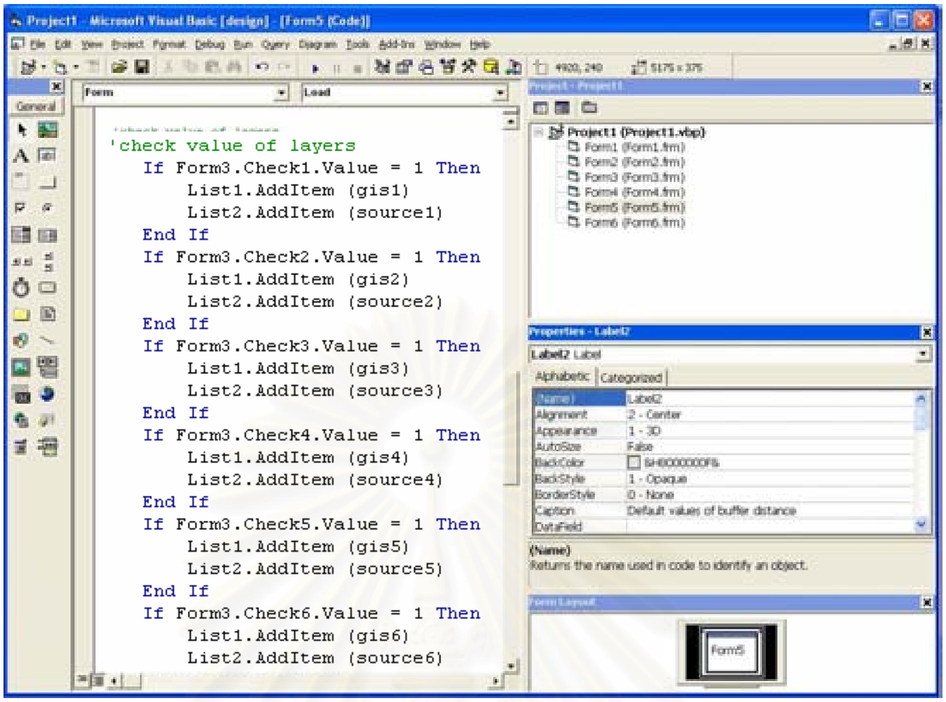

Figure 4.4 Example of "If - Then" rule coded in ES.

4.2.3 GIS models developed in ArcGIS

4.2.3.1 Models for organizing and importing GIS data into geodatabase

The new ArcToolbox called Datacopy was created in ArcCatalog. Models were built under the Datacopy toolbox for creating geodatabase and copying all GIS data provided by users into the GDB. The data structure in this study as viewed with ArcCatalog is shown in Figure 4.5. Figure 4.6 illustrates an example of model used for copying a provincial boundary feature into the GDB (GISdata.mdb).

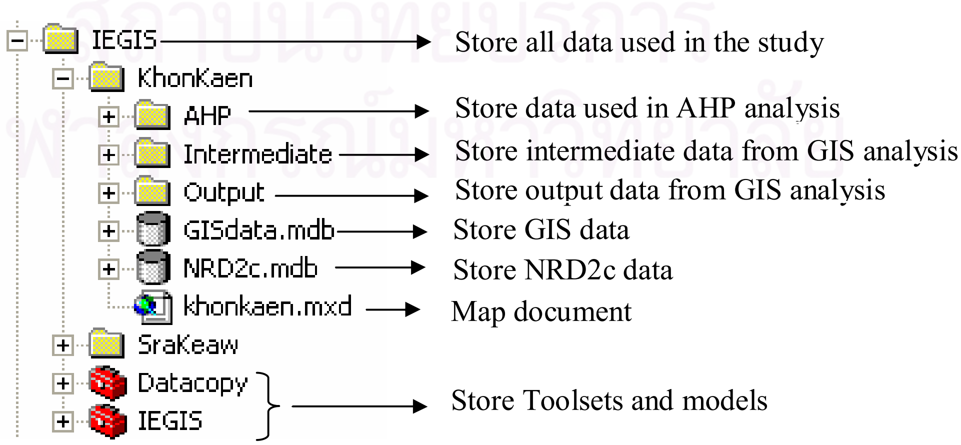

Figure 4.5 Data structure viewed with ArcCatalog.

Figure 4.6 Model for copying a provincial boundary feature into GDB.

4.2.3.2 Models for identifying a preferred secured landfill site

The new toolbox called EGIS was created in ArcMap to store toolsets and models used to run GIS analysis for identifying a preferred secured landfill site in the study area. The developed toolsets in this step are as follows:

- Screening out unsuitable areas toolset
- Identifying potential areas toolset
- Identifying candidate sites toolset
- Identifying characteristic of candidate sites toolset
- Importing NRD2c Data toolset
- Identifying NRD2c data of candidate sites toolset
- Presenting preferred site's map toolset

(1) Screening out unsuitable areas toolset

Five models, which are models of water factors, soil factors, forest factors, economic factors and social factors, were built to screen out unsuitable areas for secured landfill sites (Figure 4.7). These models have the capability to automate the GIS analysis and allow users to create their own buffer distance. An example of the model and the interface for inputting buffer values are shown in Figures 4.8 and 4.9, respectively.

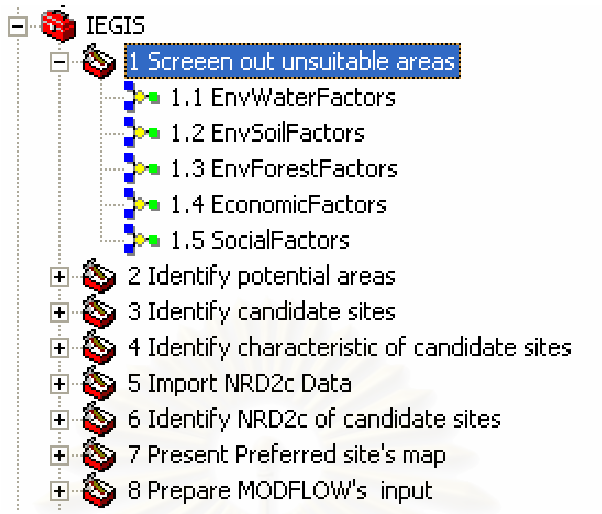

Figure 4.7 Toolset and models used for screening out unsuitable areas for secured landfill sites.

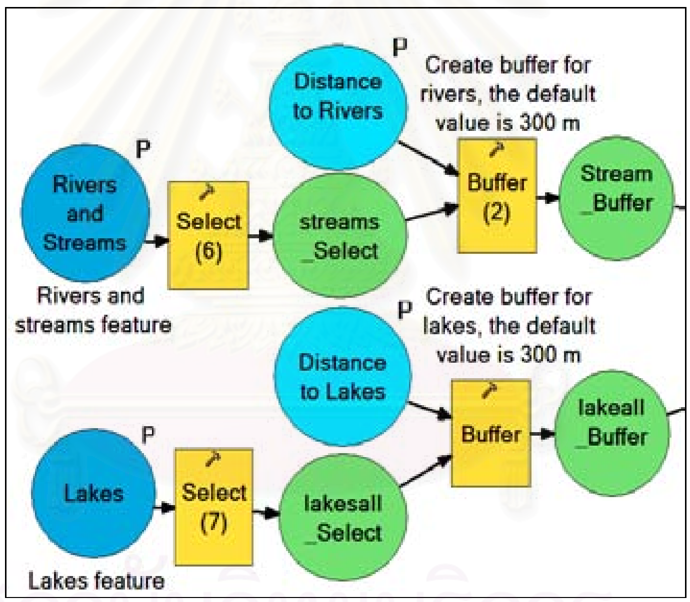

Figure 4.8 Example of ArcMap model.

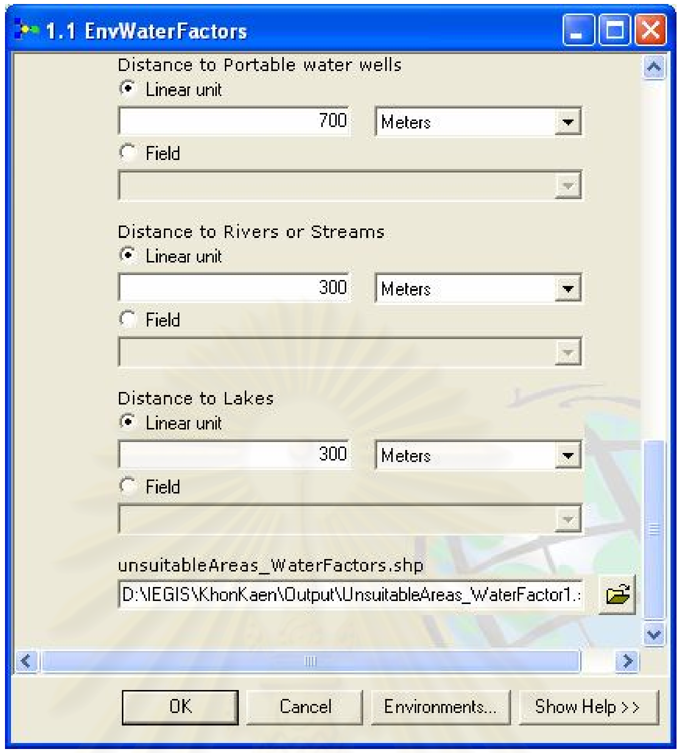

Figure 4.9 Example of an interface for inputting buffer values.

(2) Identifying potential areas toolset

A model was created to identify potential areas for secured landfill sites by the union of all unsuitable areas obtained from the previous step and erasing those areas from provincial areas.

(3) Identify candidate sites toolset

A model was created to select candidate sites which were met the appropriate size of secure landfill site in the study areas. Microsoft-Excel was used to calculate the appropriate size of secure landfill site by applying the calculation method of Sittig (1979).

(4) Identify characteristic of candidate sites toolset

After the candidate sites were identified, models were created to identify characteristics of candidate sites. There were thirteen characteristics of each site. However users can add more characteristics depending on the GIS data they input into the system.

(5) Importing NRD2c Data toolset

NRD2c data is the fundamental data at the village level which represents the general condition of the village. This study used two variables of NRD2c data, unemployed rate and number of population, as characteristics of candidate sites. Two models were created, the first model was used to import NRD2c data and the second model was used to modify NRD2c data by deleting unwanted variables.

(6) Identifying NRD2c data of candidate sites toolset

A model was created to identify unemployed rate and number of population of villages within 10 km of each candidate sites by joining prepared NRD2c data to the attribute table of villages within 10 km feature.

(7) Presenting the Preferred site's map toolset

A model was created to present a 2-dimension map and of the preferred site in ArcMap and present 3-dimension map in ArcSence.

4.2.4 AHP developed on Microsoft- Excel and VBA

Microsoft-Excel[?] and Visual Basic for Application (VBA) were used to develop an Excel application to import the required information from output files (.dbf files) of GIS analysis for implementing the AHP technique. Figure 4.10 shows an example of the VBA code used to access the different evaluation criteria from .dbf file.

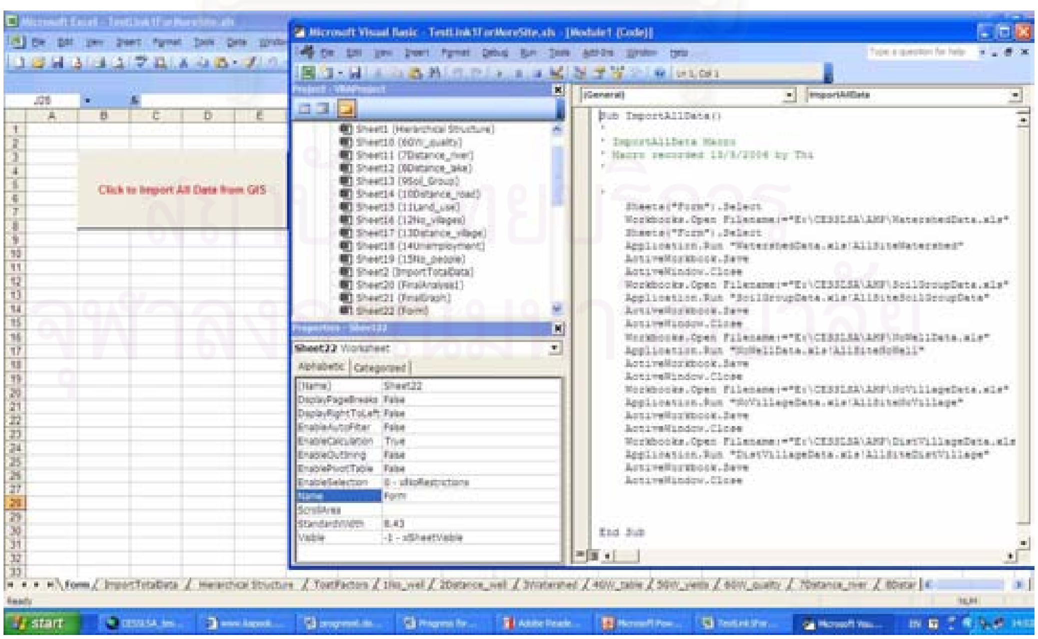

Figure 4.10 Example of VBA code used to import data from .dbf files.

Then functions in Microsoft-Excel[?] were created to implement APH technique as shown in Figure 4.11.

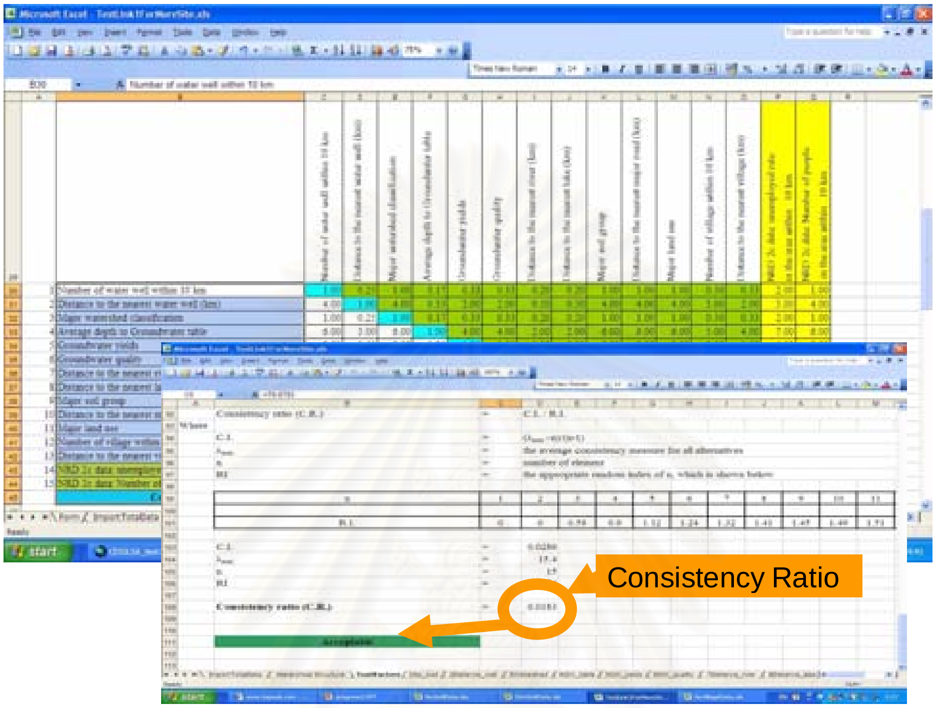

Figure 4.11 Example of function used to implement AHP technique.

4.2.5 Visual MODFLOW model Analysis

In order to prepare the Visual MODFLOW model's input files, an understanding of the subsurface is needed. Therefore, the ArcHydro groundwater toolbar, developed by Gil Strassberg and Venkatesh Merwade in 2005, was applied within ArcScene to construct 3D models of the subsurface and visualize subsurface information. The steps to construct 3D models of the subsurface are as follows:

1) Adding Arc Hydro groundwater toolbar

Within ArcScene, the Arc Hydro groundwater toolbar was added into the toolbar menu of ArcScene by customizing and adding the GroundwaterToolbar09192005.dll file through the customize option. Figure 4.12 shows the Arc Hydro Groundwater Tools V1.1 within ArcScene.

Figure 4.12 Arc Hydro Groundwater Tools V1.1.

2) Importing schema into geodatabase

The schema of the data model is a blueprint containing the description of the objects in the groundwater geodatabase, the relationships between them, and their behavior (Strassberg, 2005). In order to apply the Arc Hydro groundwater toolbar, the schema of the tool must be imported in to a new geodatabase. Thus, the model was built within ArcCatalog to create a new geodatabase. Since the original coordinate system of the Arc Hydro groundwater schema is geographic coordinates NAD 1983 HARN, it has to be changed to GCS_Indian_1975 by running the Change XML Spatial Reference toolbar as follows (applied from Strassberg, 2005):

2.1) Add the Change XML Spatial Reference toolbar to ArcCatalog by importing the ChangeXMLSpatialRef.dll file through the customize option.

2.2) Create an XML schema from the Arc Hydro Groundwater_Schema.mdb by using the Export to XML Workspace Document tool in ArcCatalog.

2.3) Open the Change XML Spatial Reference toolbar and specify the input and output XML files by browsing to the input XML schema and specifying the output location for the new XML file. Then, change the spatial reference of the schema to GCS_Indian_1975 through the spatial reference dialog and run the tool.

2.4) Import the new schema to the created geodatabase through the import XML workspace document by selecting the schema only option and specify the schema with the new spatial reference as the XML source.

Once the tool has run the geodatabase contained all the feature datasets, feature classes, and relationships defined in the XML schema, and the datasets had the geographic coordinate GCS_Indian_1975.

3) Creating the feature dataset and the relationships between feature classes and tables fit to the schematic of the model.

The geodatabase created in step 2 has a defined structure but no data in it. Therefore, this step prepared the data needed for constructing 3D models of the subsurface. The necessary data in this step was lithology data in study areas provided by the Department of Groundwater Resources. The lithology file was in PDF format and had to be translated to DBF format for further analysis in ArcMap and ArcScene. The important classes and relationships in this step are as follows:

- Well - Point features describing well locations and attributes.
- BoreLine – Three-dimensional line features for representing interval data along a borehole.
- WellHasBoreLines – Relationship between Well and BoreLine features. The relationship associates the HydroID attribute of well features with the WellID of BoreLine features.
- VerticalMeasurements – Table for storing vertical information describing point and line data along a borehole. The table is the basis for creating BoreLine features.

The combination of the Well, and BoreLine feature classes with the VerticalMeasurements table supports the representation of wells and vertical information recorded along the well as shown in Figure 4.13.

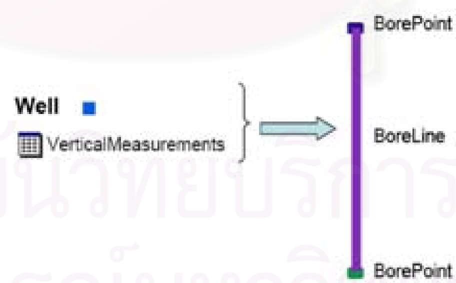

Figure 4.13 Representation of wells and vertical information along wells (Strassberg, 2005).

There are three models created in this step which are Create new Geodatabase model, Well preparation model and VerticalMeassurement model.

4) Creating BoreLines

Based on well locations in the Well feature class and vertical information stored in the VerticalMeasurements table, BoreLines are created by running Make BoreLines from Wells Tool (Figure 4.14). In this process each BoreLine is constructed from two vertices that have x, y, and z coordinates. The x and y coordinates are the coordinates of the associated well, and the z coordinates are the top and bottom elevation attributes of the vertical measurement. It means that each BoreLine represents a property or feature located along the well.

Figure 4.14 Make BoreLines from Wells under Arc Hydro Groundwater Tools.

5) Creating GeoSections from BoreLines

GeoSection is a three-dimensional polygon feature class, and is used to store and display subsurface properties as cross sections or fence diagrams. A cross section is a vertical plane through the subsurface, and a fence diagram is a three-dimensional network of cross sections between several wells. Both cross sections and fence diagrams are created by defining a set of vertical polygons over one or more planes. Each polygon represents a stratigraphic or hydrogeologic unit and a grouping of polygons forms a cross section or fence diagram. The tool used to create GeoSections in this study is a BoreLine Geosection Tool. It linearly connects two BoreLines to form a three-dimensional polygon. The hydrogeologic unit identifier (HGUID) must be the same in both BoreLines and is written as an attribute of the GeoSection feature. The algorithm of the tool includes the following steps:

- A section is defined by an ordered selection of well features.
- The BoreLine feature class is queried for each well and associated BoreLine features are identified.
- If BoreLines of the same hydrogeologic unit exist for two consecutive wells a GeoSection is created to connect the two BoreLines

- The hydrogeologic unit identifier (HGUID) is stored on the GeoSection.

Figure 4.15 shows an example of a GeoSection created from two BoreLines.

Figure 4.15 Example of a GeoSection created from two BoreLines.

The Visual MODFLOW model's input files in ASCII format were then prepared through the developed models as follows:

- Surface Elevation model - produces surface elevation in ASCII format.
- Layer 1 model - produces bottom elevation of layer 1 in ASCII format.
- Layer 2 model - produces bottom elevation of layer 3 in ASCII format.
- Layer 3 model - produces bottom elevation of layer 3 in ASCII format.
- Layer 4 model - produces bottom elevation of layer 4 in ASCII format.
- Well model – produces pumping wells and observation wells files in ASCII format.

Details of Models and their elements are shown in Appendix A.

4.3 Application of EGIS for secured landfill site in Khon Kaen Province

Application of EGIS to analyze for the secured landfill site had been made for Khon Kaen Province. In the EGIS processing, the system operation was coherently validated for output generated whether it is in conformance with the designated result. The followings are the outputs of the EGIS operation.

4.3.1 Screening criteria produced by ES

The GIS data for Khon Kaen Province used as input to the ES included:

- Province boundary feature
- Amphoe boundary (District boundary) feature
- Tambon boundary (Sub-District boundary) feature
- Village feature
- Land use feature
- Lakes feature
- Rivers/ stream/ water body feature
- Flood risk areas feature
- Aquifer (groundwater yields and quality) feature
- Groundwater contour feature
- Recharge area feature
- Well feature
- Wastewater treatment plant feature
- Watershed classification feature
- Mining feature
- National park feature
- National reserved forest zone feature
- Heritage feature
- Soil group feature

Sources of GIS data are presented in Appendix B

Based on the available GIS data of Khon Kaen Province used in the ES, the screening criteria consisted of three main factors including environmental factors, economic factors and social factors as shown in Table 4.3.

Table 4.3 Screening criteria of Khon Kaen Province identified by the Expert System.

No.	Factors	Default values of buffer distance
1	**Environmental factors**	
	Water	
	- watershed areas class 1 and 2	
	- flood prone areas/ high risk areas of flood	
	- river and water resources	300 m
	- groundwater table depth	<1.5 m
	- recharge areas	
	- high yields and high quality of groundwater	
	- existing water wells	700 m
	- wastewater treatment plant	700 m
	- wetland	300 m
	Soil	
	- low permeability soil	
	Forest	
	- conservation forest	
	- national park	
2	**Economic factors**	
	- major highway	< 100 m > 10 km
	- airport	5 km
3	**Social factors**	
	- communities and residential areas	3 km
	- historical sites or ancient monuments	1 km

4.3.2 Screening out unsuitable areas for secured landfill sites by GIS models

According to the screening criteria identified by the ES in Table 4.3, ArcMap models of water factors, soil factors, forest factors, economic factors and social factors were run to screen out unsuitable areas for secured landfill sites.

4.3.2.1 Environmental factors

1) Water factor

(1) Watershed areas class 1 and 2:

Watershed areas class 1A; 2A and 2B were selected from the watershed classification feature by using a query builder in the select tool.

(2) Flood prone areas/ high risk areas of flood

High risk area of flood was selected from the flood risk areas feature by using a query builder in the select tool.

(3) River and water resources

A three hundred meters buffer was created around river and lake in river and lake features through the buffer tool.

(4) Groundwater table

Areas with groundwater contour less than 1.5 meters were selected from the groundwater contour feature and created as polygon for further analysis.

(5) Recharge areas

All recharge areas, areas allow water to readily seep into the ground to replenish an aquifer, were defined as unsuitable areas. In this study this feature was produced by Groundwater Research Center, Faculty of Technology, Khon Kaen University.

(6) High yields and high quality of groundwater

High yields and high quality of groundwater areas were defined as followed:

- Yields = 2-10 m^3/hour and Total dissolved solid (TDS) = 750-1,500 mg/l or;
- Yields = 2-10 m^3/hour and Total dissolved solid (TDS) <750 mg/l or;
- Yields = 10-20 m^3/hour and Total dissolved solid (TDS) = 750-1,500 mg/l or;
- Yields = 10-20 m^3/hour and Total dissolved solid (TDS) <750 mg/l

These areas were selected from the aquifer feature by using the select tool.

(7) Existing water wells

A seven hundred meter buffer was created around wells through buffer tool.

(8) Wastewater treatment plant

A seven hundred meter buffer was created around wastewater treatment plant through the buffer tool

(9) Wetland

Wetland was selected from the land use feature and a 300 meter buffer of wetland was created.

After all unsuitable areas due to the water factor were extracted, they were grouped together by using the union tool to obtain unsuitable areas for secured landfills based on water factor as shown in Figure 4.16

2) Soil

Areas with soil group number 44 which have highest permeability were selected as unsuitable areas for secured landfill sites as shown in Figure 4.17

3) Forest

(1) Conservation forest

Conservation forest or called forest zone C was selected from the reservation forest feature.

(2) National park

All national parks were defined as unsuitable areas for secured landfill sites because they play significant roles in maintaining ecological stability and preserving biological diversity.

Both conservation forest and National parks were then grouped together by using the union tool. The result is presented in Figure 4.18

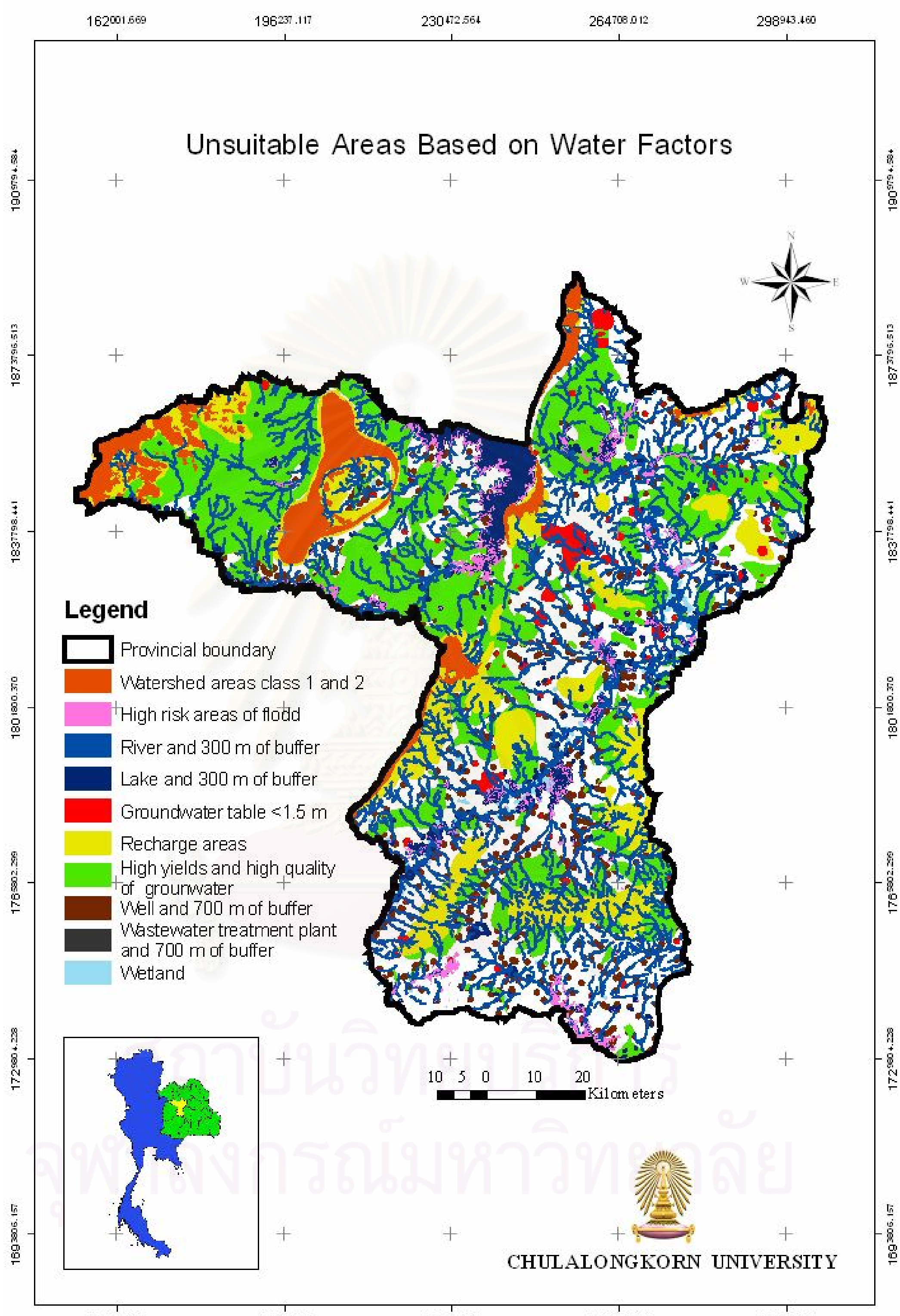

Figure 4.16 Unsuitable areas for secured landfills based on water factor.

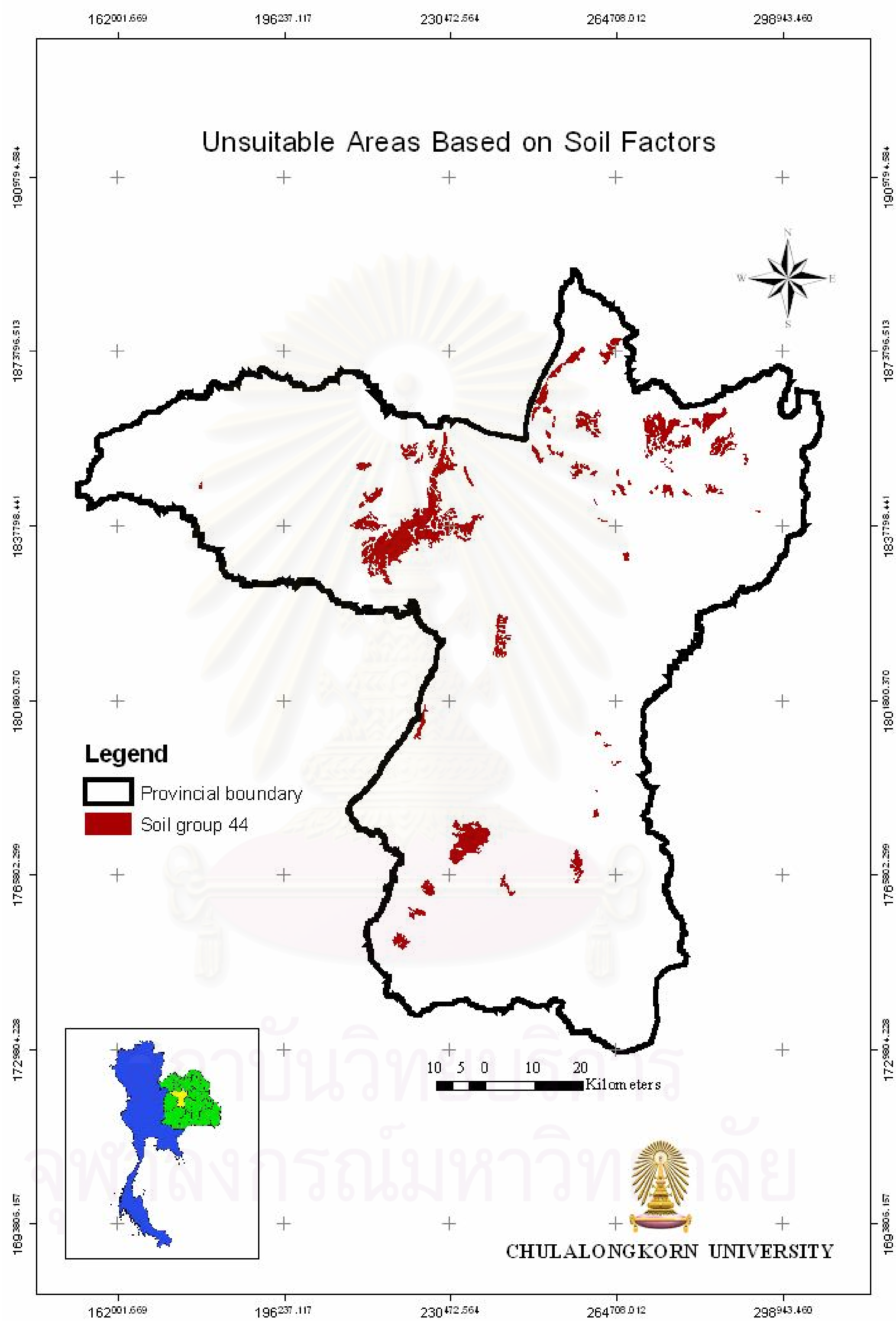

Figure 4.17 Unsuitable areas for secured landfills based on soil factor.

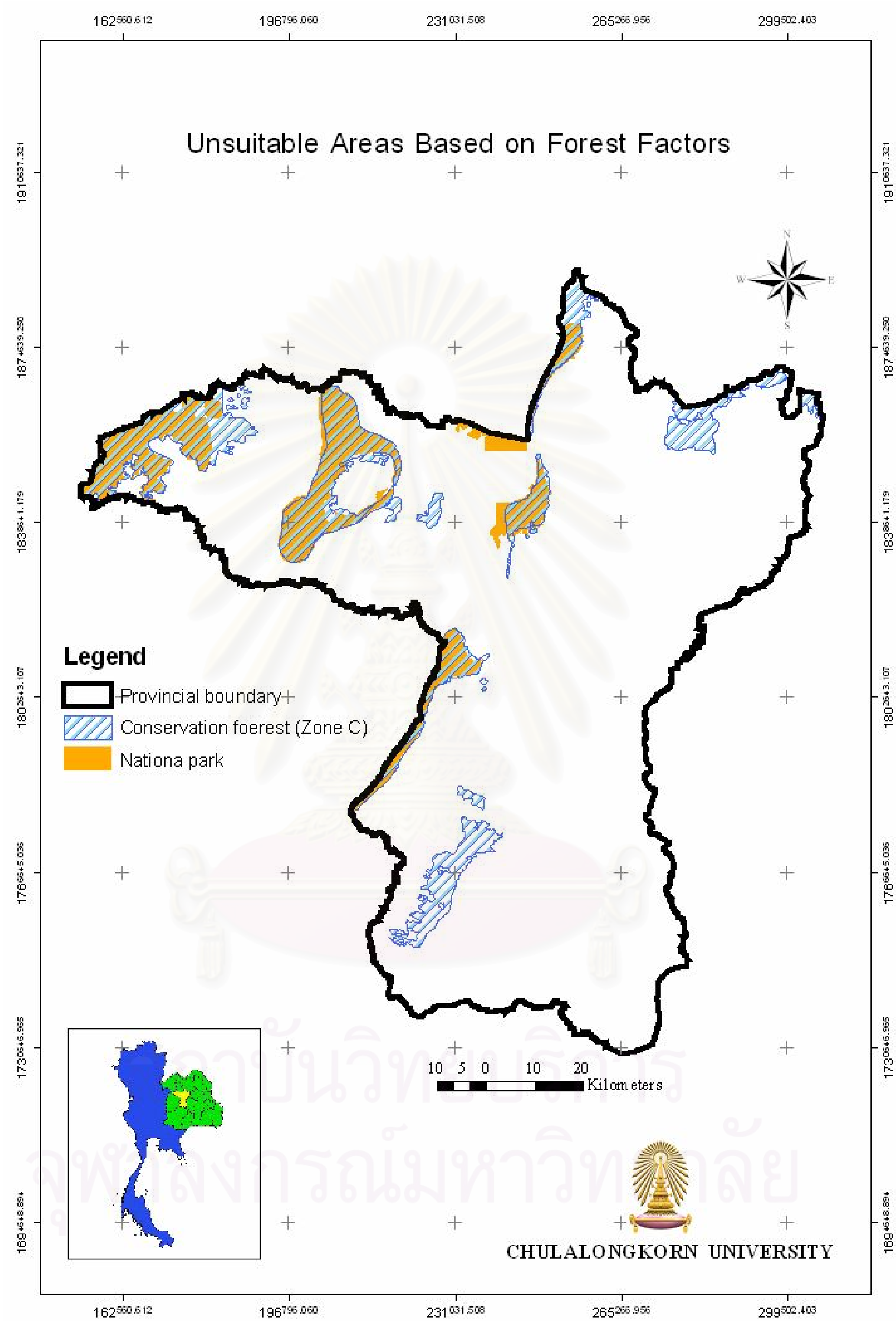

Figure 4.18 Unsuitable areas for secured landfills based on forest factor.

4.3.2.2 Economic factors

1) Major highway

Major highways were selected from the road feature and one hundred meters and ten thousand meters of buffer around major highways were created. Then those buffer areas were erased from the provincial boundary feature to obtain areas which are closed to major road more than 100 meters and far from major road more than 10,000 meters.

2) Airport

Airports were selected from the land use feature and five hundred meter buffer was created.

The extracted areas from the major road feature and airports with 5,000 meter buffer were then grouped together as shown in Figure 4.19

4.3.2.3 Social factors

1) Communities and residential areas

Communities and residential areas were defined as: city town and commercial land, factories, institutions, and built-ups areas. These areas were selected from the land use feature. Then a 2,500 meter buffer of communities and residential areas and of villages was created instead of 3,000 meter buffer because the 3,000 meter buffer excluded all areas in the province. It means that based on the 3,000 meter buffer of communities and residential areas, all areas of the province were rejected to be secured landfill sites. Thus a 2,500 meters buffer was applied.

2) Historical sites or ancient monuments

A one hundred meter buffer was created around historical sites. The Historical sites and their buffer were then grouped with communities and residential areas and their buffer as shown in Figure 4.20.

Each unsuitable area derived from five factors (water, soil, forest, economic and social factors) were grouped to identify total unsuitable areas for secured landfill sites of Khon Kaen Province. The total unsuitable areas are illustrated in Figure 4.21.

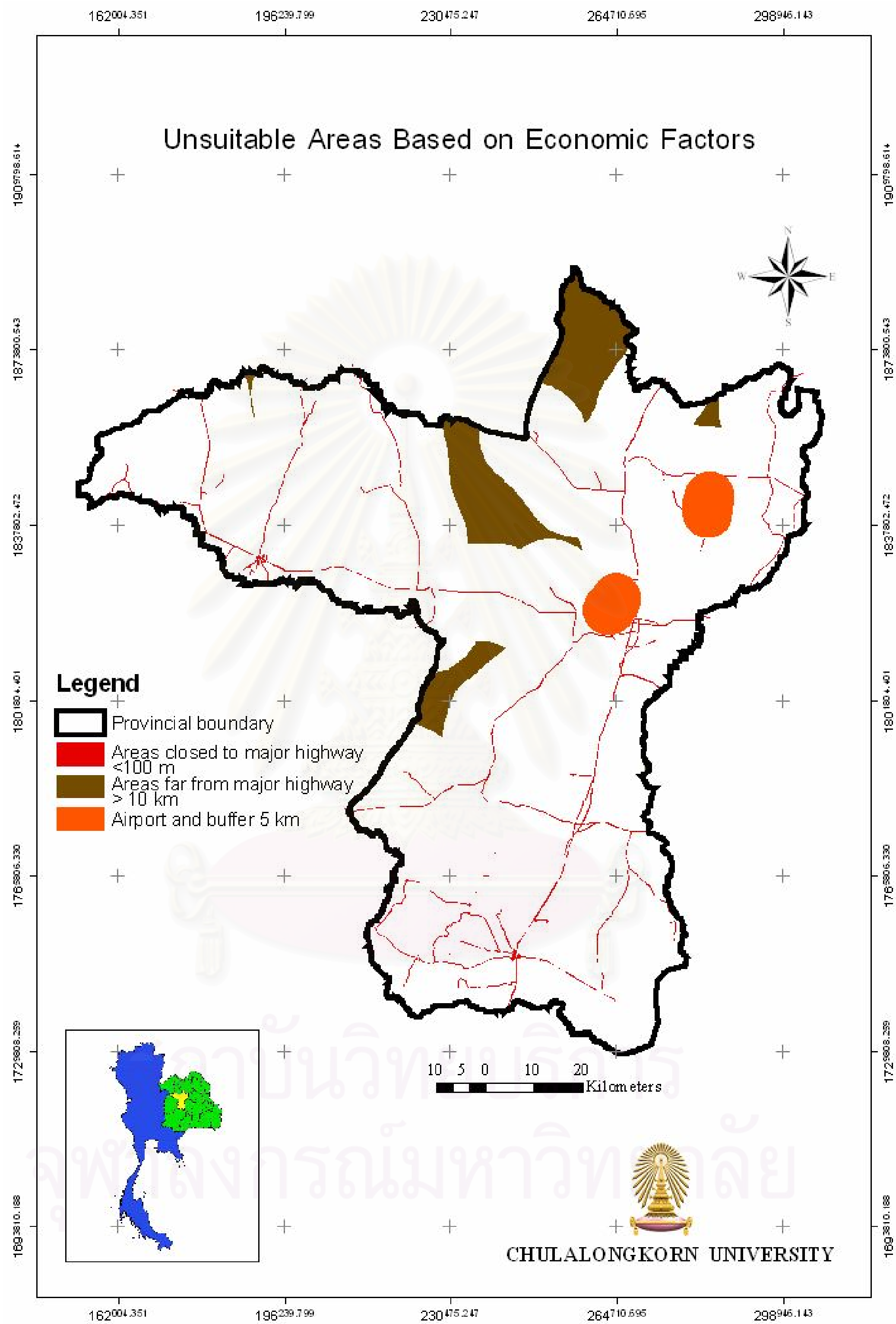

Figure 4.19 Unsuitable areas for secured landfills based on economic factor.

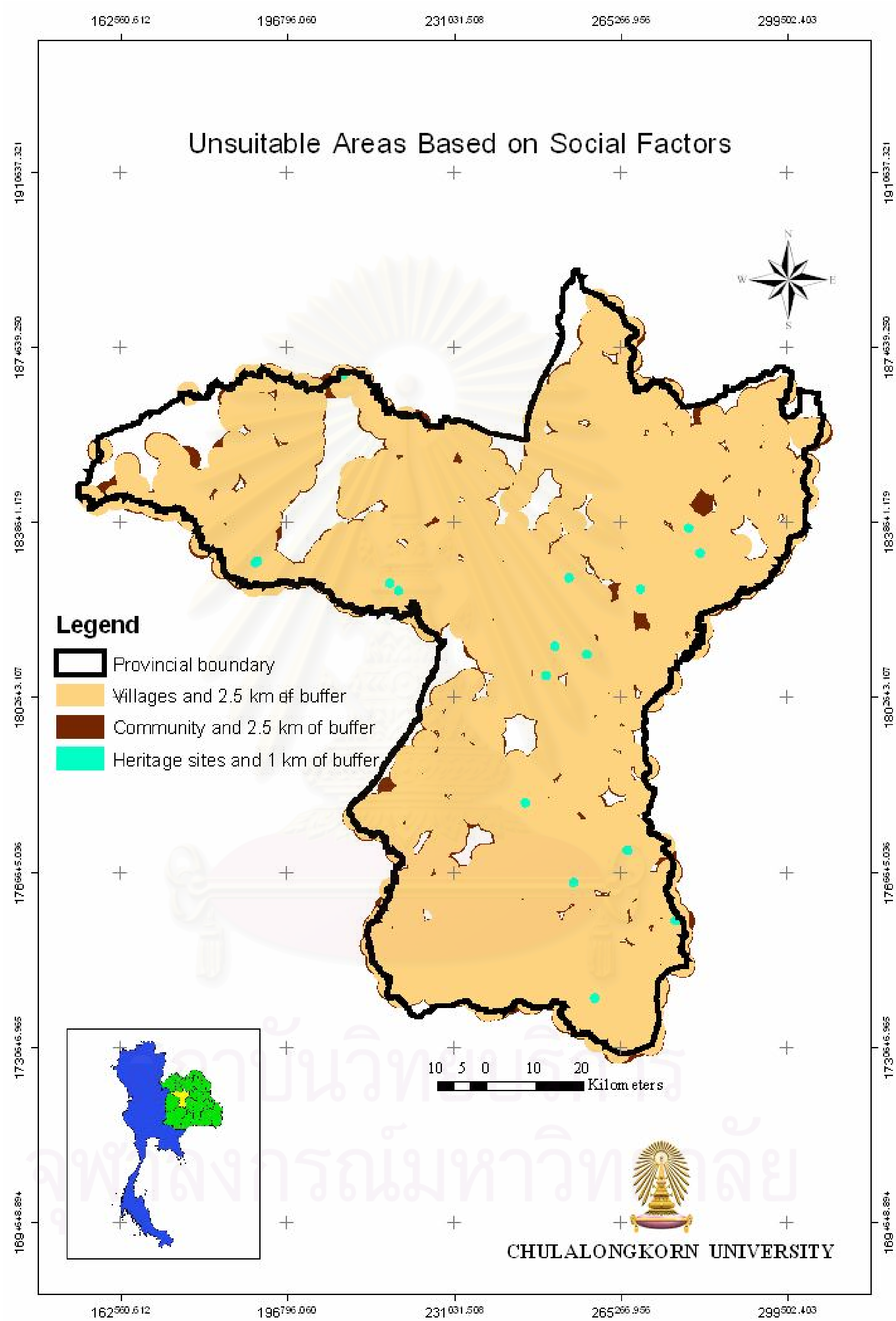

Figure 4.20 Unsuitable areas for secured landfills based on social factor.

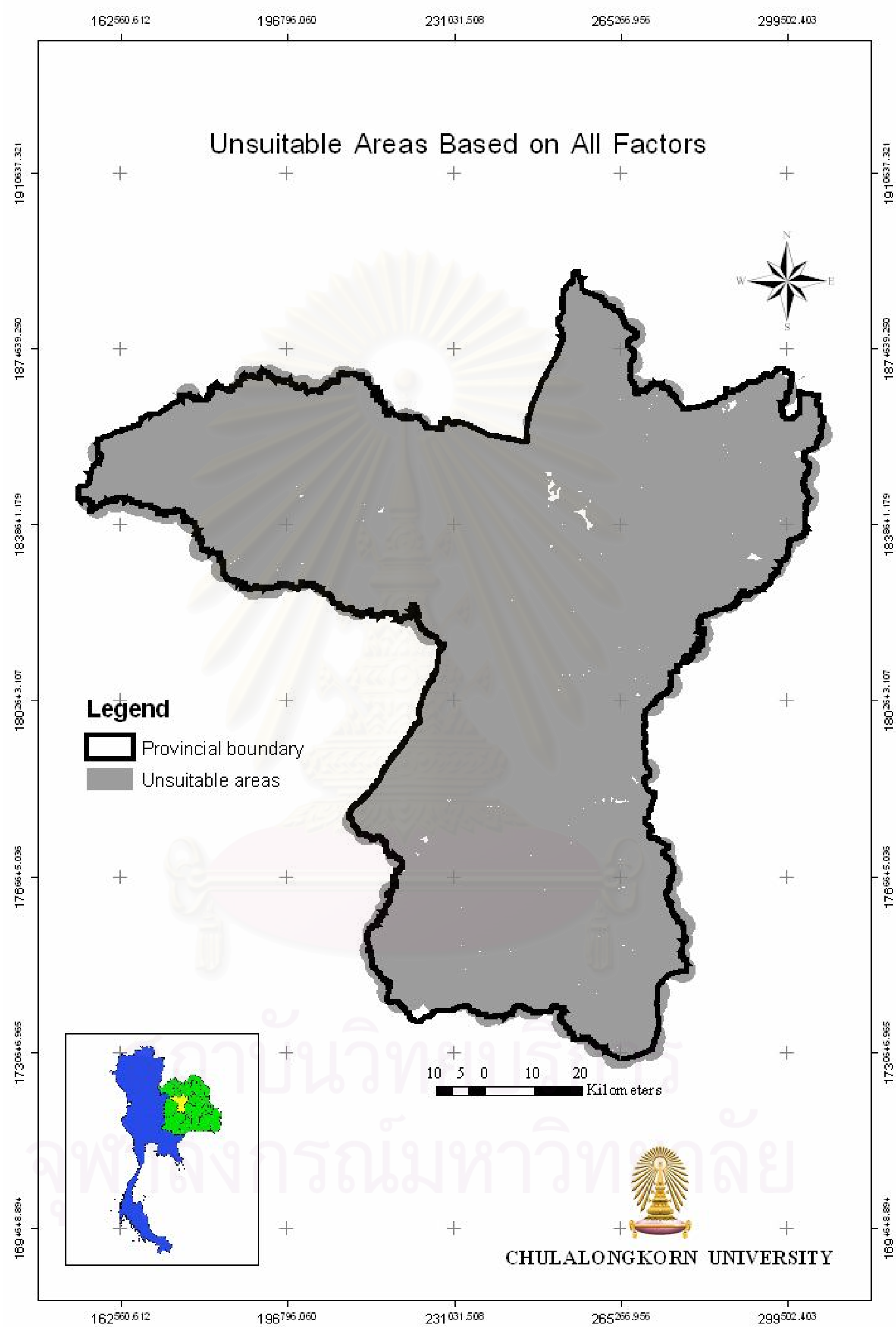

Figure 4.21 Unsuitable areas for secured landfills of Khon Kaen Province.

4.3.3 Identification of Potential areas for secured landfill sites

After the models were run to screen the unsuitable areas, potential areas for secured landfill sites were identified by running the potential areas model. The results indicated that there were one hundred and nine sites with areas of 0.193157 to 9,116,304.6 m^2. Figure 4.22 represents potential areas for secured landfill sites in Khon Kaen Province.

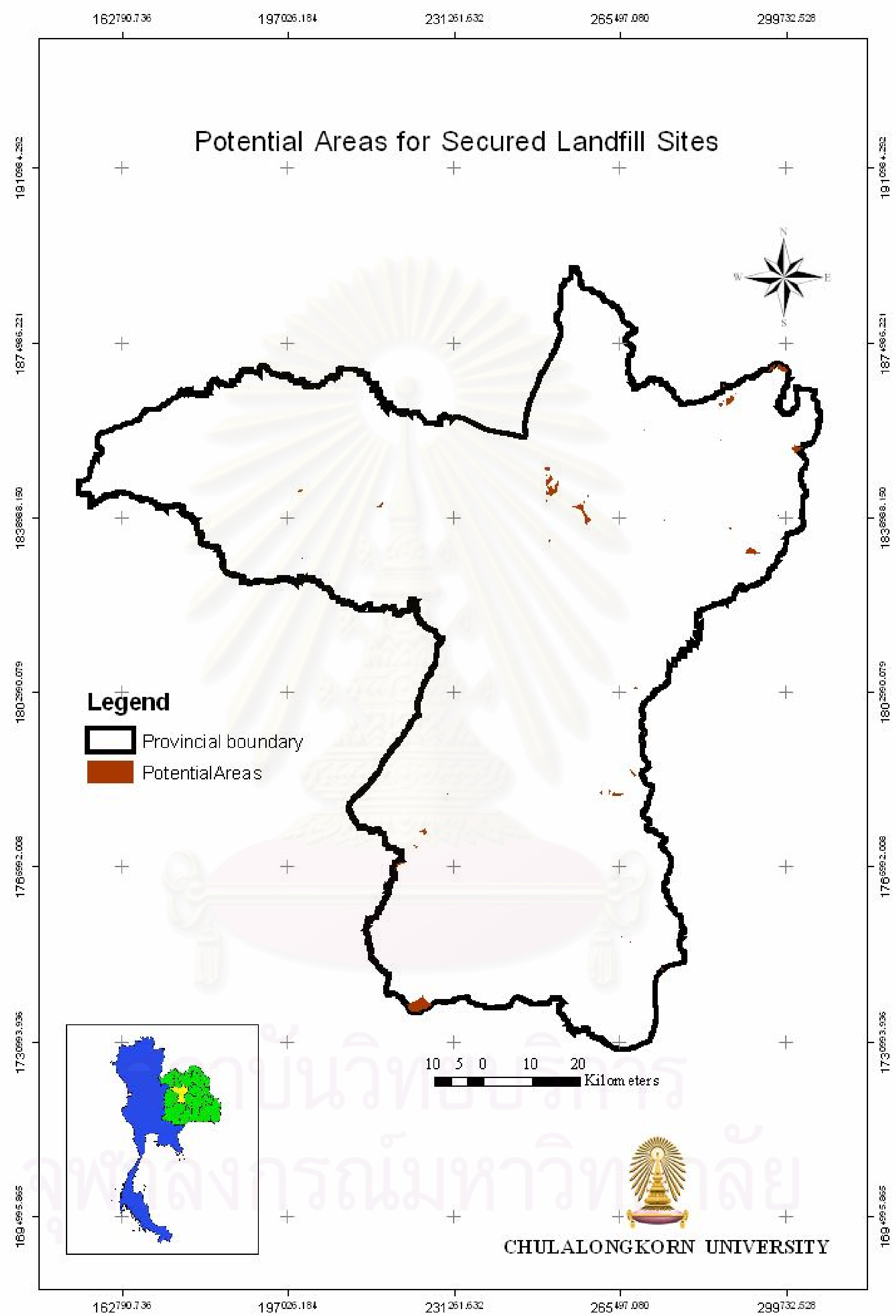

Figure 4.22 Potential areas for secured landfill sites of Khon Kaen Province.

4.3.4 Identification of Candidate sites for secured landfill

The system calculated the appropriate size of secured landfill site. The calculated result (Table 4.4) was used as an input to GIS analysis to identify the candidate sites for secured landfill. The results of GIS analysis indicated that there were eleven candidate sites for secured landfill in Khon Kaen province as presented in Figure 4.23.

Table 4.4 Calculation of secured landfill's size.

INPUT	**Value**	**Unit**
Number of population	1,767,643	person
Hazardous waste generation rate	0.04	kilogram/person/day
Waste density	450	kilogram/cubic meter
Hazardous waste volume		
= 1,767,643 x 0.04 x 450	57,350.20	cubic meter/year
Trench life	20	year
Trench dimensions		
wide	15	meter
deep	3	meter
long	65	meter
Trench spacing	3	meter
Buffer from usable filling areas to property line	50	meter
SOLUTIONS	**Values**	**Units**
Trench volume needed		
= 57,350.20 x 20	1,147,003.90	cubic meter
Number of trenches needed		
= (1,147,003.90)/ (15 x 3 x 65)	392.14	trenches
Usable areas needed		
= (15+3) x (65+4) x 392.14	479,977.02	square meter
= (Square root of 479,977.02) x (Square root of 479,977.02)	692.8 x 692.8	square meter

Table 4.4 Calculation of secured landfill's size (continued).

SOLUTIONS	Values	Units
Usable areas and buffer Areas		
= [692.8 + (2x50)] x [692.8 + (2x50)]	628,537.76	square meter
Areas for access road, dumping pad and miscellaneous uses (25% of Usable areas and buffer Areas)		
= 628,537.76 x 0.25	157,134.44	square meter
Minimum Gross Areas Required		
= 628,537.76 + 157,134.44	785,672.21	square meter
= 785,672.21 / 1,600	491.05	rai

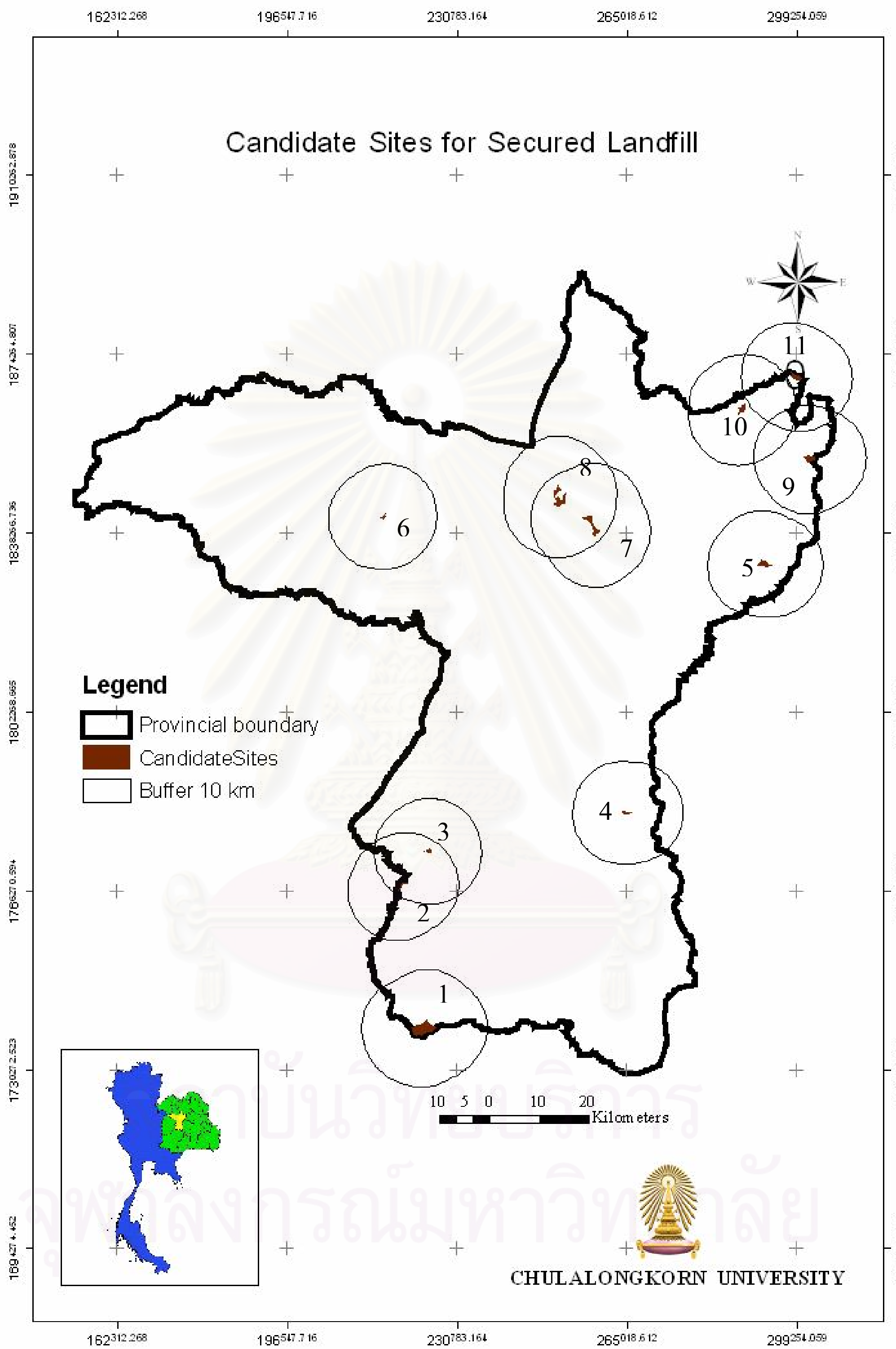

Figure 4.23 Candidate sites for secured landfill of Khon Kaen Province.

4.3.5 Field investigation of candidate sites

Field survey of the candidate sites were conducted to investigate the characteristics of the sites such as existing land use, access road, and surrounding communities. The investigated results present that land use conditions of candidate sites conformed to GIS data in this study. The survey results are depicted in Table 4.5 and Figure 4.24.

Table 4.5 Characteristics of candidate sites from field surveys.

Site	Land use	Access road	Location
1	Paddy field, grass	non-asphalt road	Tambon Tawad, Amphoe Wang Noi
2	Paddy field, grass	non-asphalt road	Tambon Non Sa-at, Amphoe Wang Yai
3	Paddy field, grass	non-asphalt road	Tambon Pho chai, King Amphoe Kok Pho Chai
4	Field crops: cassava, sugar cane	non-asphalt road	Tambon Phulek, Amphoe Banphai
5	Field crops: cassava, sugar cane,	non-asphalt road	Tambon Ban Non, Amphoe Sam Sung
6	Paddy field, forest	non-asphalt road	Tambon Song Pluai, Tambon Nachum Saeng Amphoe Phu Wiang
7	Field crops: cassava Paddy field	non-asphalt road	Tambon Muang Wan, Amphoe Nam Phong, Tambon, Khok sonk Amphoe Ubonrat Tambon Ban Kho, Amphoe Muang
8	Field crops: cassava, sugar cane, rubber tree	non-asphalt road	Tambon Khok Song, Amphoe Ubonrat

Table 4.5 Characteristics of candidate sites from field surveys (continued).

Site	Land use	Access road	Location
9	Field crops: cassava, sugar cane	non-asphalt road	Tambon Dunsai, Amphoe Kranuan
10	Field crops: cassava, sugar cane Paddy field	non-asphalt road	Tambon Hau na kham, Amphoe Kranuan Tambon Na Ngoen, Amphoe Nam Phong
11	Forest Field crops: sugar cane Paddy field	non-asphalt road	Tambon Hau Na Kham, Amphoe Kranuan

Notably, this study employed the high risk areas of flood instead of flood prone areas in the screening process of unsuitable areas. Therefore, the paddy fields were found at sites 1, 2, 3, 6, 7, 10 and 11. It is recommended that the GIS data of flood prone should be taken as the priority rather than the GIS data of flood risk areas in this process.

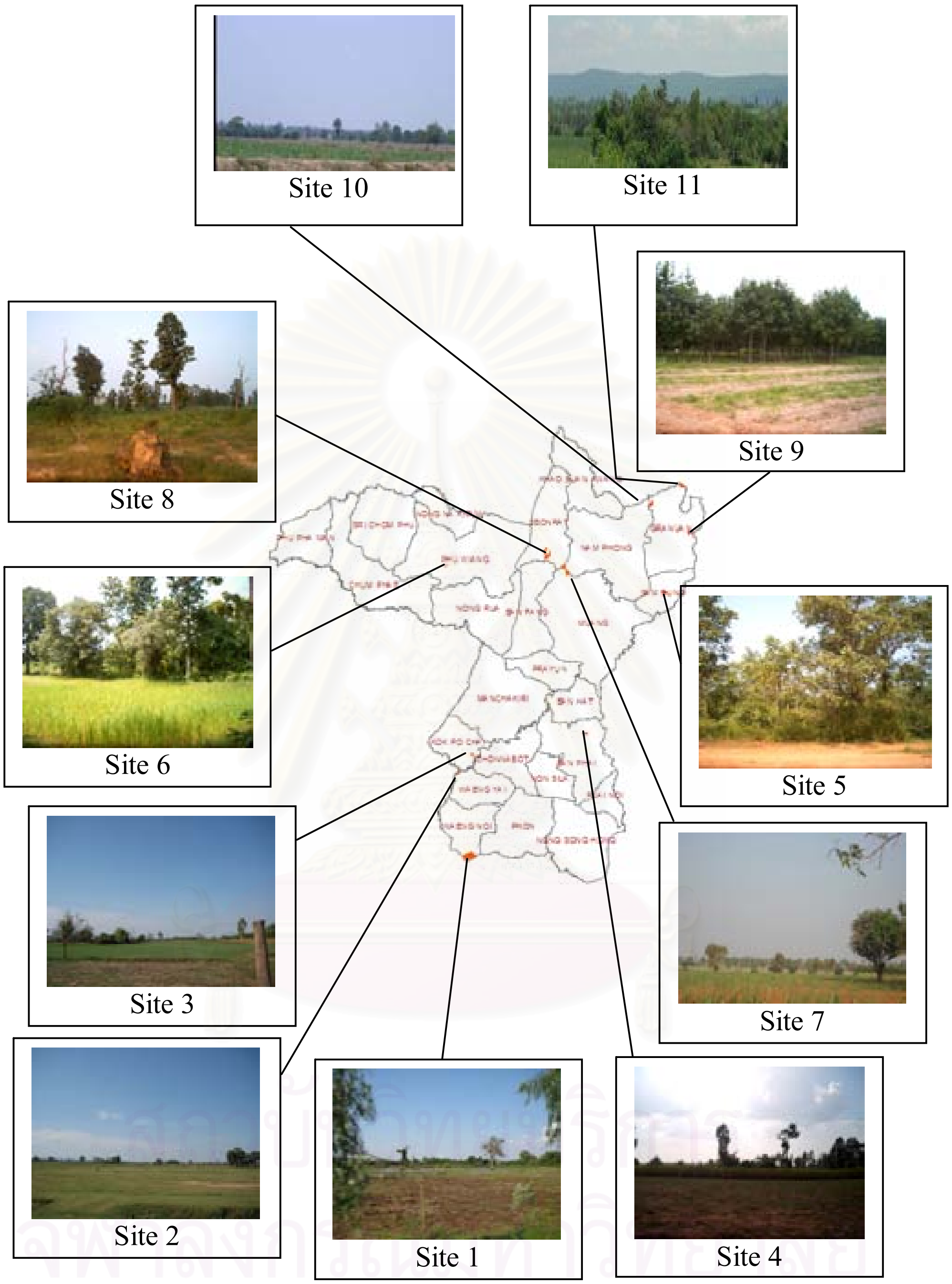

Figure 4.24 Existing conditions of candidate sites.

4.3.6 Candidate sites ranking

4.3.6.1 Characterization of candidate sites

By ArcMap, the candidate sites were characterized based on the factors (eg. distance from the nearest water resource) derived from the considered criteria (eg. water resource) used in the screening process. There were thirteen factors used for ranking candidate sites, which are as follows.

- Number of water well within 10 km – buffer distance of 10 km around candidate sites was built. Then the well feature was intersected with this buffer feature to get a number of water wells within 10 km.
- Distance to the nearest water well (km) – The near tool was used to compute the distance to the nearest well within the maximum search radius.
- Major watershed classification – Watershed classification feature was intersected with the candidate sites. Then area values of each watershed classification area in the candidate sites were calculated by using a calculate areas tool. The watershed classification with the largest areas was the major watershed classification.
- Average depth to water table (m) – Groundwater contour feature was intersected with the candidate sites to characterize groundwater contour in the candidate sites, and calculate the average depth of water table of the candidate sites.
- Groundwater yields (m^3/hour) - Aquifer feature was intersected with candidate sites to characterize groundwater yields in the candidate sites, and identify the highest groundwater yields of the candidate sites.
- Groundwater quality (TDS, mg/l) - Aquifer feature was intersected with candidate sites to characterize groundwater quality in the candidate sites, and identify the maximum total dissolved solids (TDS) in groundwater of the candidate sites.
- Distance to the nearest river (m) - The near tool was used to compute the distance to the nearest river within the maximum search radius.
- Distance to the nearest lake (m) - The near tool was used to compute the distance to the nearest lake within the maximum search radius.
- Major soil group – Soil group feature was intersected with candidate sites. Then the area values of each soil group in the candidate sites were

calculated by using a calculate areas tool. The soil group with the largest area was the major soil group.

- Distance to the nearest major road (km) - Major road was selected from road feature. The near tool was used to compute the distance to the nearest major road within the maximum search radius.
- Major land use – Land use feature was intersected with candidate sites. Then the area values of each land use type in candidate sites were calculated by using the calculate areas tool. The land use type with largest areas was the major land use.
- Number of villages within 10 km – 10 km buffer around candidate sites was built. Then the village feature was intersected with 10 km buffer feature to get the number of villages within 10 km.
- Distance to the nearest village (km) - The near tool was used to compute the distance to the nearest village within the maximum search radius.

After that, ArcMap models automated on GIS analysis and provided the characteristics of each candidate site based on the thirteen factors.

4.3.6.2 Import NRD2c data

On the ArcCatalog, NRD2c data in the year 2007 of Khon Kaen Province was copied into the folder, namely Khon Kaen, through the copy NRD2c data model. Then, NRD2c data was modified through the modify NRD2c data model for deleting unwanted data and keeping only variables number Q1_3_1 and Q45_1b which are variables of number of population and employment rate, respectively. Employment rate data was subtracted from one hundred to get unemployed rate. The modified NRD2c data was combined with the village within buffer of 10 km feature to obtain the unemployed rate and number of population within 10 km.

Characteristics of candidate sites based on thirteen factors from GIS data and two factors from NRD2c are shown in Table 4.6.

Table 4.6 Characteristics of candidate sites based on fifteen factors.

Factor/ Candidate site	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
1. Number of water well within 10 km	19	29	45	68	32	80	26	19	20	19	6
2. Distance to the nearest water well (m)	4,585	3,363	3,288	3,341	2,312	3,165	3,241	4,088	2,730	3,964	4,935
3. Major watershed classification	5B	5B	5B	4B	4B	4A	4B	4B	4B	4B	5B
4. Average depth to Groundwater table (m)	4.1	5.375	3.5	7.75	2.75	4.875	4.375	7.125	5.75	5.25	4
5. Groundwater yields (m3/hour)	<2	2-10	2-10	<2	<2	<2	<2	<2	<2	<2	<2
6. Groundwater quality (TDS, mg/l)	>1,500	>1,500	>1,500	<750	<750	<750	<750	<750	<750	<750	<750
7. Distance to the nearest river (m)	2,374.7	498.3	1,281.4	1,257.8	5,086.0	1,333.6	1,037.0	796.7	1,054.9	876.5	1,216.1
8. Distance to the nearest lake (m)	601.9	548.6	770.8	3,256.2	1,913.9	1,257.9	746.9	2,829.5	818.2	435.1	3,211.0
9. Major soil group	18	4	4	41	36	36	41	36	36	36	36
10. Distance to the nearest major road (m)	5,494.5	2,934.8	5,881.7	5,782.0	3,591.3	3,857.4	4,354.0	4,142.6	5,129.5	7,592.3	1,995.8
11. Major land use	Paddy field	Paddy field	Paddy field	Field crops	Forest	Grass	Field crops	Field crops	Field crops	Field crops	Field crops
12. Number of village within 10 km	40	38	48	46	49	93	63	55	38	30	14
13. Distance to the nearest village (m)	3,714.4	2,870.7	2,941.0	3,018.8	3,350.4	2,898.1	3,025.4	3,354.6	3,158.6	3,379.4	3,147.4
14. NRD2c data: unemployed rate within 10 km	13.18	10.89	9.57	20.81	38.31	5.79	11.03	10.85	0.10	8.62	8.33
15. NRD2c data: Number of population within 10 km	14,530	17,422	19,507	24,302	21,618	21,368	33,098	24,931	15,170	15,355	6,076

4.3.6.3 Ranking of Candidate sites

In the AHP application, the hierarchical structure for the study was established and the overall objective of the analysis was to identify the preferred site for secured landfill in Khon Kaen Province as shown in Figure 4.25.

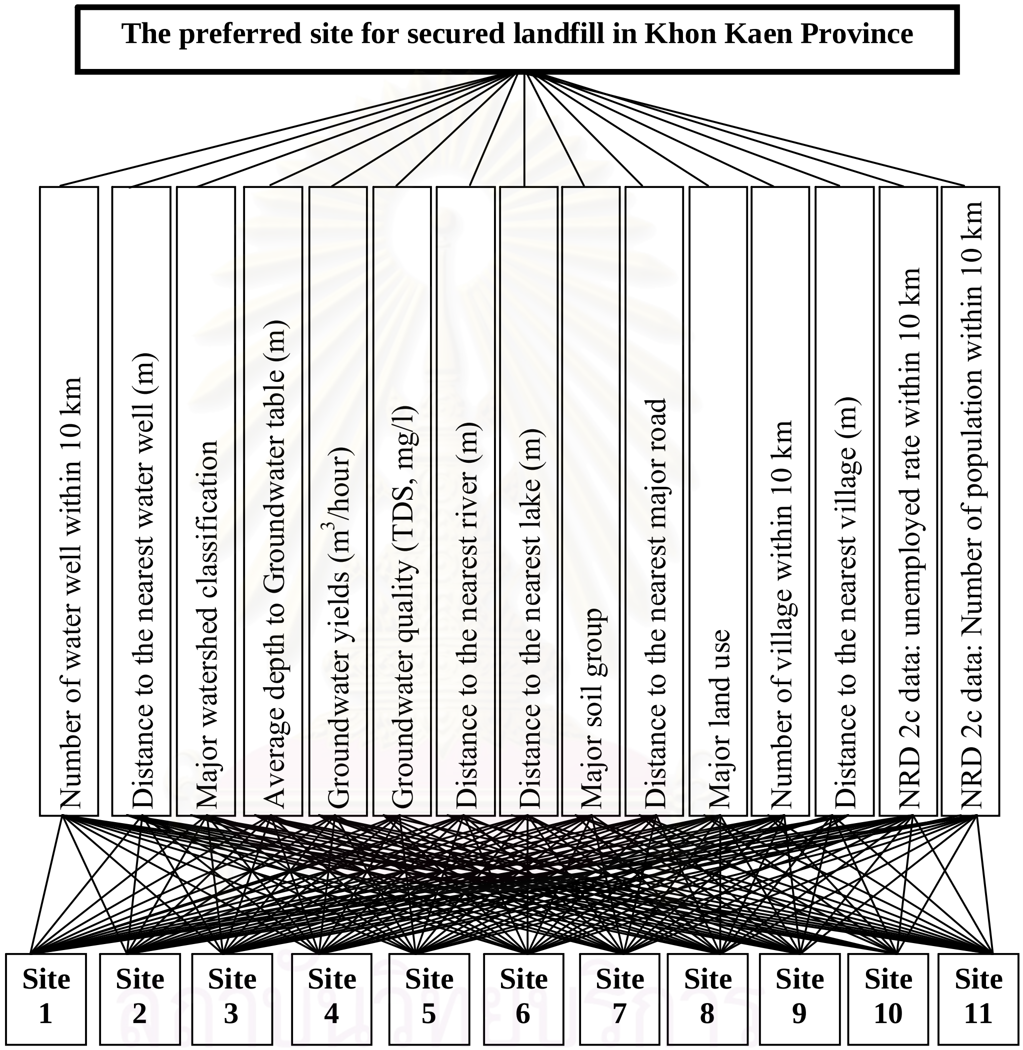

Figure 4.25 Hierarchical structures for the decision problem.

The relative weights of factors were determined by eight environmentalists, six persons from Regional Environmental Office, one person from Provincial Environmental and Natural Resources Office and one person from Local Administrative Organization. The result of determining a pairwise of the relative weights for the fifteen factors with respect to the objective of the analysis is shown in Table 4.7. The entries in Table 4.7 were then normalized to obtain the average rating associated with each factor or the relative weights of factors as shown in the last column of Table 4.8. The relative weight shows that the number of population within 10 km has the highest important rating, 0.183. It means that this factor is considered to be the most important factor in the selection of secured landfill sites. The second important factors are the distance to the nearest river with the relative weight of 0.123. The consistency ratio (C.R.) of this step is 0.029 which is considered as acceptable. The computation of C.R. is presented as below:

C.I. = $(\lambda_{max} - m)/(m-1)$	=	0.0451
Average consistency measure for all alternatives (λ_{max})	=	15.631
Number of element (m)	=	15
the appropriate random index of m (RI)	=	1.56
Consistency ratio (C.R.) = C.I/RI	=	0.029

The relative weights of the candidate sites with respect to each factor were then evaluated by using the similar procedure to the procedure for pairwise comparing the factors. Details of the relative weights of candidate sites with respect to each factor are presented in Appendix C. The overall result of this step is presented in Table 4.9, of which all consistency ratios are considered as acceptable. The relative weight shown in Table 4.7 were combined with the relative weight of the candidate sites in Table 4.9 to obtain the overall relative weights of the candidate sites as shown in Table 4.10. The overall weighted evaluation (α_j) in Table 4.10 and Figure 4.26 show that the sites ranked 1 to 5 with high weight rating were sites 3, 2, 1, 11 and 4, respectively.

Table 4.7 Matrix of pair-wise comparisons of the fifteen factors.

Factors	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Factor 12	Factor 13	Factor 14	Factor 15
Factors 1	1.00	0.24	0.48	0.21	0.28	0.21	0.19	0.21	0.35	1.07	0.35	0.44	0.31	0.95	0.20
Factor 2	4.13	1.00	2.10	0.46	0.69	0.48	0.40	0.48	2.47	3.21	1.10	0.94	0.70	1.96	0.34
Factor 3	2.08	0.48	1.00	0.22	0.29	0.27	0.20	0.22	0.41	0.64	0.35	0.35	0.30	0.98	0.18
Factor 4	4.88	2.19	4.63	1.00	2.00	1.32	0.66	0.77	2.09	4.25	2.64	2.53	1.41	1.95	0.45
Factor 5	3.63	1.46	3.50	0.50	1.00	0.50	0.32	0.46	2.18	2.82	3.12	2.29	1.17	1.87	0.32
Factor 6	4.75	2.06	3.75	0.76	2.00	1.00	0.47	0.55	2.79	4.00	3.12	2.40	1.41	1.99	0.38
Factor 7	5.25	2.50	5.00	1.52	3.13	2.13	1.00	0.86	1.98	3.07	1.73	1.50	0.94	2.30	0.67
Factor 8	4.75	2.10	4.63	1.31	2.19	1.81	1.17	1.00	1.57	3.07	1.34	1.50	0.94	2.30	0.67
Factor 9	2.85	0.40	2.44	0.48	0.46	0.36	0.51	0.64	1.00	2.26	0.44	0.35	0.47	0.67	0.30
Factor 10	0.94	0.31	1.56	0.24	0.35	0.25	0.33	0.33	0.44	1.00	0.40	0.33	0.38	1.09	0.21
Factor 11	2.88	0.91	2.88	0.38	0.32	0.32	0.58	0.75	2.25	2.50	1.00	0.33	0.46	1.10	0.26
Factor 12	2.29	1.07	2.88	0.40	0.44	0.42	0.67	0.67	2.83	3.00	1.59	1.00	0.44	1.21	0.32
Factor 13	3.25	1.44	3.38	0.71	0.85	0.71	1.06	1.06	2.13	2.63	2.17	2.25	1.00	1.21	0.48
Factor 14	1.05	0.51	1.02	0.51	0.53	0.50	0.43	0.43	0.88	0.92	0.91	0.83	0.59	1.00	0.19
Factor 15	5.13	2.97	5.50	2.21	3.13	2.60	1.50	1.50	3.38	4.75	3.88	3.13	2.06	5.38	1.00

Remark:

Factor 1	=	Number of water well within 10 km	Factor 2	=	Distance to the nearest water well (m)
Factor 3	=	Major watershed classification	Factor 4	=	Average depth to water table (m)
Factor 5	=	Groundwater yields (m^3/hour)	Factor 6	=	Groundwater quality (TDS, mg/l)
Factor 7	=	Distance to the nearest river (m)	Factor 8	=	Distance to the nearest lake (m)
Factor 9	=	Major soil group	Factor 10	=	Distance to the nearest major road (m)
Factor 11	=	Major land use	Factor 12	=	Number of village within 10 km
Factor 13	=	Distance to the nearest village (m)	Factor 14	=	NRD2c data: unemployed rate within 10 km
Factor 15	=	NRD2c data: Number of population within 10 km			

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Table 4.8 Normalized AHP matrix of paired comparisons of the fifteen factors.

Factors	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Factor 12	Factor 13	Factor 14	Factor 15	Row Sum	Row Average (relative weights of factors)
Factors 1	0.020	0.012	0.011	0.019	0.016	0.016	0.020	0.021	0.013	0.027	0.014	0.022	0.024	0.037	0.033	0.306	0.024
Factor 2	0.084	0.051	0.047	0.042	0.039	0.038	0.042	0.048	0.092	0.082	0.046	0.047	0.055	0.076	0.057	0.845	0.065
Factor 3	0.043	0.024	0.022	0.020	0.016	0.021	0.021	0.022	0.015	0.016	0.014	0.017	0.024	0.038	0.031	0.344	0.026
Factor 4	0.100	0.111	0.103	0.092	0.113	0.102	0.069	0.077	0.078	0.108	0.109	0.125	0.112	0.075	0.076	1.453	0.112
Factor 5	0.074	0.074	0.078	0.046	0.057	0.039	0.034	0.046	0.082	0.072	0.129	0.113	0.093	0.072	0.054	1.063	0.082
Factor 6	0.097	0.105	0.084	0.070	0.113	0.078	0.050	0.056	0.104	0.102	0.129	0.119	0.112	0.077	0.064	1.360	0.105
Factor 7	0.107	0.127	0.112	0.140	0.177	0.165	0.106	0.087	0.074	0.078	0.072	0.074	0.075	0.089	0.112	1.595	0.123
Factor 8	0.097	0.107	0.103	0.120	0.124	0.141	0.123	0.101	0.059	0.078	0.055	0.074	0.075	0.089	0.112	1.459	0.112
Factor 9	0.058	0.021	0.055	0.044	0.026	0.028	0.053	0.064	0.037	0.058	0.018	0.018	0.037	0.026	0.050	0.593	0.046
Factor 10	0.019	0.016	0.035	0.022	0.020	0.019	0.034	0.033	0.017	0.026	0.017	0.017	0.030	0.042	0.035	0.381	0.029
Factor 11	0.059	0.046	0.064	0.035	0.018	0.025	0.061	0.076	0.084	0.064	0.041	0.017	0.037	0.042	0.043	0.712	0.055
Factor 12	0.047	0.054	0.064	0.036	0.025	0.032	0.070	0.067	0.106	0.077	0.066	0.050	0.035	0.047	0.054	0.830	0.064
Factor 13	0.067	0.073	0.075	0.065	0.048	0.055	0.112	0.107	0.079	0.067	0.090	0.112	0.079	0.047	0.081	1.158	0.089
Factor 14	0.021	0.026	0.023	0.047	0.030	0.039	0.046	0.044	0.033	0.023	0.038	0.041	0.047	0.039	0.031	0.528	0.041
Factor 15	0.105	0.151	0.123	0.203	0.177	0.202	0.158	0.151	0.126	0.121	0.161	0.155	0.164	0.207	0.168	2.373	0.183
Column Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	15.00	1.00

Consistency Ratio (C.R.) = 0.029

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Table 4.9 Relative weights of the candidate sites with respect to each factor.

Candidate site	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Factor 12	Factor 13	Factor 14	Factor 15
Site 1	0.124	0.153	0.131	0.051	0.096	0.199	0.172	0.030	0.111	0.091	0.028	0.078	0.128	0.074	0.0905
Site 2	0.064	0.068	0.128	0.078	0.032	0.199	0.020	0.028	0.225	0.043	0.029	0.091	0.053	0.075	0.1009
Site 3	0.030	0.068	0.136	0.039	0.032	0.199	0.074	0.034	0.243	0.096	0.029	0.061	0.056	0.073	0.0721
Site 4	0.020	0.068	0.068	0.201	0.105	0.050	0.073	0.240	0.078	0.097	0.108	0.050	0.072	0.133	0.0419
Site 5	0.053	0.029	0.070	0.029	0.105	0.050	0.327	0.105	0.038	0.055	0.043	0.045	0.117	0.236	0.0464
Site 6	0.015	0.063	0.046	0.065	0.105	0.050	0.074	0.087	0.039	0.057	0.198	0.033	0.057	0.071	0.0397
Site 7	0.071	0.070	0.072	0.061	0.105	0.050	0.057	0.032	0.080	0.076	0.113	0.040	0.077	0.075	0.0299
Site 8	0.124	0.123	0.072	0.206	0.105	0.050	0.032	0.173	0.064	0.076	0.113	0.062	0.120	0.075	0.048
Site 9	0.122	0.032	0.072	0.108	0.105	0.050	0.057	0.036	0.040	0.108	0.113	0.113	0.094	0.051	0.1225
Site 10	0.124	0.097	0.072	0.100	0.105	0.050	0.033	0.024	0.040	0.244	0.113	0.185	0.128	0.068	0.1388
Site 11	0.252	0.227	0.134	0.061	0.105	0.050	0.081	0.212	0.040	0.057	0.113	0.242	0.099	0.070	0.2692
C.R.	**0.037**	**0.005**	**0.005**	**0.011**	**0.003**	**0.000**	**0.026**	**0.027**	**0.009**	**0.034**	**0.003**	**0.024**	**0.006**	**0.012**	**0.017**

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Table 4.10 Final AHP analysis for decision.

Candidate site	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Factor 12	Factor 13	Factor 14	Factor 15	overall weighted evaluation (α_j)
Site 1	0.003	0.010	0.003	0.006	0.008	0.021	0.021	0.003	0.111	0.003	0.002	0.005	0.011	0.003	0.017	0.226
Site 2	0.002	0.004	0.003	0.009	0.003	0.021	0.002	0.003	0.225	0.001	0.002	0.006	0.005	0.003	0.018	0.307
Site 3	0.001	0.004	0.004	0.004	0.003	0.021	0.009	0.004	0.243	0.003	0.002	0.004	0.005	0.003	0.013	0.322
Site 4	0.000	0.004	0.002	0.022	0.009	0.005	0.009	0.027	0.078	0.003	0.006	0.003	0.006	0.005	0.008	0.188
Site 5	0.001	0.002	0.002	0.003	0.009	0.005	0.040	0.012	0.038	0.002	0.002	0.003	0.010	0.010	0.008	0.148
Site 6	0.000	0.004	0.001	0.007	0.009	0.005	0.009	0.010	0.039	0.002	0.011	0.002	0.005	0.003	0.007	0.114
Site 7	0.002	0.005	0.002	0.007	0.009	0.005	0.007	0.004	0.080	0.002	0.006	0.003	0.007	0.003	0.005	0.146
Site 8	0.003	0.008	0.002	0.023	0.009	0.005	0.004	0.019	0.064	0.002	0.006	0.004	0.011	0.003	0.009	0.172
Site 9	0.003	0.002	0.002	0.012	0.009	0.005	0.007	0.004	0.040	0.003	0.006	0.007	0.008	0.002	0.022	0.133
Site 10	0.003	0.006	0.002	0.011	0.009	0.005	0.004	0.003	0.040	0.007	0.006	0.012	0.011	0.003	0.025	0.148
Site 11	0.006	0.015	0.004	0.007	0.009	0.005	0.010	0.024	0.040	0.002	0.006	0.015	0.009	0.003	0.049	0.203

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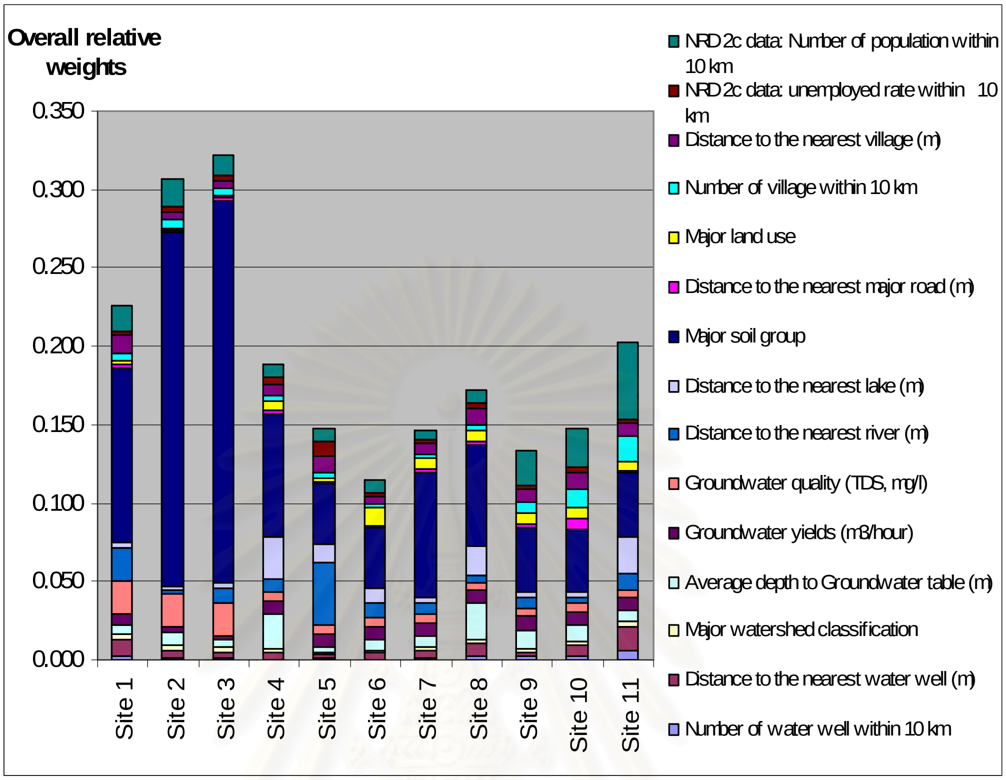

Figure 4.26 Histogram of overall weights of eleven candidate sites.

According to the weight rating, site 3 with the highest weight rating, 0.322 should be selected as the preferred site for secured landfill. However, it was found that site 3 and site 2 were surrounded by swamps and the main river, the Chi River, as shown in Figures 4.27 and 4.28, respectively. The boundary of site 1 and site 11 were closed to Chaiyaphum Province and Kalasin Province, respectively. This means that the data of characteristics of these sites in Chaiyaphum Province and Kalasin Province were missing (Figure 4.29 and Figure 4.30) due to only the GIS data of Khon Kaen Province was used in this study. The discussion between eight environmentalists who determined the relative weights about the ranking of candidate sites was conducted. Based on the discussion, site 4 was then selected as the preferred for secured landfill of Khon Kaen Province.

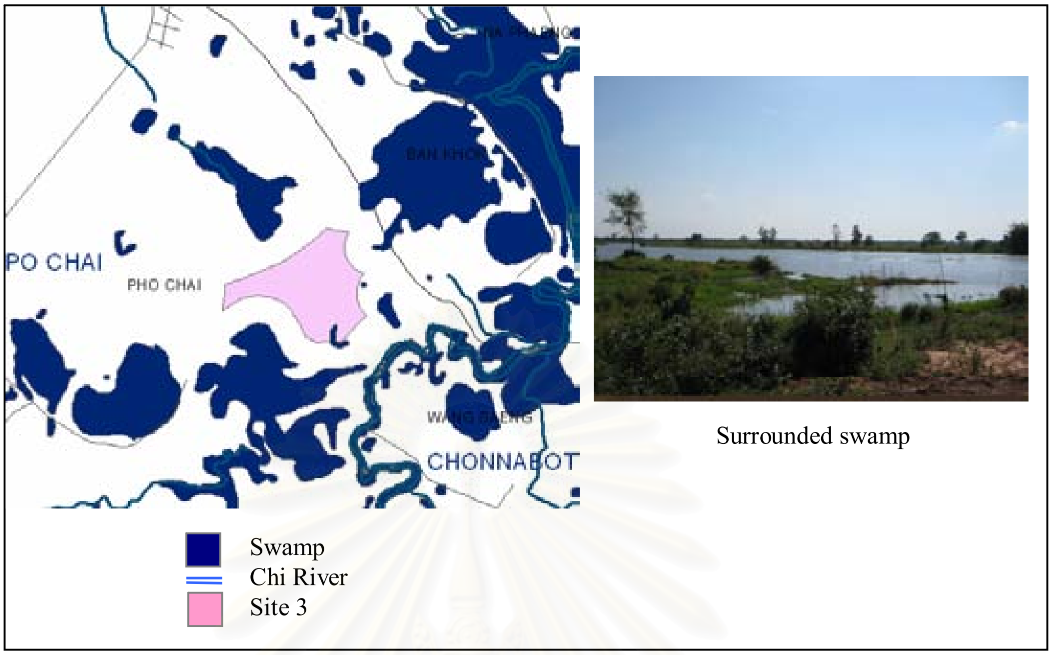

Figure 4.27 Site 3 and surrounded areas.

Figure 4.28 Site 2 and surrounded areas.

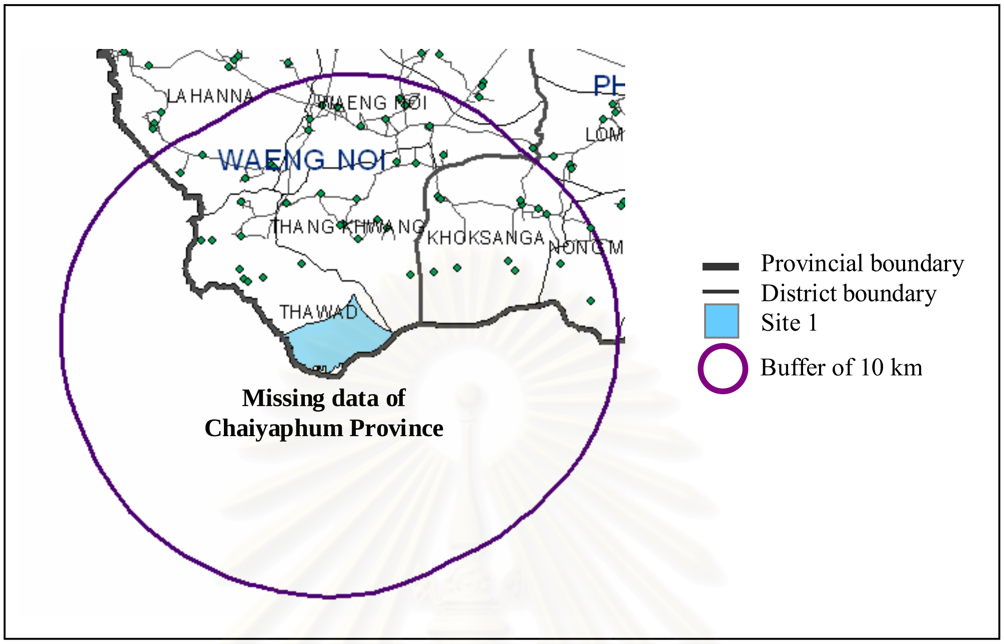

Figure 4.29 Site 1 and 10 km buffer.

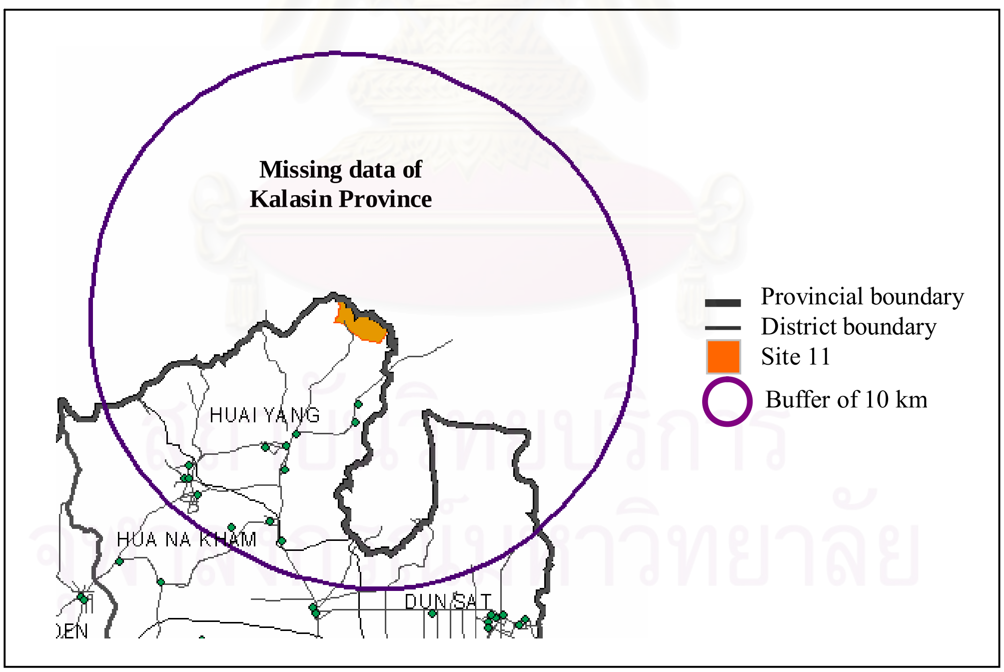

Figure 4.30 Site11 and 10 km buffer.

Even almost factors used in this study have ratio values such as number of villages, population, distance to the environmental receptors, some factors are still not objective in ranking within the factors such as land use, soil group, watershed, etc. It is likely limited to assess site by comparing all factors objectively. Therefore, this research aims at using expertise of local stakeholders and knowledgeable people. For this case, AHP was chosen to apply for the model because the whole process can be repeated and revised, until all participants satisfied and consistency of all opinion can be checked. The stakeholder are chosen based on their expertise and/or are responsible to solid and hazardous waste management. Beside, this AHP process can enhance participation of the stakeholders.

In addition, it should be noted that the relative weight determiners in this study were environmentalists and some of them might not have experiences in siting of secured landfill. However, this group was trained properly before performing in weighting and scoring.

4.3.7 Planning maps

The preferred site was then visualized in two and three dimensions in order to present the characteristics of the site and surrounding areas within 5 kilometers as shown in Figures 4.31 and 4.32, respectively.

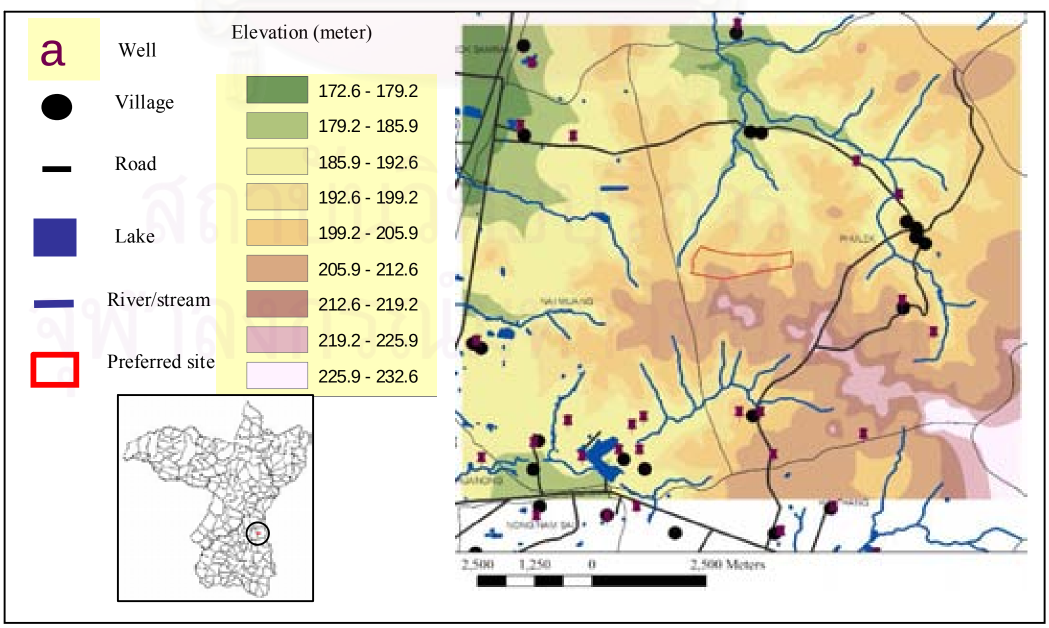

Figure 4.31 Two-dimensional map of preferred site (Site 4).

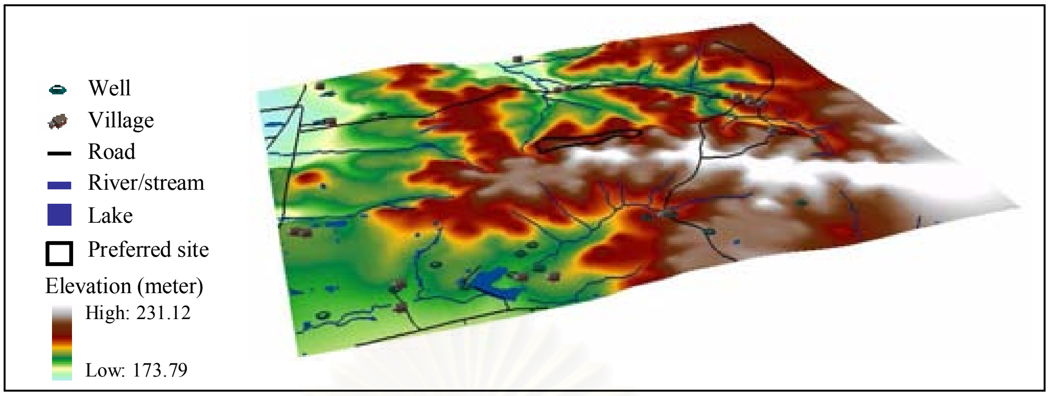

Figure 4.32 Three-dimensional map of the preferred site
(the convection factor to place heights is 10).

4.3.8 Result of Visual MODFLOW Model

4.3.8.1 Subsurface of the preferred site

Borelines of the preferred site were created by running Make BoreLines from Wells Tool. The created Borelines are shown in Figure 4.33.

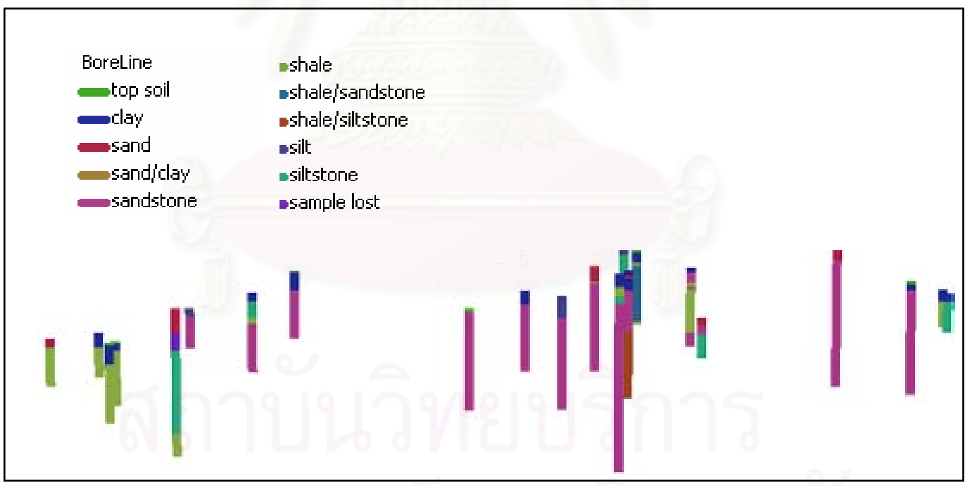

Figure 4.33 Borelines of preferred site.

Then the related BoreLines features were selected and GeoSections were constructed between the BoreLines. Figure 4.34 shows an example of selection line defined by a sequence of wells. From the created GeoSections (Figure 4.35), we can assume that soil layers in the areas could be classified by soil characteristics of 4 layers as shown below:

- Layer 1 is topsoil with about 0.5-1.5 m. thickness.
- Layer 2 is clay with about 1.5- 3 m. thickness.
- Layer 3 is sand with about 2- 6 m. thickness.
- Layer 4 is sandstone with about 25- 38 m. thickness.

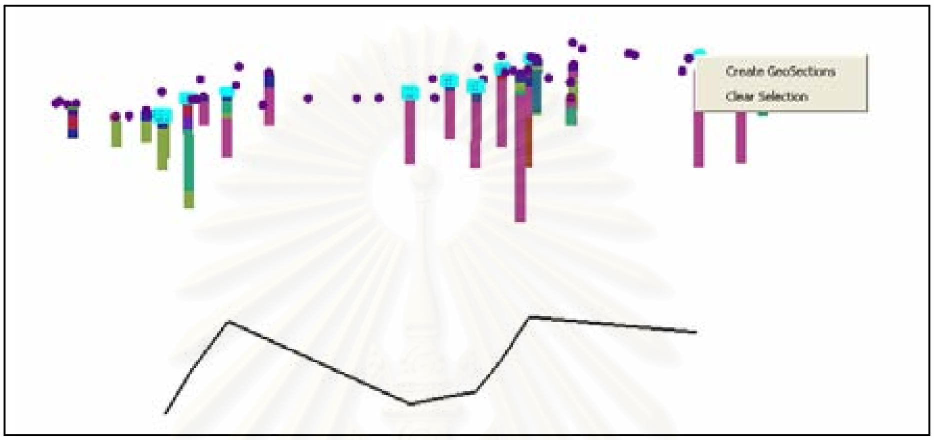

Figure 4.34 Example of selection line defined by a sequence of wells.

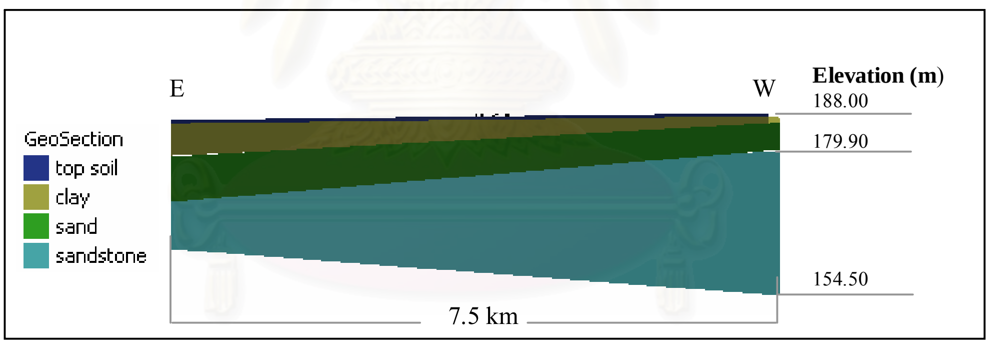

Figure 4.35 GeoSections of the preferred site along E-W direction.

4.3.8.2 Field investigation

Field investigation of the preferred site was conducted to assure that the preferred site has subsurface characteristics that conform to the results from the previous step. The results show that subsurface characteristics of the areas closed to the preferred site conformed to the Geosections as shown in Figure 4.36

Figure 4.36 Soil profile and rock type of the areas closed to the preferred site.

4.3.8.3 Results of Visual MODFLOW model

Boundary map of the preferred site was imported into Visual MODFLOW, the area size, 9.32 ? 12.12 km^2, was divided into 50 columns and 50 rows as shown in Figure 4.37.

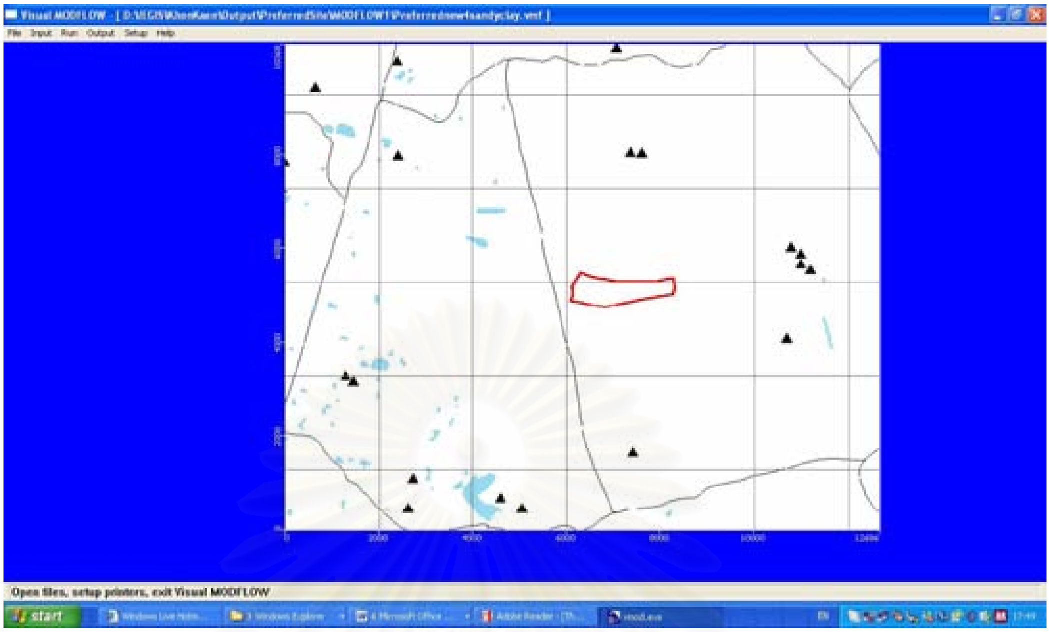

Figure 4.37 Visual MODFLOW Input Module showing boundary of the site.

In order to provide uniform cell in the z direction of the model, two layers were prepared by merging layer 1 with layer 2 and layer 3 with layer 4. Models in ArcMap were run to prepare the surface and bottom elevations of each layer in ASCII format and imported into Visual MODFLOW model. Figure 4.38 shows the model cross-section with two layers when viewing in column 28.

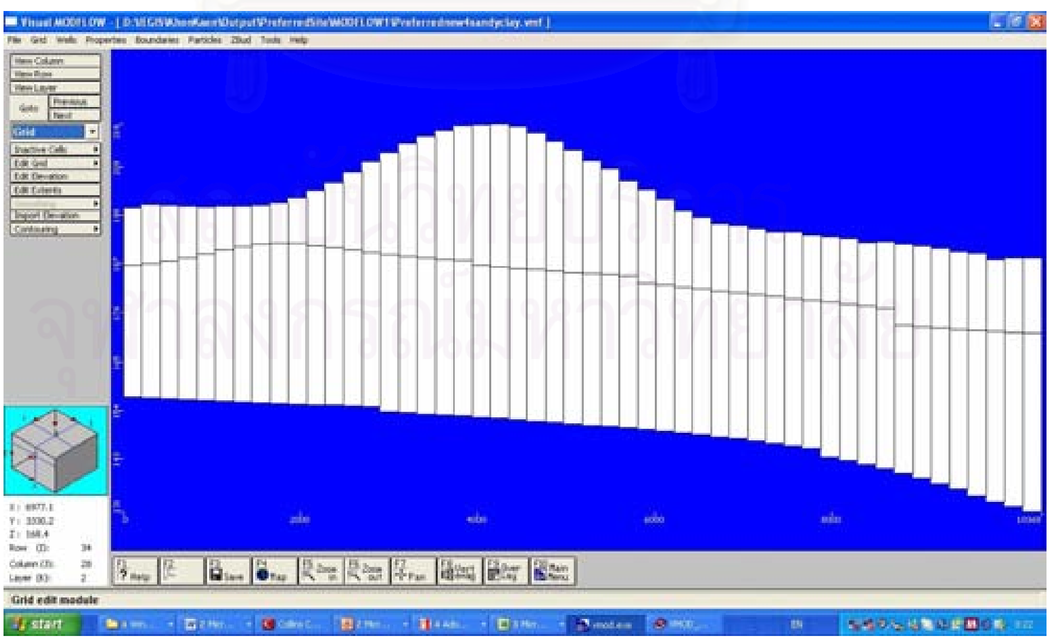

Figure 4.38 Column view of the model.

The basic parameters such as recharge rate, pumping well, aquifer properties, flow boundary conditions and constant head boundary were then assigned to the model with a steady state condition to visualize groundwater flow directions and velocities. The hydraulic conductivity, specific storage, specific yield, and porosity were taken from the Enviro-Base program in the Visual MODFLOW pakage. Table 4.11 illustratess parameters used in the model. The result of model calibration is shown in Figure 4.39. The purpose of the plot is to provide a graphical representation of the quality of the fit between the observed data and the calculated results from the model. The normalized RMS was 3.62 and the mean error was 0.22 m, which is considerably acceptable.

Table 4.11 Parameters used in the model.

Parameter	Value	Remark
Layer 1 : Kx, Ky (m/s)	0.0005	Enviro-Base program
Layer 1 : Kz (m/s)	0.005	Enviro-Base program
Layer 2 : Kx, Ky (m/s)	0.00063	Enviro-Base program
Layer 2 : Kz (m/s)	0.0063	Enviro-Base program
Specific storage (1/m)	0.00003	Spizt and Moreno (1996)
Specific yield	0.15	Enviro-Base program
Porosity	0.4	Enviro-Base program
Dispersion (m)	0.6	Enviro-Base program
Recharge (mm/year)	141	10% of average annual precipitation of the year 1997 – 2007 (1,406.94 mm/year)

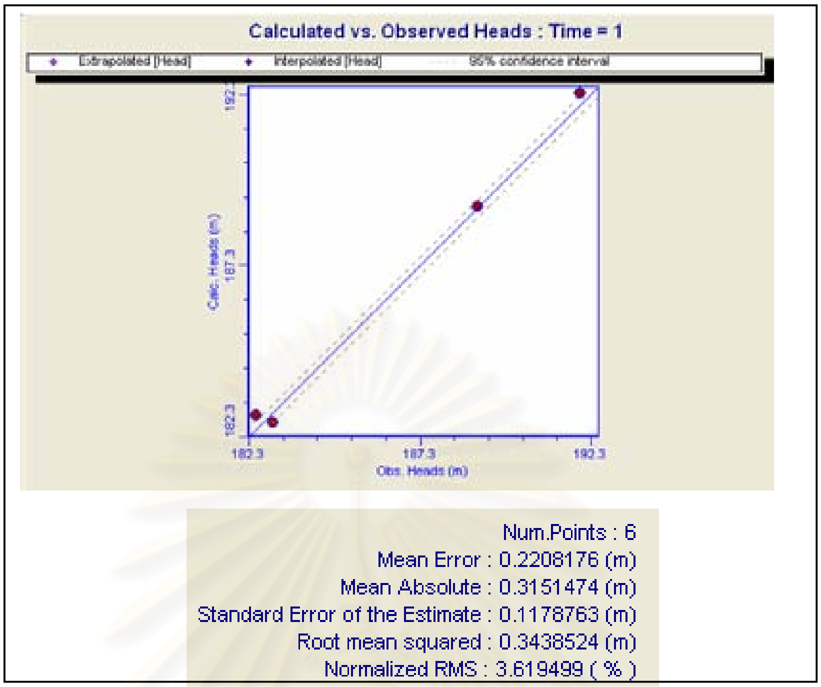

Figure 4.39 Calibration plot displayed the calculated versus observed heads.

The velocities map of layer 2 is shown in Figure 4.40. The groundwater flows from the east toward the northwest of the study area.

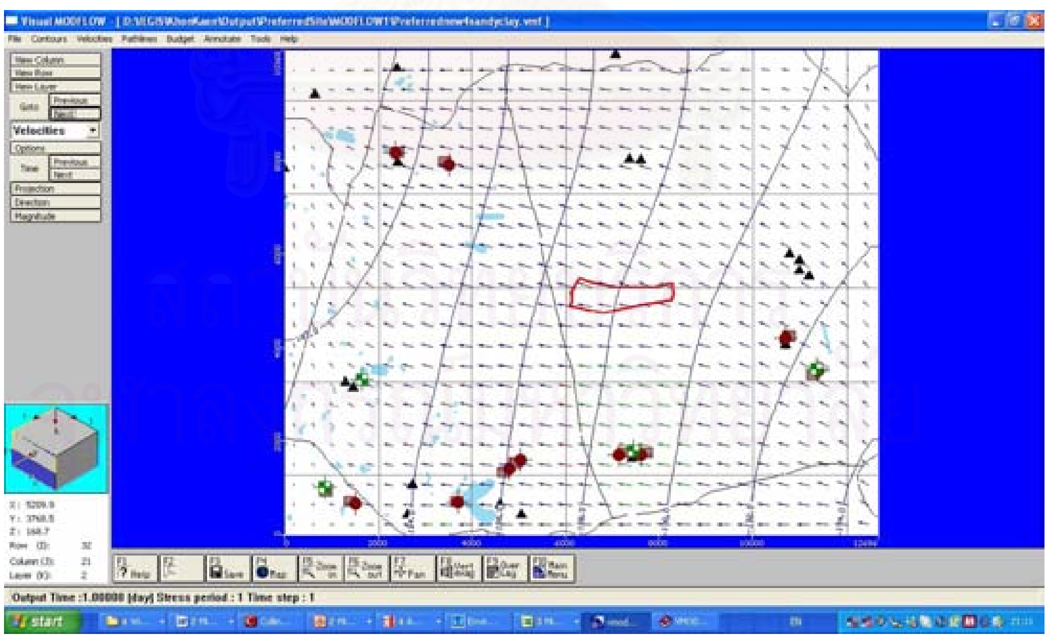

Figure 4.40 Groundwater flow directions and velocities map of layer 2.

MODPATH model was run with five forward particle tracking in the preferred site. The assumed recharge concentration of lead used in the model was 5 mg/L based on the concentration used for leachability test. The result reveals that the flowpaths of these particles as they travel through the groundwater had the same direction as the groundwater flow (Figure 4.41). Then MTD3 model was attempted to determine the concentration contour of lead after 7,300 day (20 years) of leakage (Figure 4.42). The result indicates that lead will not affect to any well. However, since most of the input parameters to the model were selected from the default values provided by program, the site investigation should be conducted to obtain the field parameters of the site.

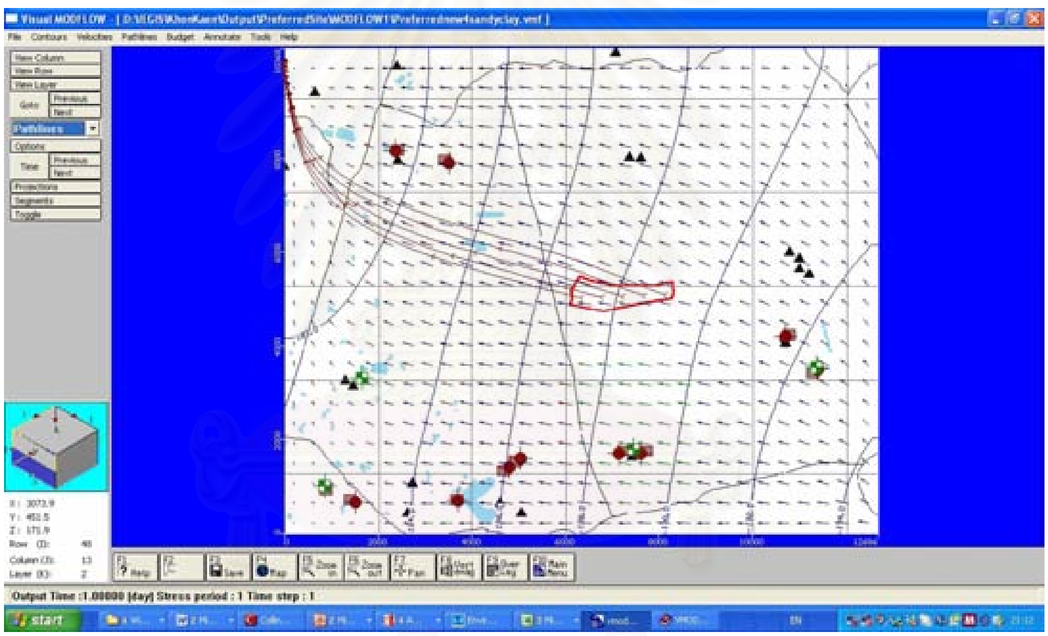

Figure 4.41 Pathlines of lead simulated by particle tracking.

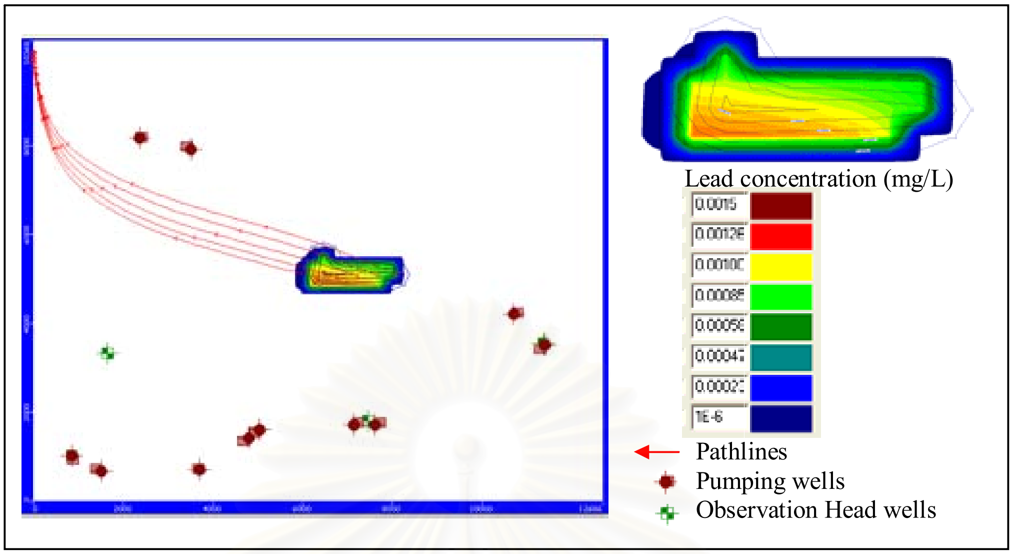

Figure 4.42 The plum concentration of the particle in layer 2 at the simulation of 7,300 days (20 years).

4.3.9 Mitigation measures for the preferred site

Even it is found that lead will not reach any well within 7,300 days after leaking, the groundwater monitoring program of the preferred site is still necessary. Groundwater monitoring wells (piezometers) should be installed in the preferred site i.e. one hydraulically upgradient of the preferred site to provide background groundwater quality, and at least three downgradient of the site to monitor contaminant leakage. However, the engineering design for the secured landfill with technical mitigation measures have to be strictly performed. The most important aspect is a social factor that strongly requires participatory approach to implement secured landfill.

4.4 Determination of minimum criteria for secured landfill

In addition, EGIS was verified by implementing to the PCD criteria. The comparison was made for the output of secured landfill sites generated by PCD criteria and this study's criteria used for Khon Kaen Province. Then, the minimum criteria were determined by subtracting the full criteria of PCD out until the output were relatively resulted with the full PCD criteria. The minimum criteria are implied as the must criteria in which the users must have for secured landfill analysis. In order to identify the minimum GIS data required (stated as the must criteria) for finding the secured landfill, the full criteria of PCD were used as the input to ES and GIS. The candidate sites were produced as illustrated in Figure 4.43. Then, the full criteria were subtracted until the output of the remaining criteria was relatively to the full criteria of PCD. The must criteria for secured landfill are as follows.

- Communities and residential areas or village points
- National park
- Forest zone C
- River and water resources
- Administrative boundary (Province, District, Sub-District)

Based on PCD's full criteria of hazardous waste disposal facilities, there were 30 candidate sites as a result (Figures 4.43). When running GIS based on the must criteria, there were 33 candidate sites (Figure 4.44). Candidate sites of Khon Kaen Province (11 sites) were subset of candidates sites based on both sets of criteria.

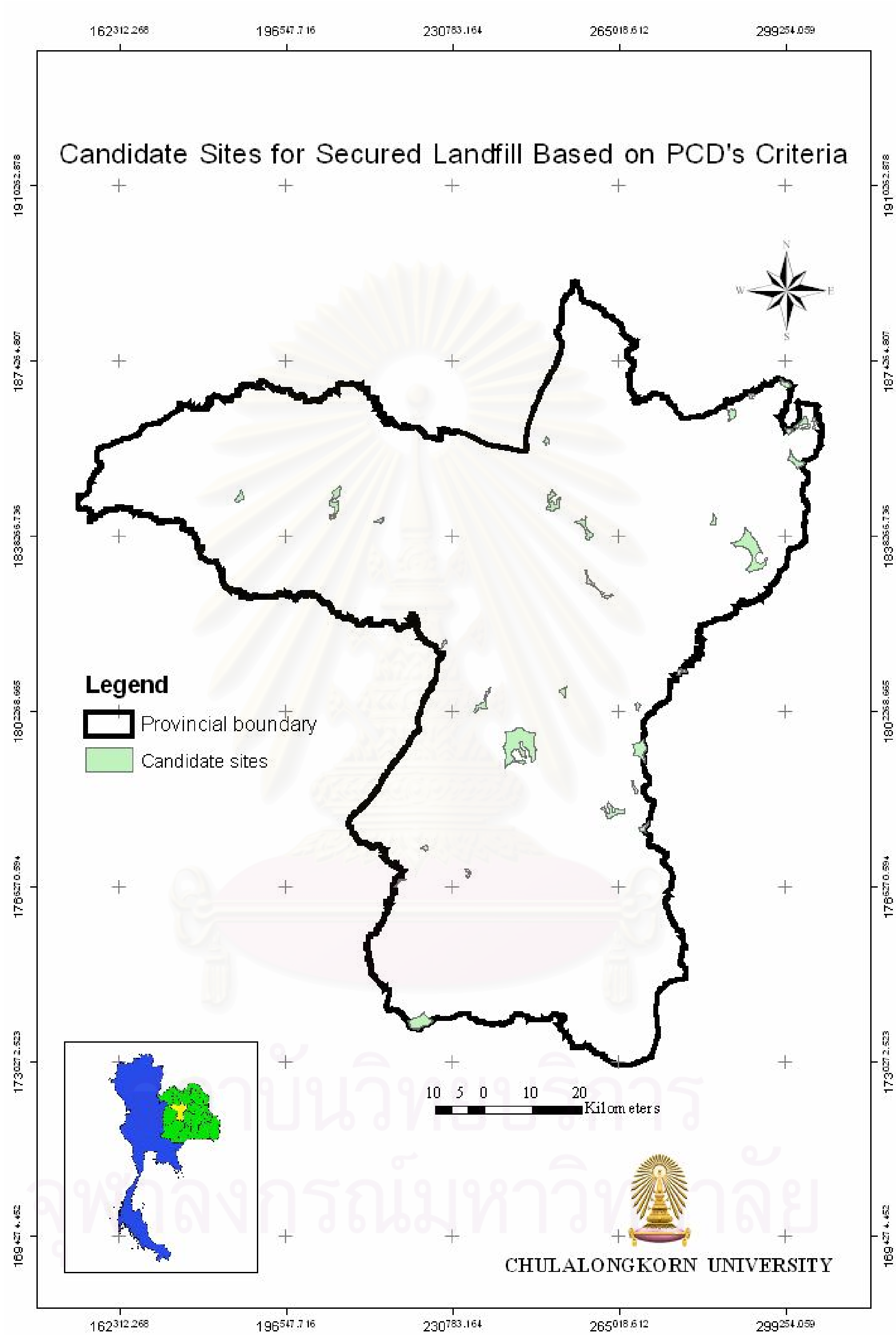

Figure 4.43 Candidate sites based on PCD's criteria.

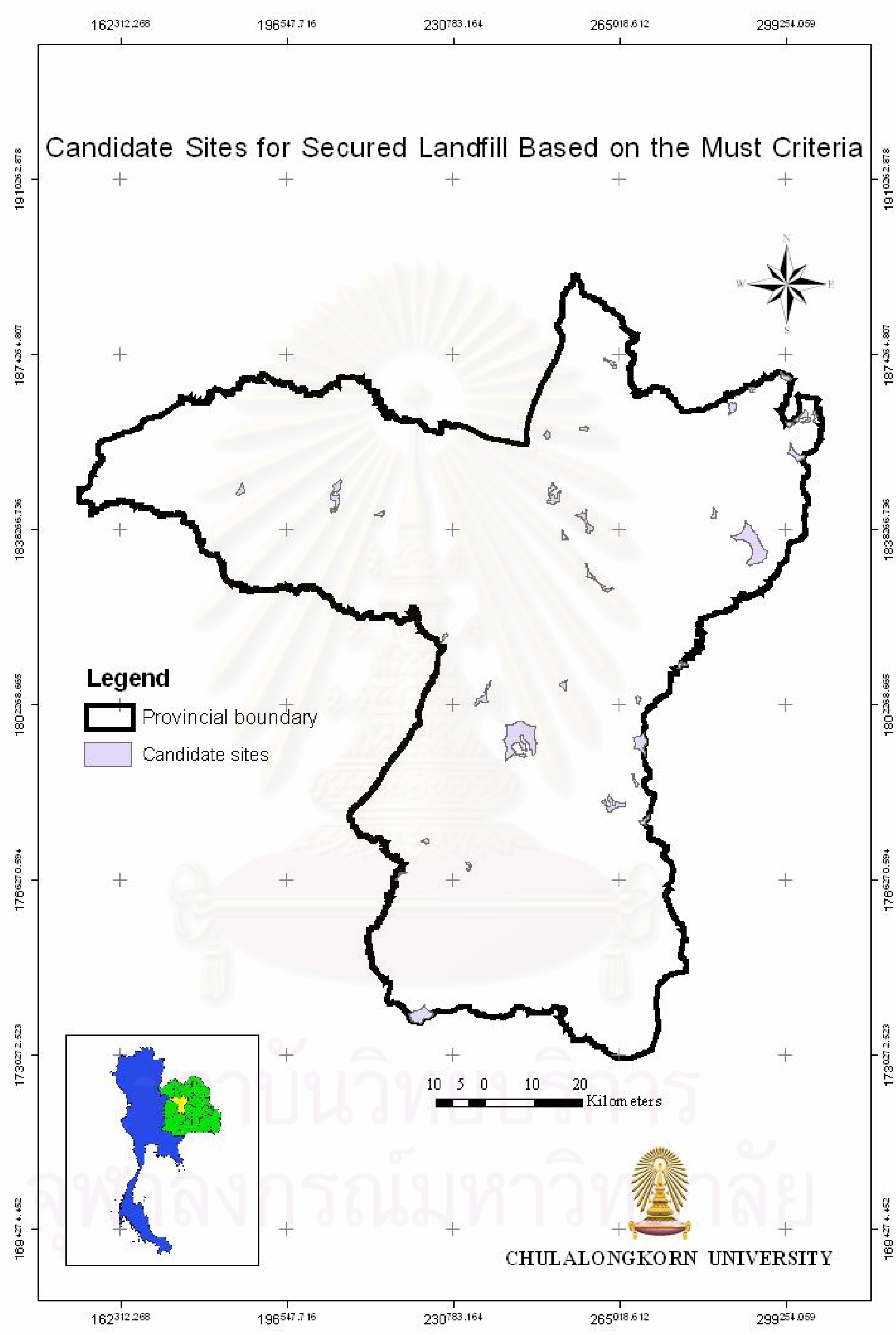

Figure 4.44 Candidate sites based on the must criteria.

4.5 Application of EGIS for secured landfill site in Mahasarakham Province.

The EGIS was tested with Mahasakam Province to indicate the generality of the system. The results show that EGIS is flexible and can be used to identify candidate sites of secured landfill for Mahasakam Province (Figure 4.45). Although missing some GIS data do not affect the system, which means that the system can run and generate the output properly. But it will result in generating numerous candidate sites. Besides, the users must understand the properties of GIS models in the system because the users have to change some elements of models to make the model fit with the input data (the details are presented in Users' manual in Appendix D).

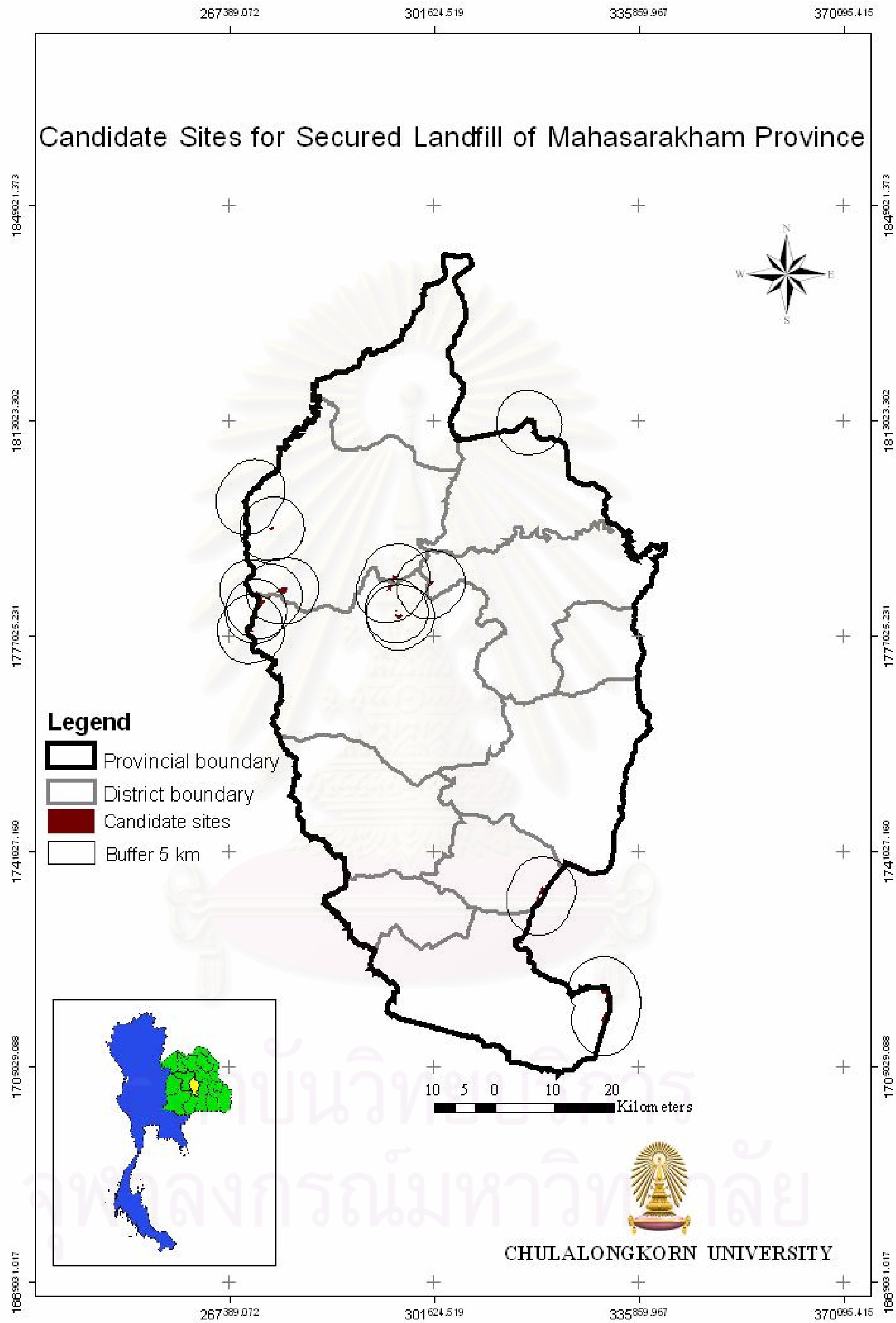

Figure 4.45 Candidate sites for secured landfill of Mahasarakham Province.

4.6 Limitations of EGIS

- Since the criteria of secured landfill used in this study were 23 criteria, if users need to take other criteria into account they have to add those criteria in to models in ArcGIS by themselves.
- The number of candidate sites which EGIS can handle is fifteen sites. If the number of candidate sites is more than fifteen, users should do as follows:
    - divide the study area into two parts and apply ES , GIS and AHP in each part,
    - select the candidate sites produced from each part based on the top rank in order,
    - plus number of the selected candidate sites not more than 15 sites,
    - rerun the system only AHP and Visual MODFLOW model.
- The lithology data from the Department of Groundwater Resources is in PDF format and the users have to convert it to DBF format for further analysis in ArcMap and ArcScene by themselves.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The site selection of secured landfill is likely complicated as it is not only technical but also social concerns. Technically, the appropriate tool for secured landfill site analysis should be implemented in the site selection procedure. This study aims at developing a comprehensive tool to facilitate the analysis of secured landfill sites. It integrates Geographic Information System (GIS), Expert System (ES), Analytic Hierarchy Process (AHP) and Visual MODFLOW model into a package tool. The study methodology was consisted of three main steps including formulating criteria of secured landfills, developing EGIS and applying EGIS to Khon Kaen Province. Formulation of the criteria for secured landfills was accomplished by compiling the criteria of USEPA, MOInd and PCD. The development of EGIS for analysis of secured landfill site included ES for criteria selection, GIS models for identifying candidate sites, AHP for ranking candidate sites as well as selecting the preferred site, Visual MODFLOW model for assessing the groundwater impact of the preferred site. Application of EGIS for secured landfill site was implemented for Khon Kaen Province.

The results of EGIS testing indicate the system can effectively facilitate the siting process of secured landfills. The EGIS application for Khon Kaen Province was used as a case study. The criteria selected by ES imported to GIS model, produced 11 candidate sites. With AHP, the sites ranked 1 to 5 with high weight rating were site 3 (Tambon Pho chai, King Amphoe Kok Pho Chai), site 2 (Tambon Non Sa-at, Amphoe Wang Yai), site 1 (Tambon Tawad, Amphoe Wang Noi), site 11 (Tambon Hau Na Kham, Amphoe Kranuan), and site 4 (Tambon Phulek, Amphoe Banphai), respectively. The information of field investigation of such ranked sites was taken into account for consideration, site 4 was selected as the preferred site. Visual MODFLOW model for site 4 was simulated to assess the impact of leachate to groundwater. Under the designated conditions, it is estimated that within 20 years contaminant using lead as the test parameter would not reach to any well in the surrounded area.

In addition, the minimum criteria for secured landfill were determined to define the must criteria. There are 5 criteria that the users must input to EGIS, which are communities and residential areas or village points, National park, forest zone C, river and water resources and administrative boundary.

In conclusion, the use of this tool provides decision support to users in selection of the preferred secured landfill site, which means that the objective of this study has been achieved. The advantage of EGIS is that it is generality and friendly to users and even though they are not GIS experts, they just follow the guidance of the system. It could be used as a participatory tool to identify the suitable sites of secured landfill by incorporating public opinions at the outset of the decision-making process

5.2 Recommendations

1) Visual MODFLOW Model

(1) Preparing input to Visual MODFLOW model

- To correctly apply the Arc Hydro groundwater toolbar, users need to create the feature dataset and the relationships between feature classes and tables fit to the schematic of the toolbar.
- To write code for automatic transformation of lithology data from PDF to DBF format for inputting into the Arc Hydro groundwater toolbar.

(2) Visual MODFLOW model should be simulated for all candidate sites and the results should be accounted to consider for final ranking process.

2) Secured landfill siting process using EGIS should be taken as a data driven decision process. The EGIS is mostly technical process, it can not be used as a final decision. EGIS including public participation would create public acceptance, leading to final decision.

3) An environmental impact assessment has to be undertaken for the secured landfill site project. Therefore, the developed EGIS system can be used as a tool in the process.

4) Further studies should be carried out to investigate the development of groundwater model embedded into the GIS to reduce the problem of data handling.

5) Site investigation plays very important role in the process of siting and should be done before selecting the preferred site.

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APPENDICES

APPENDIX A

Models and their elements

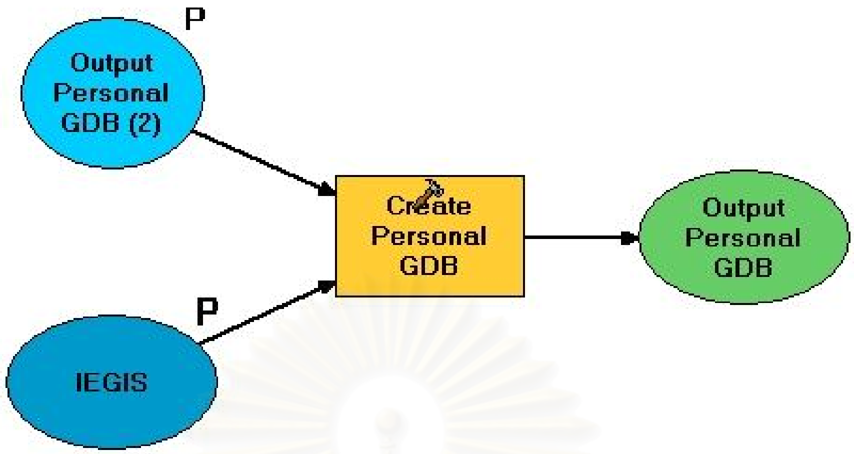


Figure A-1 Model of Create a new Geodatabase

Figure A-2 An example: Model of Copy GIS data in to Geodatabase.

Figure A-3 Model of water factors

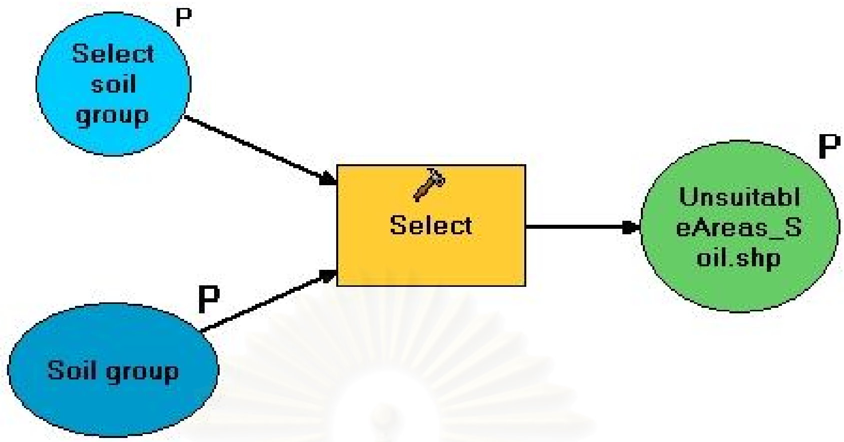


Figure A-4 Model of soil factors

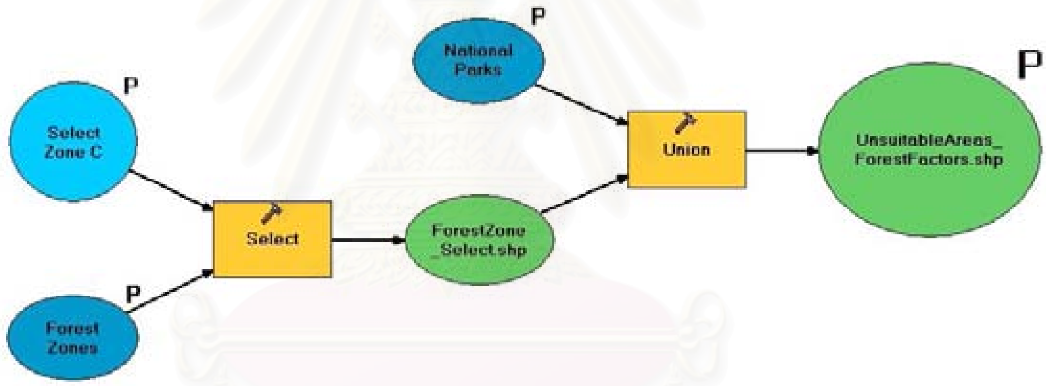


Figure A-5 Model of forest factors

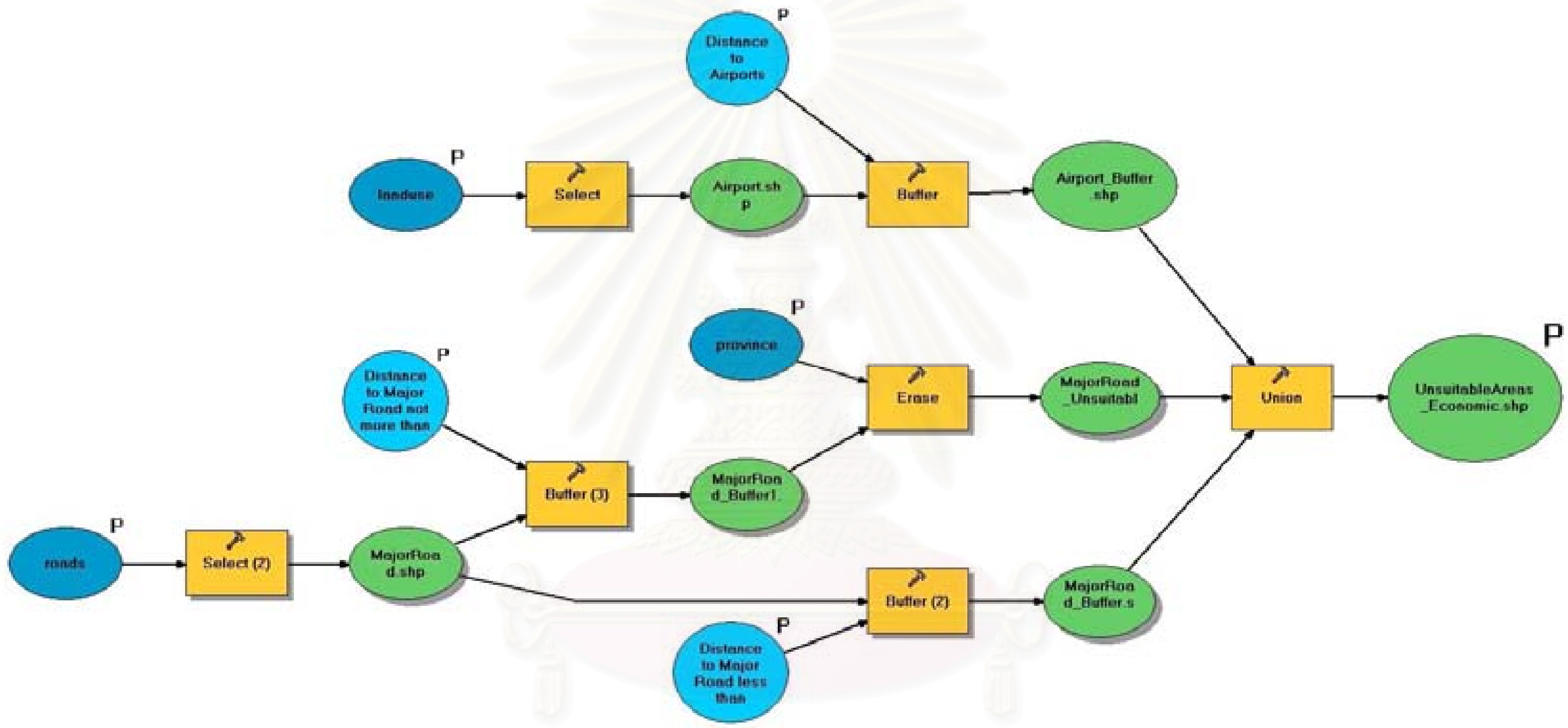


Figure A-6 Model of economic factors

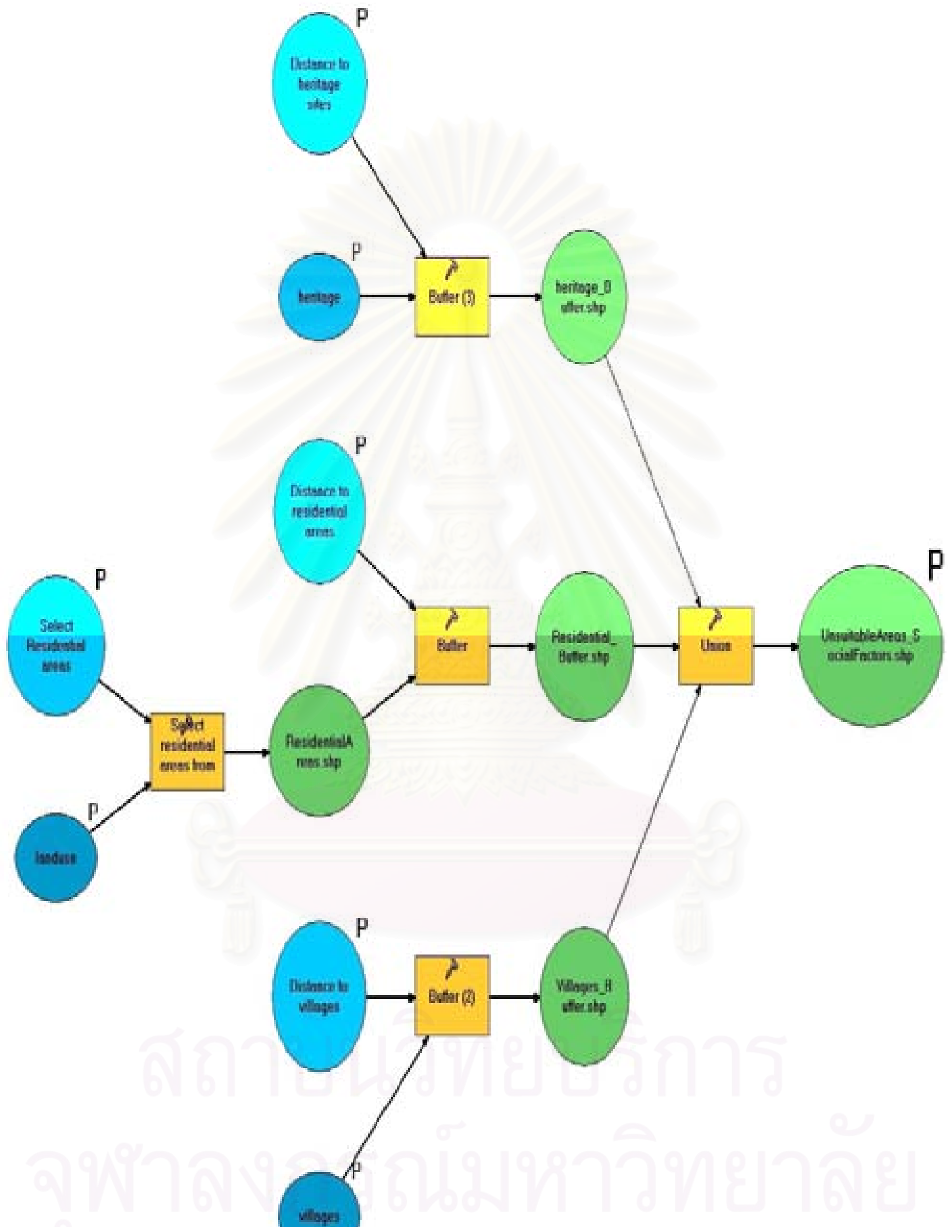


Figure A-7 Model of social factors

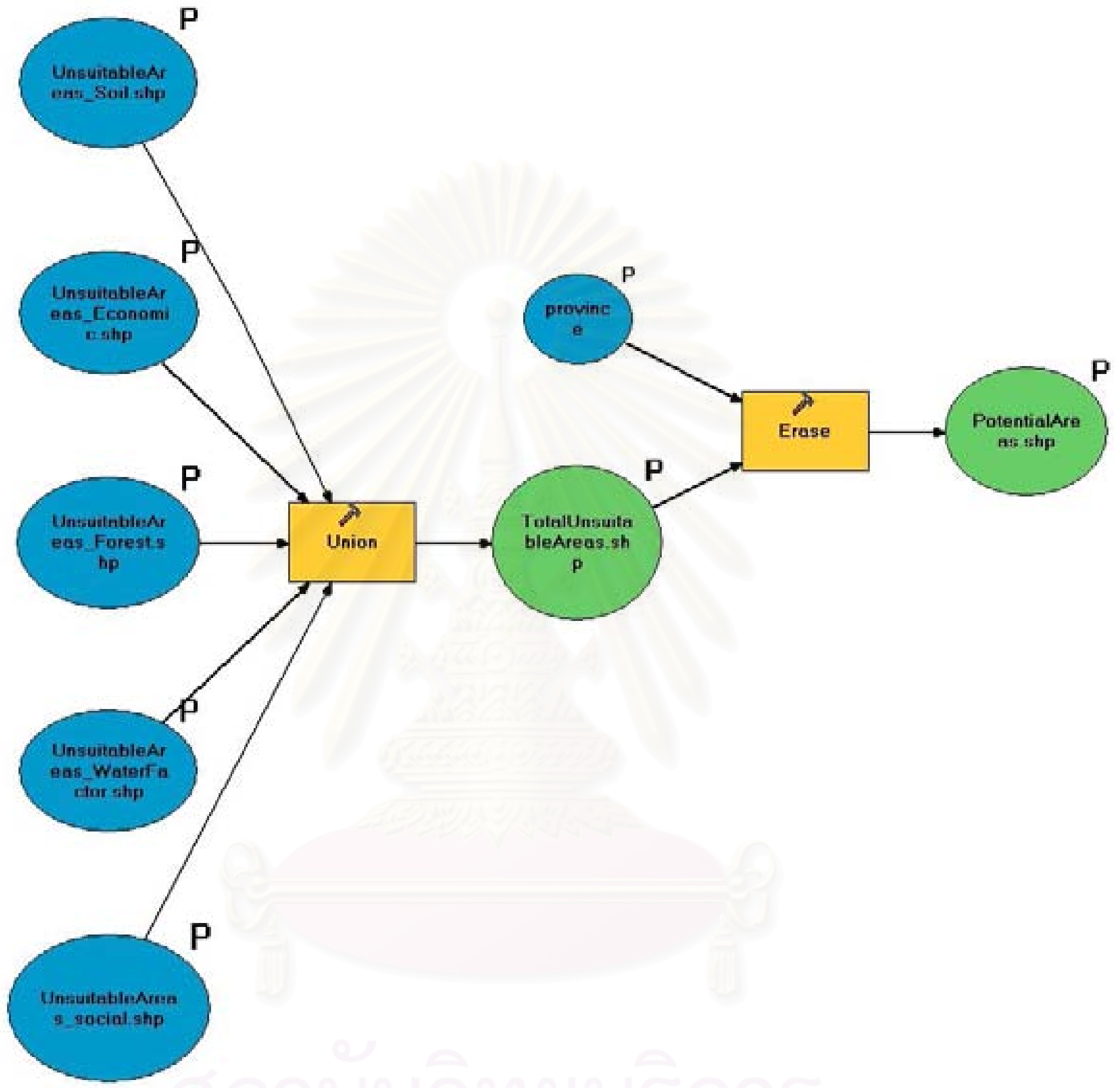


Figure A-8 Model of Identify potential areas

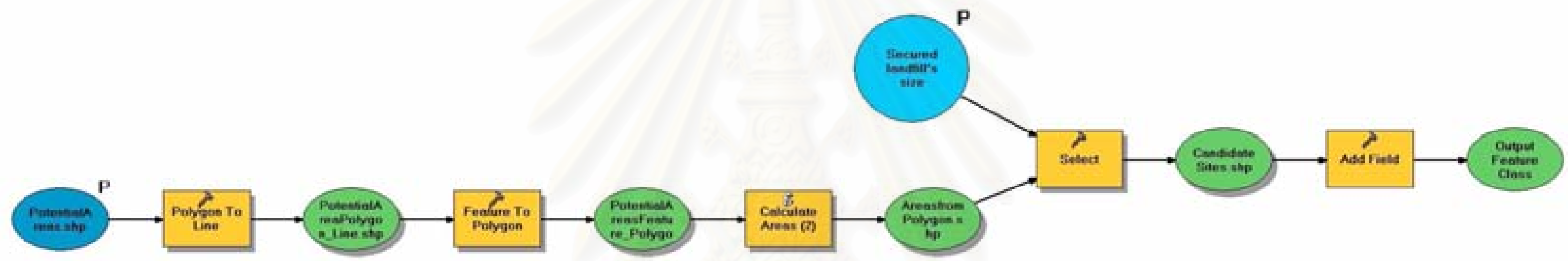


Figure A-9 Model of Identify candidate sites

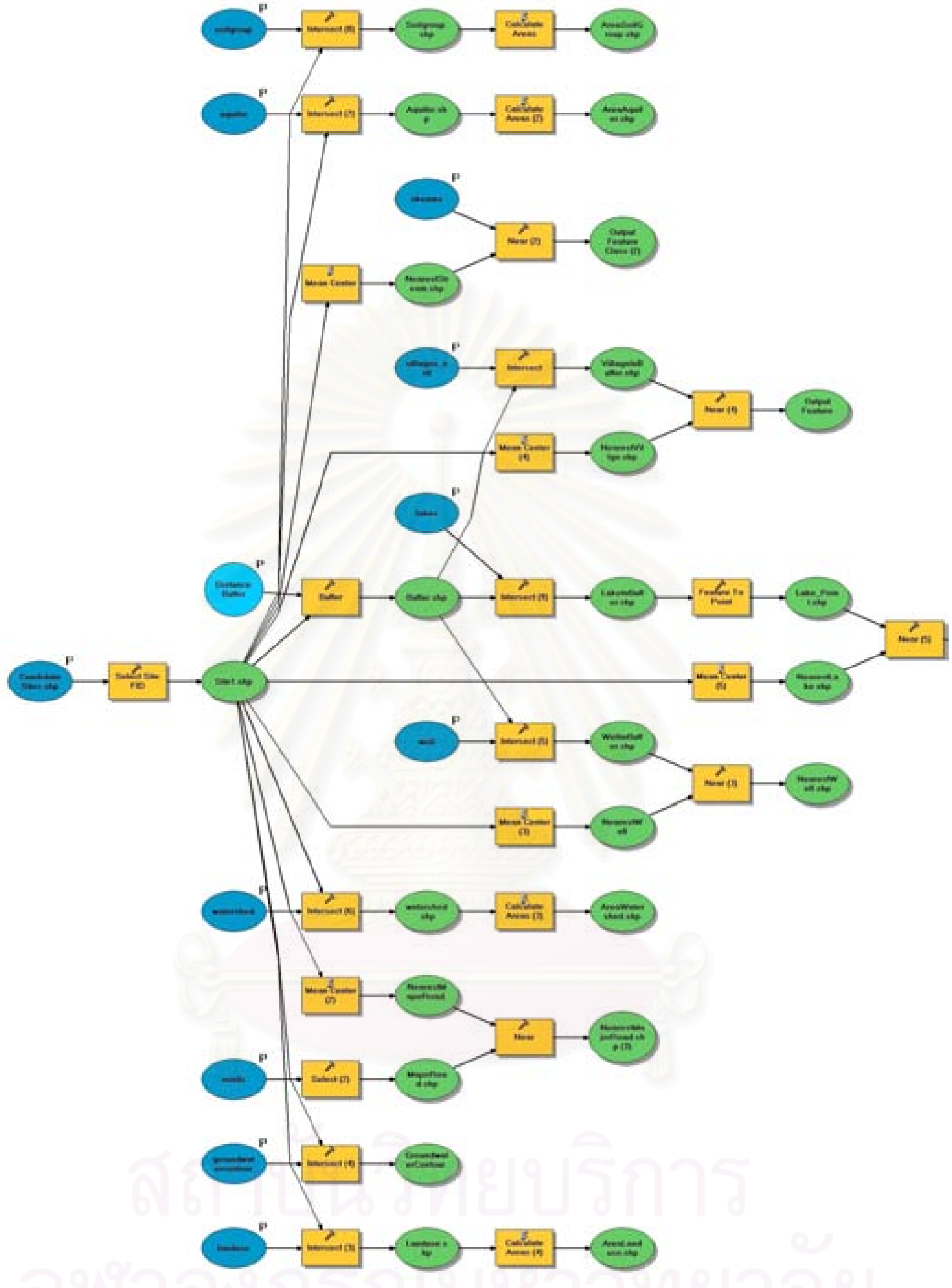


Figure A-10 An example: Model of Identify characteristic of candidate site 1

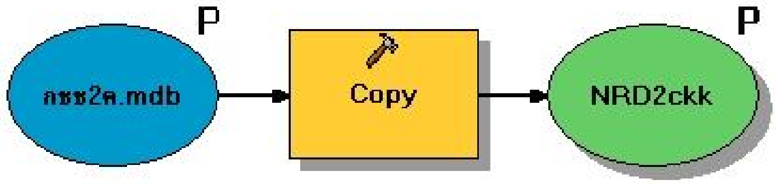


Figure A-11 Model of copy NRD2c data

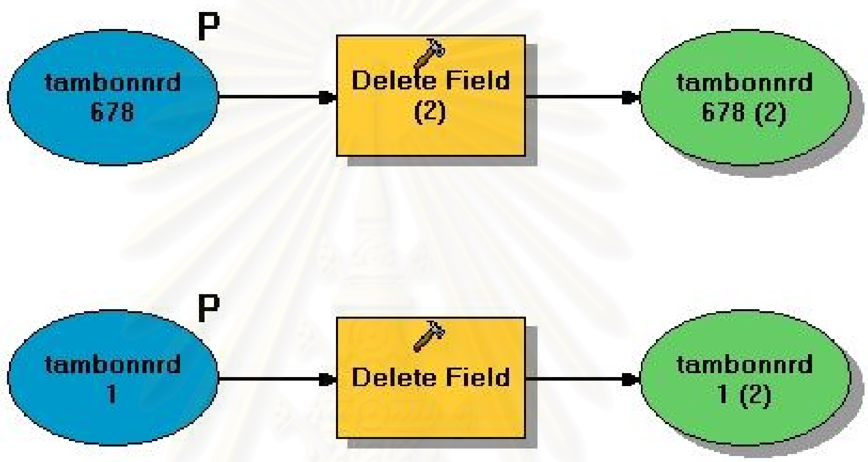


Figure A-12 Model of modify NRD2c data

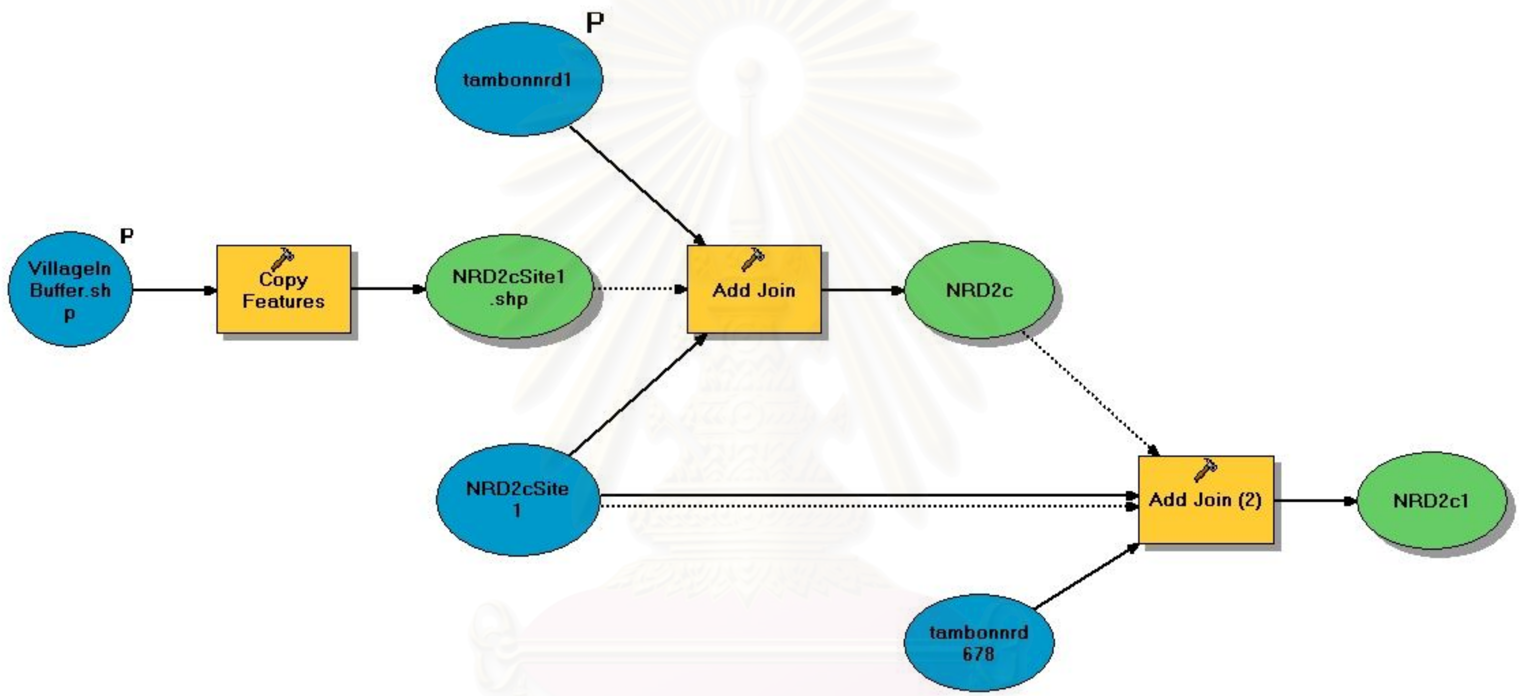


Figure A-13 An example: Model of identify NRD2c data of candidate site 1

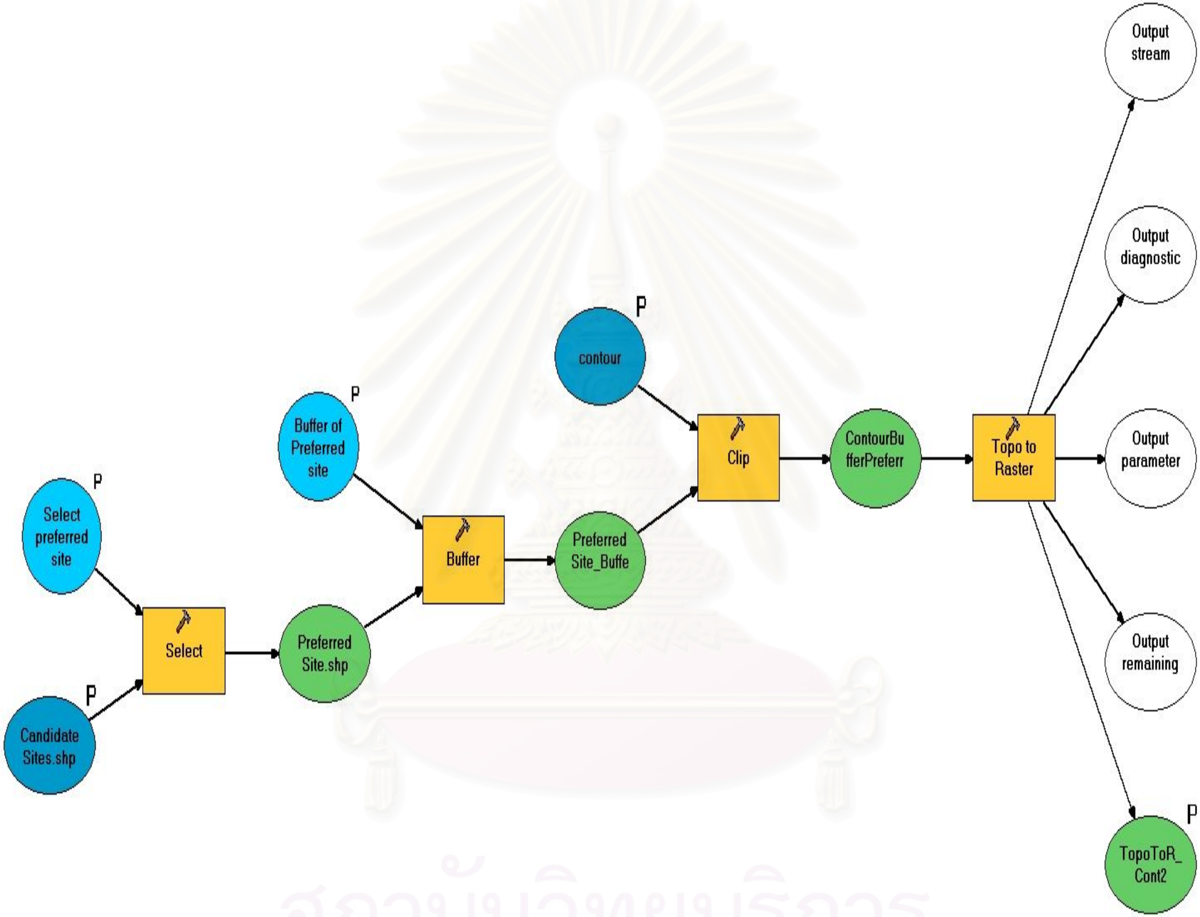


Figure A-14 Model of preferred site's map

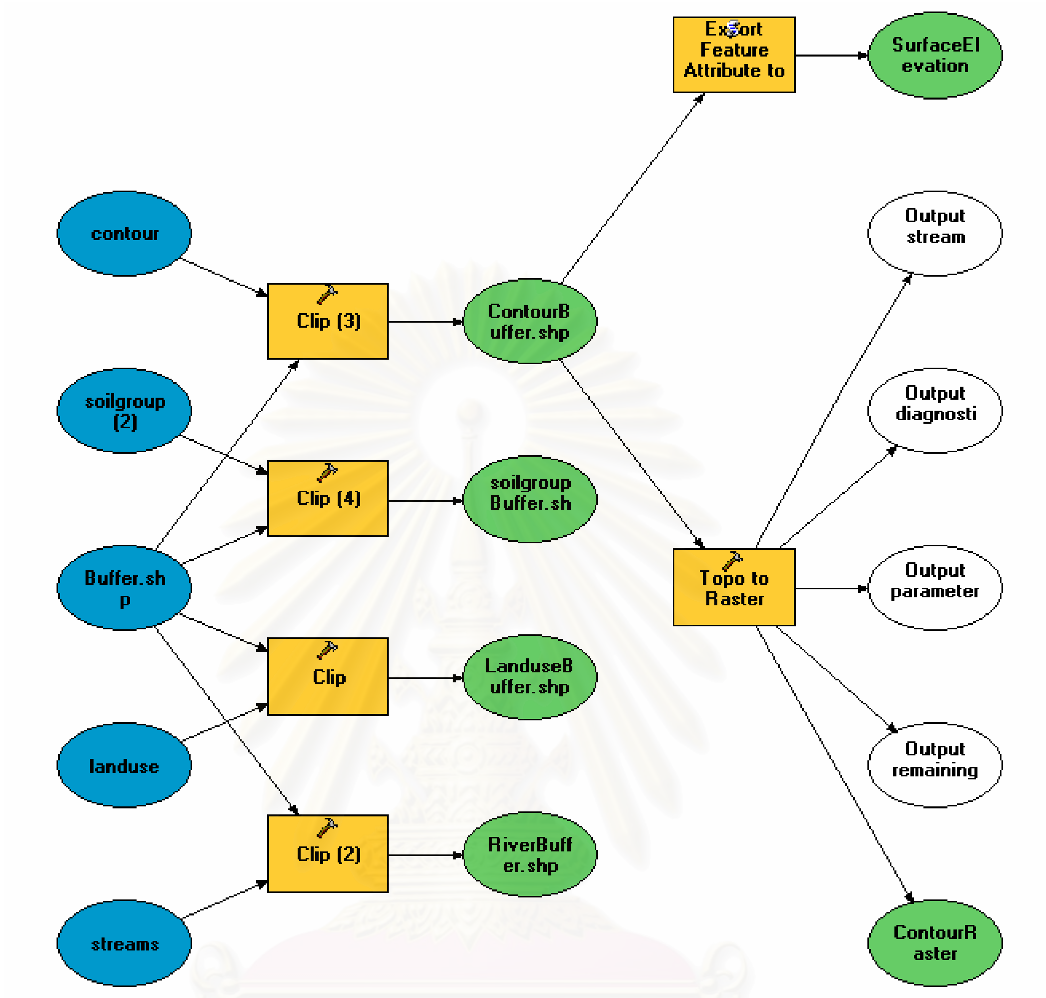


Figure A-15 Model of surface elevation

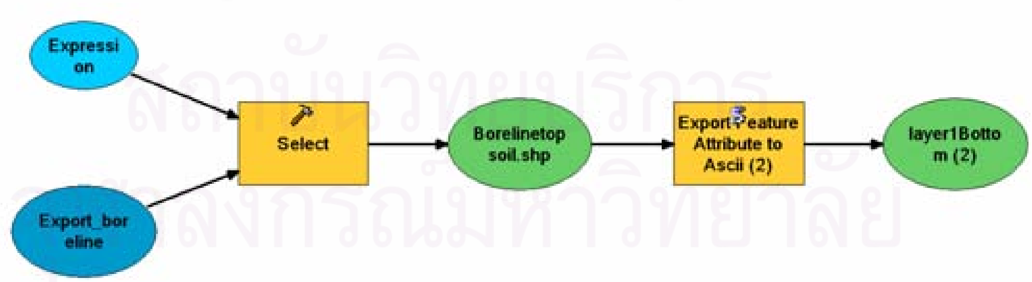


Figure A-16 An example: Model of layer 1

APPENDIX B

Sources of GIS data used in this study

Table B-1 Sources of GIS data used in this study

GIS data	Scale	Year (B.E.)	Source
Province Boundary	1:50,000	2545	Topographic Map Series L7017 (1969 - 1994) from Royal Thai Survey Department checked with Administrative Boundary from Governor's Office of Khon Kaen Province. Data entered by Computer Centre, Khon Kaen University.
Amphoe Boundary	1:50,000	2545	Topographic Map Series L7017 (1969 - 1994) from Royal Thai Survey Department checked with Administrative Boundary from Governor's Office of Khon Kaen Province. Data entered by Computer Centre, Khon Kaen University.
Tambon Boundary	1:50,000	2545	Administrative Boundary Maps (Districts,Tambons, Municipalities) and Provinical Basic Data (acquired 2000) by National Statistical Office, Office of Prime Minister. Data entered by Computer Centre, Khon Kaen University.
Recharge areas	1:50,000	2545	Groundwater Research Center,Faculty of Technology ,Khon Kaen University

Table B-1 Sources of GIS data used in this study (continued)

GIS data	Scale	Year (B.E.)	Source
Village Point	1:50,000	2545	Topographic Map Series L7017 (1969 - 1994) by Royal Thai Survey Department combined with LANDSAT TM Imagery (acquired Jan. 1999). Checks with Village Directory of Khon Kaen Province (acquired Aug 2001) from Governor's Office and NRD2C in 2001 from Khon Kaen Provincial Community Development Office. Data entered by Computer Centre, Khon Kaen University.
National Parks	1:50,000	2543	Digital Files (acquired 2000) from Natural Resources Conservation Office, Royal Forest Department and Map attached in Gazzette No.117, Section 205ก dated November 15,2000 (including Soak Tae Forest in Nam Pong National Park)
Well	1:50,000	2543	Khon Kaen Regional Environmental Health Centre 6, Ministry of Public Health
Forest Reserves	1:50,000	2543	Digital Files (acquired 2000) from Natural Resources Conservation Office, Royal Forest Department
Mining	1:50,000	2545	Khon Kaen Regional Environment Office 10, Ministry of Environment and Natural Resources

Table B-1 Sources of GIS data used in this study (continued)

GIS data	Scale	Year (B.E.)	Source
National Reserved Forest Zone (Zone A, C, E)	1:50,000	2537	Digital Files (acquired 1994) from Natural Resources Conservation Office, Royal Forest Department
Water body/ Lake	1:50,000	2545	LANDSAT TM Imagery (acquired Jan.1999) checked with Topographic Map L7017 (1969 - 1994) from Royal Thai Survey Department and field survey. Data entered by Computer Centre, Khon Kaen University.
Stream	1:50,000	2545	Topographic Map L7017 (1969 - 1994) from Royal Thai Survey Department. Data entered by Computer Centre, Khon Kaen University.
Watershed Classification	1:50,000	2528	Watershed Quality Classification Map (1983) from Office of Environment Policy and Planning, Ministry Of Science Technology and Environment. Data entered by Computer Centre, Khon Kaen University.
Wastewater treatment plant	1:50,000	2544	Khon Kaen Regional Environment Office 10, Ministry of Environment and Natural Resources
Soil group	1:250,000	2545	Khon Kaen Regional Environment Office 10, Ministry of Environment and Natural Resources

Table B-1 Sources of GIS data used in this study (continued)

GIS data	Scale	Year (B.E.)	Source
Wetlands	1:50,000	2537	LANDSAT TM Imagery (acquired 1994) combining with Topographic Map L7017 (1969 - 1994) from Royal Thai Survey Department. Wetlands categorized according to OEPP criteria. Data entered by Computer Centre, Khon Kaen University.
Land Use	1:50,000	2544	LANDSAT TM Imagery (acquired Jan.1999) checked with Topographic Map from Royal Thai Survey Department and field survey. Data entered by Computer Centre, Khon Kaen University.
Heritage Sites	1:50,000	2545	Document on the seminar "Cultural Heritage Management and Local Administrative Organization in Khon Kaen Province", on 26-27 March, 2002. Office of Archaeology and National Museum 7, Khon Kaen, The Fine Arts Department.
Road	1:50,000	2545	Topographic Map L7017 (1969 - 1994) from Royal Thai Survey Department. Data entered by Computer Centre, Khon Kaen University.
Solid waste disposal sites	1:50,000	2545	Khon Kaen Regional Environment Office 10, Ministry of Environment and Natural Resources

Table B-1 Sources of GIS data used in this study (continued)

GIS data	Scale	Year (B.E.)	Source
Contour	1:50,000	2546	Topographic Map L7017 (1969 - 1994) from Royal Thai Survey Department. Data entered by Computer Centre, Khon Kaen University.
Flood risk areas	100,000	2545	Khon Kaen Regional Environment Office 10, Ministry of Environment and Natural Resources
Aquifer (groundwater yields and quality)	1:50,000	2545	Khon Kaen Regional Environment Office 10, Ministry of Environment and Natural Resources
Groundwater contour	1:50,000	2548	Environmental Center, Khon Kaen University.

APPENDIX C

Details of the relative weights of candidate sites with respect to each factor

Table C-1 Pairwise rating of candidate sites on the basis of number of water well within10 km.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	2.35	4.01	6.02	3.75	7.49	2.47	1.00	1.00	1.00	0.32
Site 2	0.43	1.00	3.16	4.66	1.30	6.18	0.89	0.38	0.38	0.38	0.24
Site 3	0.25	0.32	1.00	3.27	0.44	1.45	0.29	0.23	0.24	0.23	0.19
Site 4	0.17	0.21	0.31	1.00	0.21	2.64	0.18	0.17	0.17	0.17	0.14
Site 5	0.27	0.77	2.28	4.88	1.00	5.87	0.55	0.32	0.32	0.32	0.23
Site 6	0.13	0.16	0.69	0.38	0.17	1.00	0.16	0.14	0.14	0.14	0.13
Site 7	0.40	1.13	3.50	5.50	1.83	6.25	1.00	0.38	0.42	0.38	0.26
Site 8	1.00	2.63	4.38	5.88	3.13	7.38	2.63	1.00	1.00	1.00	0.33
Site 9	1.00	2.63	4.25	5.88	3.13	7.25	2.38	1.00	1.00	1.00	0.33
Site 10	1.00	2.63	4.38	6.00	3.13	7.38	2.63	1.00	1.00	1.00	0.33
Site 11	3.13	4.13	5.38	7.25	4.38	8.00	3.88	3.00	3.00	3.00	1.00
Column Sum	**8.77**	**17.94**	**33.32**	**50.70**	**22.44**	**60.88**	**17.04**	**8.62**	**8.67**	**8.61**	**3.50**

Table C-2 Normalized AHP matrix of paired comparisons of number of water well within 10 km.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.11	0.13	0.12	0.12	0.17	0.12	0.15	0.12	0.12	0.12	0.09	1.36	0.12
Site 2	0.05	0.06	0.09	0.09	0.06	0.10	0.05	0.04	0.04	0.04	0.07	0.70	0.06
Site 3	0.03	0.02	0.03	0.06	0.02	0.02	0.02	0.03	0.03	0.03	0.05	0.33	0.03
Site 4	0.02	0.01	0.01	0.02	0.01	0.04	0.01	0.02	0.02	0.02	0.04	0.22	0.02
Site 5	0.03	0.04	0.07	0.10	0.04	0.10	0.03	0.04	0.04	0.04	0.07	0.59	0.05
Site 6	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.04	0.17	0.02
Site 7	0.05	0.06	0.11	0.11	0.08	0.10	0.06	0.04	0.05	0.04	0.07	0.78	0.07
Site 8	0.11	0.15	0.13	0.12	0.14	0.12	0.15	0.12	0.12	0.12	0.10	1.36	0.12
Site 9	0.11	0.15	0.13	0.12	0.14	0.12	0.14	0.12	0.12	0.12	0.10	1.34	0.12
Site 10	0.11	0.15	0.13	0.12	0.14	0.12	0.15	0.12	0.12	0.12	0.10	1.37	0.12
Site 11	0.36	0.23	0.16	0.14	0.19	0.13	0.23	0.35	0.35	0.35	0.29	2.77	0.25
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.056 ; λmax = 11.56 ; m = 11 ; RI = 1.51

C.R = 0.037

Table C-3 Pairwise rating of candidate sites on the basis of distance to the nearest water well (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	2.50	2.50	2.50	4.48	2.64	1.76	1.37	4.30	1.66	0.67
Site 2	0.40	1.00	1.00	1.00	2.76	1.07	1.00	0.47	2.53	0.70	0.30
Site 3	0.40	1.00	1.00	1.00	2.71	1.00	1.00	0.50	2.53	0.70	0.30
Site 4	0.40	1.00	1.00	1.00	2.76	1.07	1.00	0.47	2.53	0.70	0.29
Site 5	0.22	0.36	0.37	0.36	1.00	0.44	0.44	0.28	0.73	0.30	0.17
Site 6	0.38	0.94	1.00	0.94	2.25	1.00	0.80	0.48	2.40	0.64	0.28
Site 7	0.57	1.00	1.00	1.00	2.25	1.25	1.00	0.48	2.40	0.70	0.29
Site 8	0.73	2.13	2.00	2.13	3.63	2.06	2.06	1.00	4.07	1.00	0.44
Site 9	0.23	0.40	0.40	0.40	1.38	0.42	0.42	0.25	1.00	0.32	0.20
Site 10	0.60	1.44	1.44	1.44	3.38	1.56	1.44	1.00	3.13	1.00	0.33
Site 11	1.50	3.38	3.38	3.50	5.75	3.63	3.50	2.25	5.13	3.00	1.00
Column Sum	**6.43**	**15.13**	**15.08**	**15.26**	**32.34**	**16.13**	**14.43**	**8.55**	**30.73**	**10.69**	**4.25**

Table C-4 Normalized AHP matrix of paired comparisons of distance to the nearest water well (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.16	0.17	0.17	0.16	0.14	0.16	0.12	0.16	0.14	0.15	0.16	1.69	0.15
Site 2	0.06	0.07	0.07	0.07	0.09	0.07	0.07	0.06	0.08	0.07	0.07	0.75	0.07
Site 3	0.06	0.07	0.07	0.07	0.08	0.06	0.07	0.06	0.08	0.07	0.07	0.75	0.07
Site 4	0.06	0.07	0.07	0.07	0.09	0.07	0.07	0.06	0.08	0.07	0.07	0.75	0.07
Site 5	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.04	0.32	0.03
Site 6	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.06	0.08	0.06	0.06	0.70	0.06
Site 7	0.09	0.07	0.07	0.07	0.07	0.08	0.07	0.06	0.08	0.07	0.07	0.77	0.07
Site 8	0.11	0.14	0.13	0.14	0.11	0.13	0.14	0.12	0.13	0.09	0.10	1.36	0.12
Site 9	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.05	0.35	0.03
Site 10	0.09	0.09	0.10	0.09	0.10	0.10	0.10	0.12	0.10	0.09	0.08	1.07	0.10
Site 11	0.23	0.22	0.22	0.23	0.18	0.22	0.24	0.26	0.17	0.28	0.24	2.50	0.23
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.008 ; λmax = 11.08 ; m = 11 ; RI = 1.51

C.R = 0.005

Table C-5 Pairwise rating of candidate sites on the basis of major watershed classification.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	1.00	1.00	1.90	1.90	2.21	1.90	1.90	1.90	1.90	1.11
Site 2	1.00	1.00	0.73	1.90	1.90	2.21	1.90	1.90	1.90	1.90	1.11
Site 3	1.00	1.38	1.00	1.90	1.90	2.21	1.90	1.90	1.90	1.90	1.11
Site 4	0.53	0.53	0.53	1.00	1.00	1.12	1.00	1.00	1.00	1.00	0.50
Site 5	0.53	0.53	0.53	1.00	1.00	1.78	1.00	1.00	1.00	1.00	0.50
Site 6	0.45	0.45	0.45	0.90	0.56	1.00	0.47	0.47	0.47	0.47	0.32
Site 7	0.53	0.53	0.53	1.00	1.00	2.13	1.00	1.00	1.00	1.00	0.50
Site 8	0.53	0.53	0.53	1.00	1.00	2.13	1.00	1.00	1.00	1.00	0.50
Site 9	0.53	0.53	0.53	1.00	1.00	2.13	1.00	1.00	1.00	1.00	0.50
Site 10	0.53	0.53	0.53	1.00	1.00	2.13	1.00	1.00	1.00	1.00	0.47
Site 11	0.90	0.90	0.90	2.00	2.00	3.13	2.00	2.00	2.00	2.13	1.00
Column Sum	**7.50**	**7.88**	**7.23**	**14.61**	**14.28**	**22.14**	**14.18**	**14.18**	**14.18**	**14.31**	**7.62**

Table C-6 Normalized AHP matrix of paired comparisons of major watershed classification.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.13	0.13	0.14	0.13	0.13	0.10	0.13	0.13	0.13	0.13	0.15	1.44	0.13
Site 2	0.13	0.13	0.10	0.13	0.13	0.10	0.13	0.13	0.13	0.13	0.15	1.41	0.13
Site 3	0.13	0.17	0.14	0.13	0.13	0.10	0.13	0.13	0.13	0.13	0.15	1.49	0.14
Site 4	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	0.07	0.07	0.07	0.75	0.07
Site 5	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.77	0.07
Site 6	0.06	0.06	0.06	0.06	0.04	0.05	0.03	0.03	0.03	0.03	0.04	0.50	0.05
Site 7	0.07	0.07	0.07	0.07	0.07	0.10	0.07	0.07	0.07	0.07	0.07	0.79	0.07
Site 8	0.07	0.07	0.07	0.07	0.07	0.10	0.07	0.07	0.07	0.07	0.07	0.79	0.07
Site 9	0.07	0.07	0.07	0.07	0.07	0.10	0.07	0.07	0.07	0.07	0.07	0.79	0.07
Site 10	0.07	0.07	0.07	0.07	0.07	0.10	0.07	0.07	0.07	0.07	0.06	0.79	0.07
Site 11	0.12	0.11	0.12	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.13	1.48	0.13
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.008 ; λmax = 11.08 ; m = 11 ; RI = 1.51

C.R = 0.005

Table C-7 Pairwise rating of candidate sites on the basis of average depth to water table (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	0.46	1.26	0.23	2.16	0.89	1.00	0.25	0.40	0.44	1.00
Site 2	2.19	1.00	1.88	0.31	2.02	1.14	1.45	0.32	0.80	0.89	1.52
Site 3	0.79	0.53	1.00	0.21	1.55	0.47	0.53	0.21	0.35	0.35	0.73
Site 4	4.38	3.25	4.88	1.00	3.86	2.89	2.93	1.07	2.32	2.58	3.04
Site 5	0.46	0.50	0.65	0.26	1.00	0.35	0.33	0.17	0.26	0.28	0.32
Site 6	1.13	0.88	2.13	0.35	2.88	1.00	1.07	0.29	0.53	0.53	1.07
Site 7	1.00	0.69	1.88	0.34	3.00	0.94	1.00	0.28	0.47	0.53	1.07
Site 8	4.00	3.13	4.75	0.94	5.75	3.50	3.63	1.00	2.30	2.47	2.90
Site 9	2.50	1.25	2.88	0.43	3.88	1.88	2.13	0.44	1.00	1.07	1.96
Site 10	2.25	1.13	2.88	0.39	3.63	1.88	1.88	0.40	0.94	1.00	1.71
Site 11	1.00	0.66	1.38	0.33	3.13	0.94	0.94	0.34	0.51	0.58	1.00
Column Sum	**20.69**	**13.45**	**25.54**	**4.77**	**32.84**	**15.87**	**16.88**	**4.77**	**9.87**	**10.73**	**16.32**

Table C-8 Normalized AHP matrix of paired comparisons of average depth to water table (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.05	0.03	0.05	0.05	0.07	0.06	0.06	0.05	0.04	0.04	0.06	0.56	0.05
Site 2	0.11	0.07	0.07	0.06	0.06	0.07	0.09	0.07	0.08	0.08	0.09	0.86	0.08
Site 3	0.04	0.04	0.04	0.04	0.05	0.03	0.03	0.04	0.04	0.03	0.04	0.42	0.04
Site 4	0.21	0.24	0.19	0.21	0.12	0.18	0.17	0.22	0.23	0.24	0.19	2.21	0.20
Site 5	0.02	0.04	0.03	0.05	0.03	0.02	0.02	0.04	0.03	0.03	0.02	0.32	0.03
Site 6	0.05	0.07	0.08	0.07	0.09	0.06	0.06	0.06	0.05	0.05	0.07	0.72	0.07
Site 7	0.05	0.05	0.07	0.07	0.09	0.06	0.06	0.06	0.05	0.05	0.07	0.67	0.06
Site 8	0.19	0.23	0.19	0.20	0.18	0.22	0.21	0.21	0.23	0.23	0.18	2.27	0.21
Site 9	0.12	0.09	0.11	0.09	0.12	0.12	0.13	0.09	0.10	0.10	0.12	1.19	0.11
Site 10	0.11	0.08	0.11	0.08	0.11	0.12	0.11	0.08	0.09	0.09	0.11	1.10	0.10
Site 11	0.05	0.05	0.05	0.07	0.10	0.06	0.06	0.07	0.05	0.05	0.06	0.67	0.06
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.017 ; λmax = 11.17 ; m = 11 ; RI = 1.51

C.R = 0.011

Table C-9 Pairwise rating of candidate sites on the basis of groundwater yields (m^3/hour).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	1.89	1.89	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 2	0.53	1.00	1.00	0.30	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Site 3	0.53	1.00	1.00	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Site 4	1.00	3.38	3.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 5	1.00	3.50	3.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 6	1.00	3.50	3.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 7	1.00	3.50	3.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 8	1.00	3.50	3.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 9	1.00	3.50	3.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 10	1.00	3.50	3.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 11	1.00	3.50	3.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Column Sum	**10.06**	**31.76**	**31.89**	**9.58**	**9.57**	**9.57**	**9.57**	**9.57**	**9.57**	**9.57**	**9.57**

Table C-10 Normalized AHP matrix of paired comparisons of groundwater yields (m^3/hour).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.10	0.06	0.06	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.05	0.10
Site 2	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.36	0.03
Site 3	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.35	0.03
Site 4	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.15	0.10
Site 5	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.16	0.11
Site 6	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.16	0.11
Site 7	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.16	0.11
Site 8	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.16	0.11
Site 9	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.16	0.11
Site 10	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.16	0.11
Site 11	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.16	0.11
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.005 ; λmax = 11.05 ; m = 11 ; RI = 1.51

C.R = 0.003

Table C-11 Pairwise rating of candidate sites on the basis of groundwater quality (TDS, mg/l).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	1.00	1.00	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96
Site 2	1.00	1.00	1.00	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96
Site 3	1.00	1.00	1.00	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96
Site 4	0.25	0.25	0.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 5	0.25	0.25	0.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 6	0.25	0.25	0.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 7	0.25	0.25	0.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 8	0.25	0.25	0.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 9	0.25	0.25	0.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 10	0.25	0.25	0.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site 11	0.25	0.25	0.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Column Sum	**5.02**	**5.02**	**5.02**	**19.89**	**19.89**	**19.89**	**19.89**	**19.89**	**19.89**	**19.89**	**19.89**

Table C-12 Normalized AHP matrix of paired comparisons of groundwater quality (TDS, mg/l).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	2.19	0.20
Site 2	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	2.19	0.20
Site 3	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	2.19	0.20
Site 4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.55	0.05
Site 5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.55	0.05
Site 6	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.55	0.05
Site 7	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.55	0.05
Site 8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.55	0.05
Site 9	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.55	0.05
Site 10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.55	0.05
Site 11	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.55	0.05
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.000 ; λmax = 11.00 ; m = 11 ; RI = 1.51

C.R = 0.000

Table C-13 Pairwise rating of candidate sites on the basis of distance to the nearest river (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	4.63	3.45	3.45	0.21	3.45	3.72	4.26	3.72	4.19	2.79
Site 2	0.22	1.00	0.23	0.25	0.13	0.22	0.24	0.53	0.24	0.47	0.22
Site 3	0.29	4.38	1.00	1.00	0.17	1.00	1.50	2.84	1.45	2.38	1.00
Site 4	0.29	4.00	1.00	1.00	0.17	1.00	1.37	3.02	1.45	2.38	1.00
Site 5	4.88	7.50	6.00	5.88	1.00	4.71	5.39	6.98	5.21	6.78	4.51
Site 6	0.29	4.50	1.00	1.00	0.21	1.00	1.37	3.12	1.14	2.44	1.00
Site 7	0.27	4.25	0.67	0.73	0.19	0.73	1.00	2.09	1.00	1.66	0.67
Site 8	0.23	1.88	0.35	0.33	0.14	0.32	0.48	1.00	0.72	1.00	0.31
Site 9	0.27	4.13	0.69	0.69	0.19	0.88	1.00	1.40	1.00	1.92	0.67
Site 10	0.24	2.13	0.42	0.42	0.15	0.41	0.60	1.00	0.52	1.00	0.31
Site 11	0.36	4.50	1.00	1.00	0.22	1.00	1.50	3.25	1.50	3.25	1.00
Column Sum	**8.33**	**42.88**	**15.81**	**15.75**	**2.78**	**14.72**	**18.18**	**29.48**	**17.97**	**27.45**	**13.47**

Table C-14 Normalized AHP matrix of paired comparisons of distance to the nearest river (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.12	0.11	0.22	0.22	0.07	0.23	0.20	0.14	0.21	0.15	0.21	1.89	0.17
Site 2	0.03	0.02	0.01	0.02	0.05	0.02	0.01	0.02	0.01	0.02	0.02	0.22	0.02
Site 3	0.03	0.10	0.06	0.06	0.06	0.07	0.08	0.10	0.08	0.09	0.07	0.81	0.07
Site 4	0.03	0.09	0.06	0.06	0.06	0.07	0.08	0.10	0.08	0.09	0.07	0.80	0.07
Site 5	0.59	0.17	0.38	0.37	0.36	0.32	0.30	0.24	0.29	0.25	0.33	3.60	0.33
Site 6	0.03	0.10	0.06	0.06	0.08	0.07	0.08	0.11	0.06	0.09	0.07	0.82	0.07
Site 7	0.03	0.10	0.04	0.05	0.07	0.05	0.06	0.07	0.06	0.06	0.05	0.63	0.06
Site 8	0.03	0.04	0.02	0.02	0.05	0.02	0.03	0.03	0.04	0.04	0.02	0.35	0.03
Site 9	0.03	0.10	0.04	0.04	0.07	0.06	0.06	0.05	0.06	0.07	0.05	0.62	0.06
Site 10	0.03	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.04	0.02	0.37	0.03
Site 11	0.04	0.10	0.06	0.06	0.08	0.07	0.08	0.11	0.08	0.12	0.07	0.89	0.08
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.039 ; λmax = 11.39 ; m = 11 ; RI = 1.51

C.R = 0.026

Table C-15 Pairwise rating of candidate sites on the basis of distance to the nearest lake (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	1.14	0.89	0.16	0.25	0.29	0.89	0.19	0.80	1.23	0.17
Site 2	0.88	1.00	0.80	0.16	0.25	0.29	0.73	0.18	0.73	1.14	0.17
Site 3	1.13	1.25	1.00	0.18	0.29	0.33	1.14	0.20	1.00	1.30	0.18
Site 4	6.13	6.25	5.63	1.00	4.32	4.62	6.23	2.09	6.48	8.05	1.14
Site 5	4.00	4.00	3.50	0.23	1.00	1.94	4.85	0.33	3.93	5.54	0.26
Site 6	3.50	3.50	3.00	0.22	0.51	1.00	4.14	0.25	3.50	4.97	0.25
Site 7	1.13	1.38	0.88	0.16	0.21	0.24	1.00	0.19	0.67	1.71	0.18
Site 8	5.38	5.50	5.13	0.48	3.00	4.00	5.25	1.00	5.36	6.80	0.57
Site 9	1.25	1.38	1.00	0.15	0.25	0.29	1.50	0.19	1.00	1.78	0.19
Site 10	0.81	0.88	0.77	0.12	0.18	0.20	0.58	0.15	0.56	1.00	0.16
Site 11	6.00	5.88	5.50	0.88	3.88	4.00	5.50	1.75	5.38	6.25	1.00
Column Sum	**31.19**	**32.14**	**28.08**	**3.74**	**14.14**	**17.19**	**31.81**	**6.51**	**29.41**	**39.78**	**4.27**

Table C-16 Normalized AHP matrix of paired comparisons of distance to the nearest lake (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.03	0.04	0.03	0.04	0.02	0.02	0.03	0.03	0.03	0.03	0.04	0.33	0.03
Site 2	0.03	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.02	0.03	0.04	0.31	0.03
Site 3	0.04	0.04	0.04	0.05	0.02	0.02	0.04	0.03	0.03	0.03	0.04	0.37	0.03
Site 4	0.20	0.19	0.20	0.27	0.31	0.27	0.20	0.32	0.22	0.20	0.27	2.64	0.24
Site 5	0.13	0.12	0.12	0.06	0.07	0.11	0.15	0.05	0.13	0.14	0.06	1.16	0.11
Site 6	0.11	0.11	0.11	0.06	0.04	0.06	0.13	0.04	0.12	0.12	0.06	0.95	0.09
Site 7	0.04	0.04	0.03	0.04	0.01	0.01	0.03	0.03	0.02	0.04	0.04	0.35	0.03
Site 8	0.17	0.17	0.18	0.13	0.21	0.23	0.17	0.15	0.18	0.17	0.13	1.90	0.17
Site 9	0.04	0.04	0.04	0.04	0.02	0.02	0.05	0.03	0.03	0.04	0.04	0.39	0.04
Site 10	0.03	0.03	0.03	0.03	0.01	0.01	0.02	0.02	0.02	0.03	0.04	0.26	0.02
Site 11	0.19	0.18	0.20	0.23	0.27	0.23	0.17	0.27	0.18	0.16	0.23	2.33	0.21
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.o41 ; λmax = 11.41 ; m = 11 ; RI = 1.51

C.R = 0.027

Table C-17 Pairwise rating of candidate sites on the basis of major soil group.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	0.33	0.33	1.35	3.34	3.34	1.20	1.82	3.23	3.23	3.23
Site 2	3.00	1.00	1.00	3.75	4.55	4.55	3.75	3.92	4.55	4.55	4.55
Site 3	3.00	1.00	1.00	4.00	5.21	5.21	4.00	4.32	5.21	5.21	5.21
Site 4	0.74	0.27	0.25	1.00	2.21	2.21	1.00	1.05	2.21	2.21	2.21
Site 5	0.30	0.22	0.19	0.45	1.00	1.00	0.33	0.53	1.00	1.00	1.00
Site 6	0.30	0.22	0.19	0.45	1.00	1.00	0.35	0.57	1.00	1.00	1.00
Site 7	0.83	0.27	0.25	1.00	3.00	2.88	1.00	1.25	1.82	1.82	1.79
Site 8	0.55	0.26	0.23	0.95	1.88	1.75	0.80	1.00	1.66	1.66	1.66
Site 9	0.31	0.22	0.19	0.45	1.00	1.00	0.55	0.60	1.00	1.00	1.00
Site 10	0.31	0.22	0.19	0.45	1.00	1.00	0.55	0.60	1.00	1.00	1.00
Site 11	0.31	0.22	0.19	0.45	1.00	1.00	0.56	0.60	1.00	1.00	1.00
Column Sum	**10.65**	**4.22**	**4.02**	**14.31**	**25.19**	**24.94**	**14.09**	**16.27**	**23.68**	**23.68**	**23.64**

Table C-18 Normalized AHP matrix of paired comparisons of major soil group.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.09	0.08	0.08	0.09	0.13	0.13	0.09	0.11	0.14	0.14	0.14	1.22	0.11
Site 2	0.28	0.24	0.25	0.26	0.18	0.18	0.27	0.24	0.19	0.19	0.19	2.48	0.23
Site 3	0.28	0.24	0.25	0.28	0.21	0.21	0.28	0.27	0.22	0.22	0.22	2.67	0.24
Site 4	0.07	0.06	0.06	0.07	0.09	0.09	0.07	0.06	0.09	0.09	0.09	0.86	0.08
Site 5	0.03	0.05	0.05	0.03	0.04	0.04	0.02	0.03	0.04	0.04	0.04	0.42	0.04
Site 6	0.03	0.05	0.05	0.03	0.04	0.04	0.02	0.04	0.04	0.04	0.04	0.43	0.04
Site 7	0.08	0.06	0.06	0.07	0.12	0.12	0.07	0.08	0.08	0.08	0.08	0.88	0.08
Site 8	0.05	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.71	0.06
Site 9	0.03	0.05	0.05	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.44	0.04
Site 10	0.03	0.05	0.05	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.44	0.04
Site 11	0.03	0.05	0.05	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.44	0.04
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.014 ; λmax = 11.14 ; m = 11 ; RI = 1.51

C.R = 0.009

Table C-19 Pairwise rating of candidate sites on the basis of distance to the nearest major road (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	1.52	1.00	1.00	1.75	1.71	1.37	1.37	1.07	0.33	1.71
Site 2	0.66	1.00	0.30	0.30	0.62	0.57	0.41	0.41	0.33	0.20	2.04
Site 3	1.00	3.29	1.00	1.00	1.57	1.45	1.39	1.39	1.14	0.33	1.72
Site 4	1.00	3.29	1.00	1.00	1.55	1.75	1.37	1.37	1.14	0.31	1.71
Site 5	0.57	1.63	0.64	0.65	1.00	1.00	0.50	0.57	0.39	0.21	1.75
Site 6	0.58	1.75	0.69	0.57	1.00	1.00	0.62	0.57	0.41	0.23	1.78
Site 7	0.73	2.44	0.72	0.73	2.00	1.63	1.00	1.00	0.50	0.26	1.63
Site 8	0.73	2.44	0.72	0.73	1.75	1.75	1.00	1.00	0.50	0.32	1.53
Site 9	0.94	3.04	0.88	0.88	2.56	2.44	2.00	2.00	1.00	0.30	1.70
Site 10	3.04	5.03	3.06	3.19	4.78	4.41	3.78	3.16	3.29	1.00	1.29
Site 11	0.59	0.49	0.58	0.59	0.57	0.56	0.61	0.65	0.59	0.78	1.00
Column Sum	**10.84**	**25.91**	**10.58**	**10.63**	**19.14**	**18.27**	**14.05**	**13.50**	**10.36**	**4.27**	**17.85**

Table C-20 Normalized AHP matrix of paired comparisons of distance to the nearest major road (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.09	0.06	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.08	0.10	1.00	0.09
Site 2	0.06	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.11	0.47	0.04
Site 3	0.09	0.13	0.09	0.09	0.08	0.08	0.10	0.10	0.11	0.08	0.10	1.05	0.10
Site 4	0.09	0.13	0.09	0.09	0.08	0.10	0.10	0.10	0.11	0.07	0.10	1.06	0.10
Site 5	0.05	0.06	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.05	0.10	0.61	0.06
Site 6	0.05	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.10	0.63	0.06
Site 7	0.07	0.09	0.07	0.07	0.10	0.09	0.07	0.07	0.05	0.06	0.09	0.84	0.08
Site 8	0.07	0.09	0.07	0.07	0.09	0.10	0.07	0.07	0.05	0.07	0.09	0.84	0.08
Site 9	0.09	0.12	0.08	0.08	0.13	0.13	0.14	0.15	0.10	0.07	0.10	1.19	0.11
Site 10	0.28	0.19	0.29	0.30	0.25	0.24	0.27	0.23	0.32	0.23	0.07	2.68	0.24
Site 11	0.05	0.02	0.06	0.06	0.03	0.03	0.04	0.05	0.06	0.18	0.06	0.63	0.06
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.051 ; λmax = 11.51 ; m = 11 ; RI = 1.51

C.R = 0.034

Table C-21 Pairwise rating of candidate sites on the basis of major land use.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	1.00	1.00	0.24	0.53	0.19	0.25	0.25	0.25	0.25	0.25
Site 2	1.00	1.00	1.00	0.24	0.67	0.19	0.25	0.25	0.25	0.25	0.25
Site 3	1.00	1.00	1.00	0.24	0.67	0.19	0.25	0.25	0.25	0.25	0.25
Site 4	4.13	4.13	4.13	1.00	1.94	0.38	1.00	1.00	1.00	1.00	1.00
Site 5	1.88	1.50	1.50	0.51	1.00	0.18	0.36	0.36	0.36	0.36	0.36
Site 6	5.31	5.31	5.31	2.63	5.53	1.00	1.81	1.81	1.81	1.81	1.81
Site 7	4.00	4.00	4.00	1.00	2.78	0.55	1.00	1.00	1.00	1.00	1.00
Site 8	4.00	4.00	4.00	1.00	2.78	0.55	1.00	1.00	1.00	1.00	1.00
Site 9	4.00	4.00	4.00	1.00	2.78	0.55	1.00	1.00	1.00	1.00	1.00
Site 10	4.00	4.00	4.00	1.00	2.78	0.55	1.00	1.00	1.00	1.00	1.00
Site 11	4.00	4.00	4.00	1.00	2.78	0.55	1.00	1.00	1.00	1.00	1.00
Column Sum	**34.31**	**33.94**	**33.94**	**9.87**	**24.25**	**4.89**	**8.92**	**8.92**	**8.92**	**8.92**	**8.92**

Table C-22 Normalized AHP matrix of paired comparisons of major land use.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.03	0.03	0.03	0.02	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.31	0.03
Site 2	0.03	0.03	0.03	0.02	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.32	0.03
Site 3	0.03	0.03	0.03	0.02	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.32	0.03
Site 4	0.12	0.12	0.12	0.10	0.08	0.08	0.11	0.11	0.11	0.11	0.11	1.18	0.11
Site 5	0.05	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.47	0.04
Site 6	0.15	0.16	0.16	0.27	0.23	0.20	0.20	0.20	0.20	0.20	0.20	2.18	0.20
Site 7	0.12	0.12	0.12	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	1.24	0.11
Site 8	0.12	0.12	0.12	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	1.24	0.11
Site 9	0.12	0.12	0.12	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	1.24	0.11
Site 10	0.12	0.12	0.12	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	1.24	0.11
Site 11	0.12	0.12	0.12	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	1.24	0.11
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.005 ; λmax = 11.05 ; m = 11 ; RI = 1.51

C.R = 0.003

Table C-23 Pairwise rating of candidate sites on the basis of number of village within 10 km.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	0.73	1.23	1.45	1.94	1.56	2.24	1.81	0.89	0.42	0.31
Site 2	1.38	1.00	1.78	2.03	2.24	1.58	2.30	1.88	1.00	0.42	0.33
Site 3	0.81	0.56	1.00	1.23	1.50	1.54	2.16	1.00	0.44	0.35	0.29
Site 4	0.69	0.49	0.81	1.00	1.07	1.46	1.37	1.00	0.40	0.28	0.23
Site 5	0.51	0.45	0.67	0.94	1.00	1.38	1.71	0.80	0.32	0.24	0.23
Site 6	0.64	0.63	0.65	0.68	0.72	1.00	0.36	0.24	0.21	0.18	0.16
Site 7	0.45	0.44	0.46	0.73	0.58	2.75	1.00	0.51	0.27	0.24	0.20
Site 8	0.55	0.53	1.00	1.00	1.25	4.13	1.98	1.00	0.44	0.29	0.25
Site 9	1.13	1.00	2.25	2.50	3.13	4.88	3.75	2.25	1.00	0.36	0.33
Site 10	2.38	2.38	2.88	3.63	4.25	5.71	4.25	3.50	2.75	1.00	0.47
Site 11	3.19	3.06	3.44	4.31	4.30	6.16	4.93	3.94	3.06	2.13	1.00
Column Sum	**12.72**	**11.27**	**16.16**	**19.50**	**21.98**	**32.14**	**26.06**	**17.93**	**10.78**	**5.89**	**3.81**

Table C-24 Normalized AHP matrix of paired comparisons of number of village within 10 km.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.08	0.06	0.08	0.07	0.09	0.05	0.09	0.10	0.08	0.07	0.08	0.85	0.08
Site 2	0.11	0.09	0.11	0.10	0.10	0.05	0.09	0.10	0.09	0.07	0.09	1.00	0.09
Site 3	0.06	0.05	0.06	0.06	0.07	0.05	0.08	0.06	0.04	0.06	0.08	0.67	0.06
Site 4	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.06	0.04	0.05	0.06	0.55	0.05
Site 5	0.04	0.04	0.04	0.05	0.05	0.04	0.07	0.04	0.03	0.04	0.06	0.50	0.05
Site 6	0.05	0.06	0.04	0.04	0.03	0.03	0.01	0.01	0.02	0.03	0.04	0.36	0.03
Site 7	0.04	0.04	0.03	0.04	0.03	0.09	0.04	0.03	0.02	0.04	0.05	0.44	0.04
Site 8	0.04	0.05	0.06	0.05	0.06	0.13	0.08	0.06	0.04	0.05	0.07	0.68	0.06
Site 9	0.09	0.09	0.14	0.13	0.14	0.15	0.14	0.13	0.09	0.06	0.09	1.25	0.11
Site 10	0.19	0.21	0.18	0.19	0.19	0.18	0.16	0.20	0.26	0.17	0.12	2.04	0.19
Site 11	0.25	0.27	0.21	0.22	0.20	0.19	0.19	0.22	0.28	0.36	0.26	2.66	0.24
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.036 ; λmax = 11.36 ; m = 11 ; RI = 1.51

C.R = 0.024

Table C-25 Pairwise rating of candidate sites on the basis of distance to the nearest village (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	1.77	1.76	1.27	1.19	1.73	1.56	1.48	1.50	1.48	1.50
Site 2	0.57	1.00	0.89	0.73	0.44	1.00	0.67	0.42	0.47	0.42	0.47
Site 3	0.57	1.13	1.00	0.80	0.44	1.00	0.80	0.44	0.50	0.44	0.50
Site 4	0.78	1.38	1.25	1.00	0.57	1.23	0.89	0.53	0.80	0.53	0.67
Site 5	0.84	2.25	2.25	1.75	1.00	1.59	1.43	1.00	1.41	1.00	1.30
Site 6	0.58	1.00	1.00	0.81	0.63	1.00	0.67	0.44	0.50	0.42	0.50
Site 7	0.64	1.50	1.25	1.13	0.70	1.50	1.00	0.65	0.80	0.53	0.80
Site 8	0.68	2.38	2.25	1.88	1.00	2.25	1.54	1.00	1.48	0.84	1.30
Site 9	0.67	2.13	2.00	1.25	0.71	2.00	1.25	0.68	1.00	0.62	1.00
Site 10	0.68	2.38	2.25	1.88	1.00	2.38	1.88	1.19	1.63	1.00	1.30
Site 11	0.67	2.13	2.00	1.50	0.77	2.00	1.25	0.77	1.00	0.77	1.00
Column Sum	**7.66**	**19.02**	**17.90**	**13.99**	**8.46**	**17.68**	**12.93**	**8.60**	**11.08**	**8.06**	**10.33**

Table C-26 Normalized AHP matrix of paired comparisons of distance to the nearest village (m).

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.13	0.09	0.10	0.09	0.14	0.10	0.12	0.17	0.14	0.18	0.15	1.41	0.13
Site 2	0.07	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.04	0.05	0.05	0.58	0.05
Site 3	0.07	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.62	0.06
Site 4	0.10	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.06	0.79	0.07
Site 5	0.11	0.12	0.13	0.13	0.12	0.09	0.11	0.12	0.13	0.12	0.13	1.29	0.12
Site 6	0.08	0.05	0.06	0.06	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.62	0.06
Site 7	0.08	0.08	0.07	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.08	0.85	0.08
Site 8	0.09	0.12	0.13	0.13	0.12	0.13	0.12	0.12	0.13	0.10	0.13	1.32	0.12
Site 9	0.09	0.11	0.11	0.09	0.08	0.11	0.10	0.08	0.09	0.08	0.10	1.04	0.09
Site 10	0.09	0.12	0.13	0.13	0.12	0.13	0.15	0.14	0.15	0.12	0.13	1.40	0.13
Site 11	0.09	0.11	0.11	0.11	0.09	0.11	0.10	0.09	0.09	0.10	0.10	1.09	0.10
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.010 ; λmax = 11.10 ; m = 11 ; RI = 1.51

C.R = 0.006

Table C-27 Pairwise rating of candidate sites on the basis of unemployed rate within 10 km.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	1.00	1.00	0.47	0.24	1.14	1.00	1.00	2.34	1.00	1.00
Site 2	1.00	1.00	1.00	0.57	0.27	1.00	1.00	1.00	2.29	1.00	1.00
Site 3	1.00	1.00	1.00	0.53	0.35	1.00	1.00	1.00	1.33	1.23	1.00
Site 4	2.13	1.75	1.88	1.00	0.38	2.40	1.09	1.09	2.91	2.79	2.46
Site 5	4.25	3.75	2.88	2.63	1.00	2.19	2.74	2.91	4.21	3.50	3.50
Site 6	0.88	1.00	1.00	0.42	0.46	1.00	1.00	1.00	1.00	1.00	1.00
Site 7	1.00	1.00	1.00	0.92	0.36	1.00	1.00	1.00	1.17	1.00	1.00
Site 8	1.00	1.00	1.00	0.92	0.34	1.00	1.00	1.00	1.20	1.00	1.00
Site 9	0.43	0.44	0.75	0.34	0.24	1.00	0.85	0.83	1.00	0.67	0.67
Site 10	1.00	1.00	0.81	0.36	0.29	1.00	1.00	1.00	1.50	1.00	1.00
Site 11	1.00	1.00	1.00	0.41	0.29	1.00	1.00	1.00	1.50	1.00	1.00
Column Sum	**14.68**	**13.94**	**13.31**	**8.56**	**4.20**	**13.73**	**12.69**	**12.83**	**20.45**	**15.19**	**14.63**

Table C-28 Normalized AHP matrix of paired comparisons of unemployed rate within 10 km.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.07	0.07	0.08	0.05	0.06	0.08	0.08	0.08	0.11	0.07	0.07	0.81	0.07
Site 2	0.07	0.07	0.08	0.07	0.06	0.07	0.08	0.08	0.11	0.07	0.07	0.82	0.07
Site 3	0.07	0.07	0.08	0.06	0.08	0.07	0.08	0.08	0.07	0.08	0.07	0.80	0.07
Site 4	0.14	0.13	0.14	0.12	0.09	0.17	0.09	0.09	0.14	0.18	0.17	1.46	0.13
Site 5	0.29	0.27	0.22	0.31	0.24	0.16	0.22	0.23	0.21	0.23	0.24	2.60	0.24
Site 6	0.06	0.07	0.08	0.05	0.11	0.07	0.08	0.08	0.05	0.07	0.07	0.78	0.07
Site 7	0.07	0.07	0.08	0.11	0.09	0.07	0.08	0.08	0.06	0.07	0.07	0.83	0.08
Site 8	0.07	0.07	0.08	0.11	0.08	0.07	0.08	0.08	0.06	0.07	0.07	0.83	0.08
Site 9	0.03	0.03	0.06	0.04	0.06	0.07	0.07	0.06	0.05	0.04	0.05	0.56	0.05
Site 10	0.07	0.07	0.06	0.04	0.07	0.07	0.08	0.08	0.07	0.07	0.07	0.75	0.07
Site 11	0.07	0.07	0.08	0.05	0.07	0.07	0.08	0.08	0.07	0.07	0.07	0.77	0.07
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.018 ; λmax = 11.18 ; m = 11 ; RI = 1.51

C.R = 0.012

Table C-29 Pairwise rating of candidate sites on the basis of number of population within 10 km.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Site 1	1.00	0.59	1.41	2.50	2.53	2.14	3.31	2.50	0.57	0.59	0.32
Site 2	1.69	1.00	1.41	2.50	2.26	1.85	3.26	2.41	0.89	0.70	0.32
Site 3	0.71	0.71	1.00	2.00	1.50	1.33	2.93	1.78	0.62	0.59	0.26
Site 4	0.40	0.40	0.50	1.00	0.89	0.91	2.00	1.00	0.31	0.29	0.19
Site 5	0.40	0.44	0.67	1.13	1.00	1.04	2.09	1.14	0.35	0.30	0.20
Site 6	0.47	0.54	0.75	1.10	0.96	1.00	0.76	0.48	0.25	0.25	0.19
Site 7	0.30	0.31	0.34	0.50	0.48	1.31	1.00	0.44	0.24	0.23	0.17
Site 8	0.40	0.41	0.56	1.00	0.88	2.06	2.25	1.00	0.35	0.30	0.20
Site 9	1.75	1.13	1.63	3.25	2.88	3.94	4.25	2.88	1.00	0.67	0.32
Site 10	1.69	1.44	1.69	3.44	3.31	4.04	4.44	3.31	1.50	1.00	0.30
Site 11	3.16	3.16	3.90	5.15	4.90	5.27	6.02	5.03	3.16	3.29	1.00
Column Sum	**11.95**	**10.12**	**13.86**	**23.57**	**21.58**	**24.89**	**32.31**	**21.97**	**9.22**	**8.21**	**3.46**

Table C-30 Normalized AHP matrix of paired comparisons of number of population within 10 km.

Candidate Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	**Row Sum**	**relative weights**
Site 1	0.08	0.06	0.10	0.11	0.12	0.09	0.10	0.11	0.06	0.07	0.09	1.00	0.09
Site 2	0.14	0.10	0.10	0.11	0.10	0.07	0.10	0.11	0.10	0.08	0.09	1.11	0.10
Site 3	0.06	0.07	0.07	0.08	0.07	0.05	0.09	0.08	0.07	0.07	0.07	0.79	0.07
Site 4	0.03	0.04	0.04	0.04	0.04	0.04	0.06	0.05	0.03	0.04	0.06	0.46	0.04
Site 5	0.03	0.04	0.05	0.05	0.05	0.04	0.06	0.05	0.04	0.04	0.06	0.51	0.05
Site 6	0.04	0.05	0.05	0.05	0.04	0.04	0.02	0.02	0.03	0.03	0.05	0.44	0.04
Site 7	0.03	0.03	0.02	0.02	0.02	0.05	0.03	0.02	0.03	0.03	0.05	0.33	0.03
Site 8	0.03	0.04	0.04	0.04	0.04	0.08	0.07	0.05	0.04	0.04	0.06	0.53	0.05
Site 9	0.15	0.11	0.12	0.14	0.13	0.16	0.13	0.13	0.11	0.08	0.09	1.35	0.12
Site 10	0.14	0.14	0.12	0.15	0.15	0.16	0.14	0.15	0.16	0.12	0.09	1.53	0.14
Site 11	0.26	0.31	0.28	0.22	0.23	0.21	0.19	0.23	0.34	0.40	0.29	2.96	0.27
Column Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**11.00**	**1.000**

C.I. = 0.026 ; λmax = 11.26 ; m = 11 ; RI = 1.51

C.R = 0.017

APPENDIX D

User's Manual of EGIS

User's Manual of EGIS

Contents

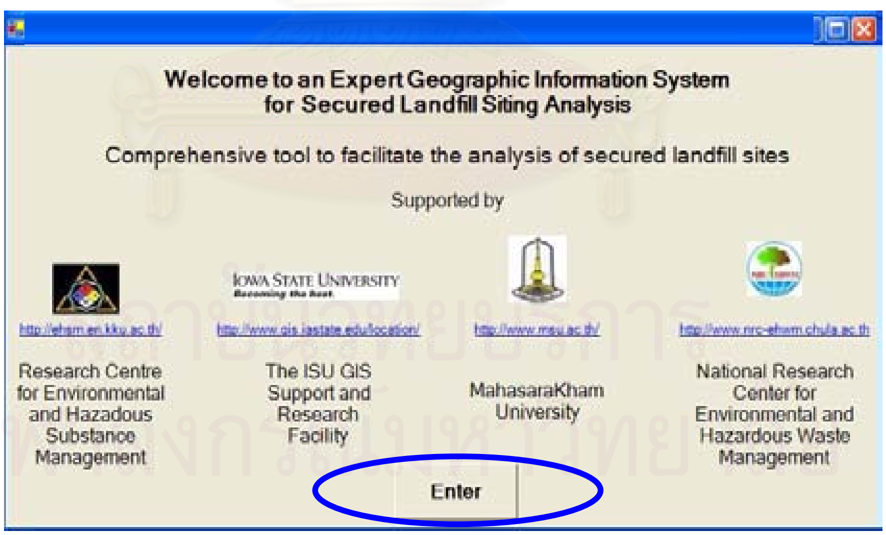
1. Brief overview of EGIS

The EGIS is the tool for facilitating the siting processes of secured landfill. It integrates Geographic Information System (GIS), Expert System (ES), Analytic Hierarchy Process (AHP), and Visual MODFLOW into a packaged tool. The GIS represents a spatial data, ES represents a knowledge base about secured landfill siting including spatial planning, AHP is applied for ranking of candidate sites, and Visual MODFLOW Model is used as a tool for predicting the possible groundwater impacts from the preferred sites.

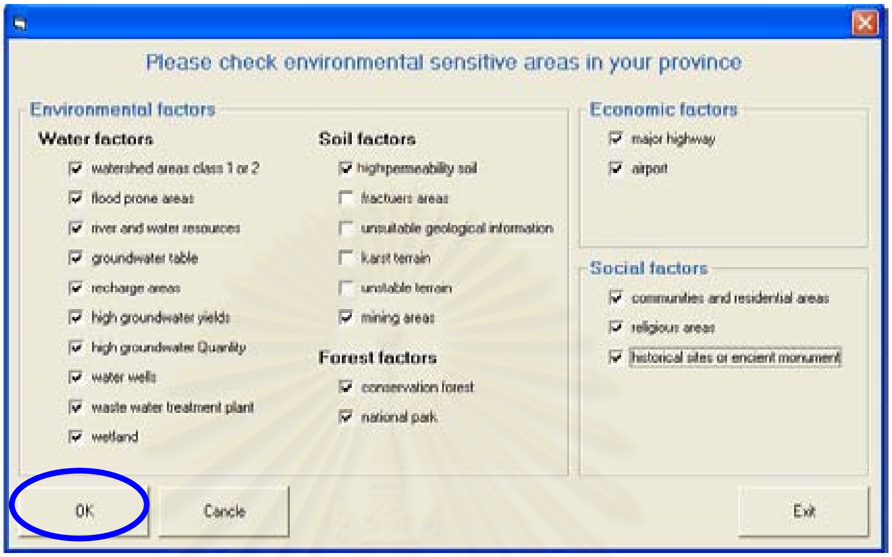
2. Identifying screening criteria by ES

Open EGIS by clicking EGIS program from the program menu

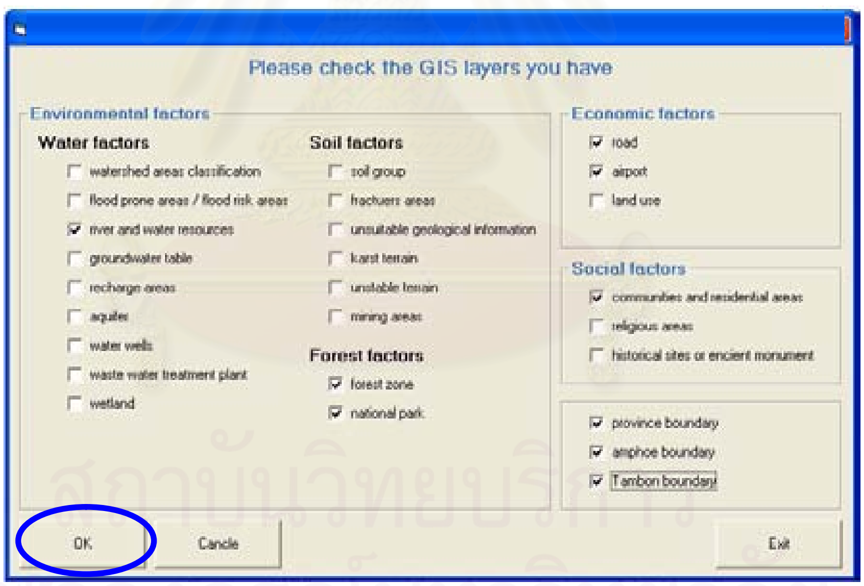
When you enter the system, the first page of ES, a welcome page will be shown. Click Enter button.



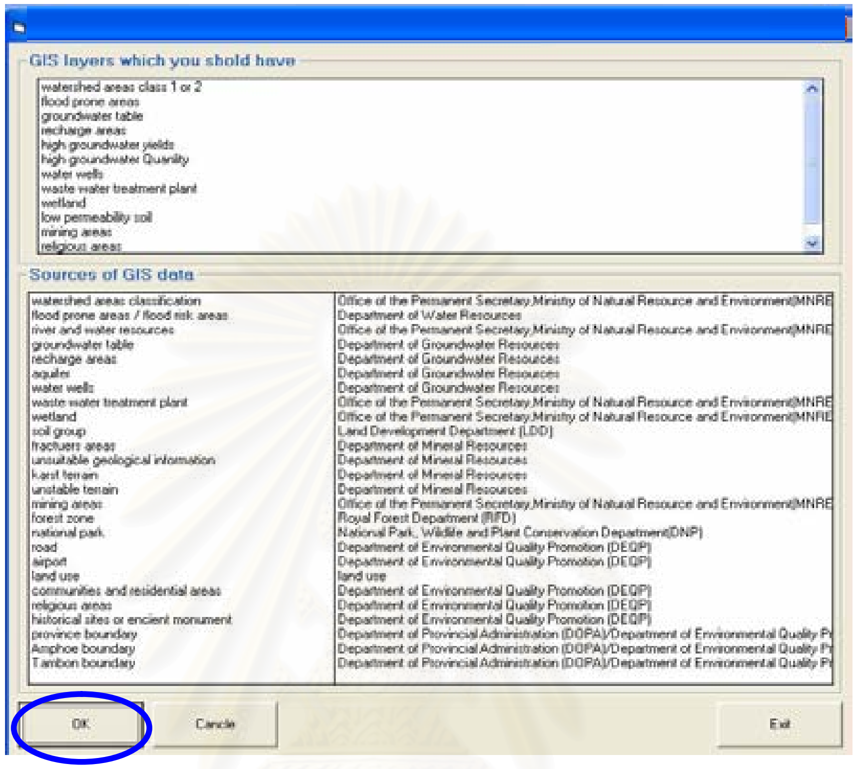
Then you will be asked to mark all the environmental sensitive areas in your study area. After you finish marking, click OK.



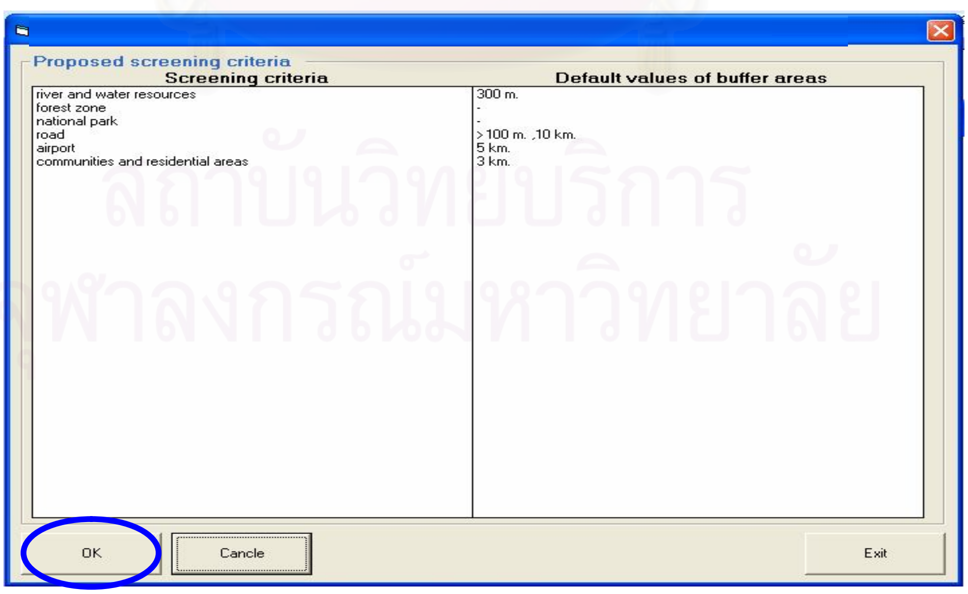
Mark all GIS data you have. Then Click OK.



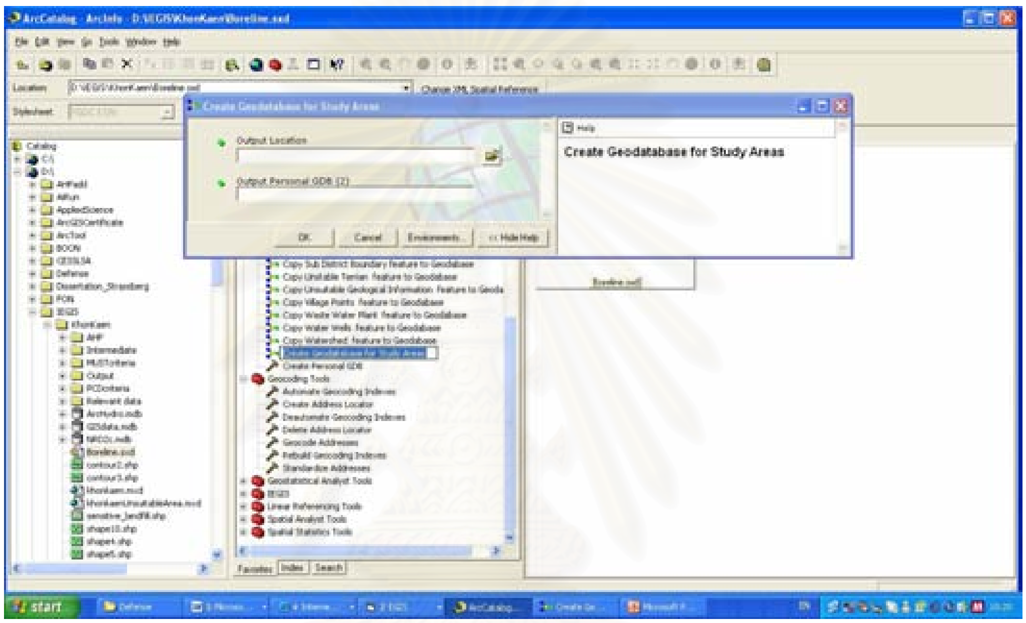
The ES will recommend GIS layers that you should have and also suggest the available sources of those GIS data as shown below. Click OK.



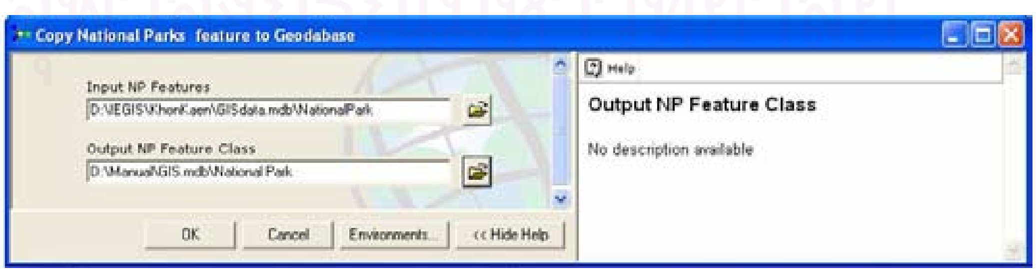
ES then provides the screening criteria with the default value of buffer distance based on the available GIS data inputted into the ES. Click OK.



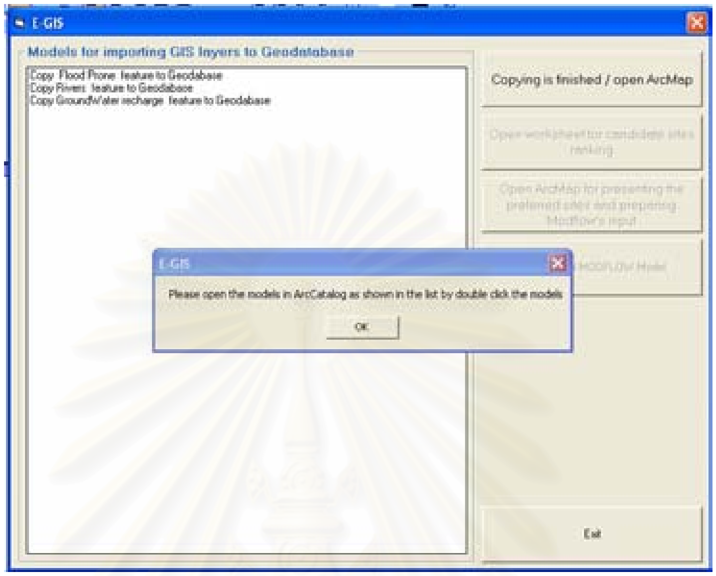
The system will open ArcCatalog. You have to create the new Geodatabase by double clicking on the model of Create Geodatabase for Study Areas. Click the Browse button next to out put location box and navigate to folder you want to store your Geodatabase, then click Add. Name the output Personal GDB as GIS, then click OK. GIS.mdb will be used to store GIS data which you will copy into the system in the next step.



To copy all GIS you have into the created Geodatabase, click the Browse button next to the Input Features box and navigate to your GIS data source, then click Add. Click the Browse button next to the Output Features box and navigate to the created Geodatabase from the previous step. Name the output feature class, click save. Click OK.

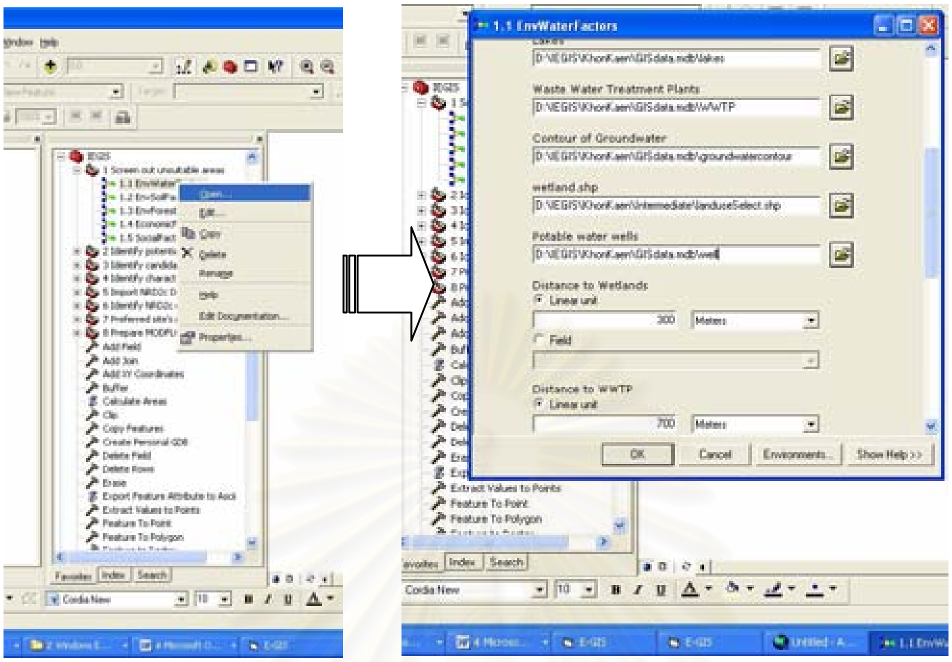


Copy others GIS data into Geodatabase using the same step as mentioned in previous. When you finished copying GIS data, activate ES. Click OK and then click open ArcMap button.



3. Screening out unsuitable areas for secured landfill sites by running GIS models

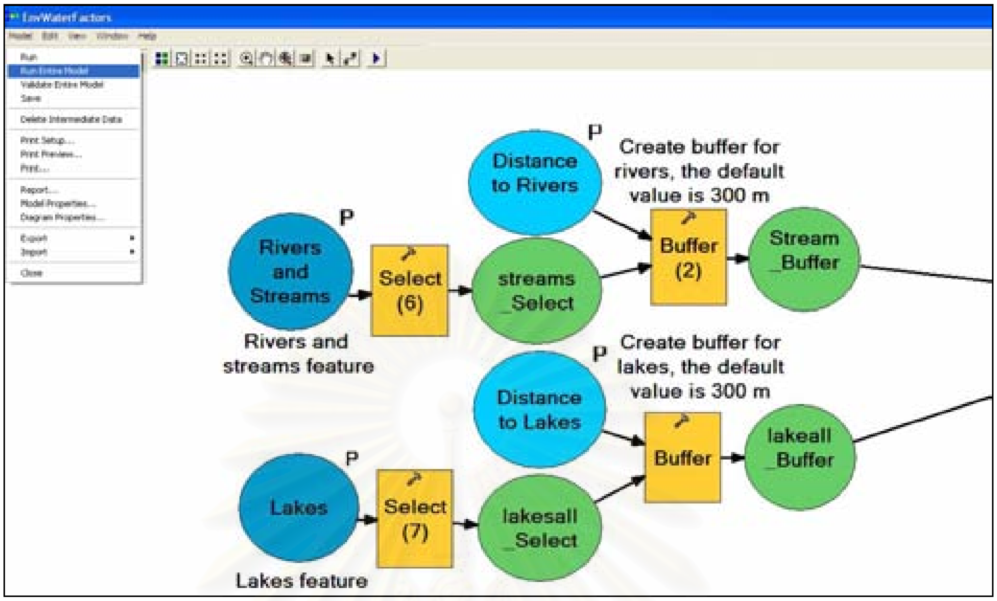
ES will open ArcMap. Click OK to create a new empty map. Click IEGIS toolset and then Click 1 Screeen out unsuitable areas to activate the Screen out unsuitable areas toolbox. Then right click at 1.1 EnvWaterFactors , click Open. The interface of the model will be showed, click the Browse button next to the Input Feature box to navigate to the data source. In this step, you can change the value of buffer distance if you want.



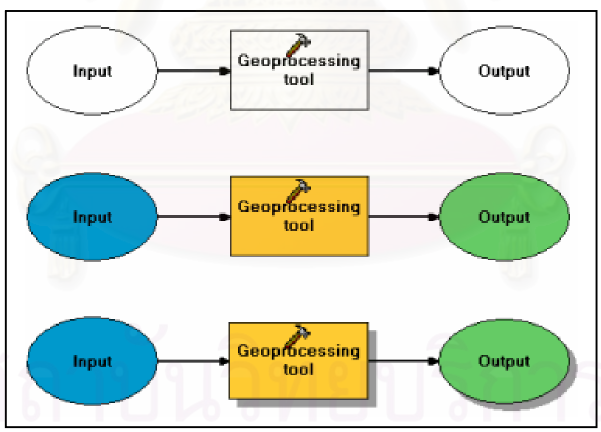
When you finish inputting all of GIS data you have, click OK to run the model. The out put of this step is the unsuitable areas for secured landfill based on the water factor.

You can also run the model by right clicking on it and choose edit. The ModelBuilder window will pop up. A model diagram shows all the processes and the sequence in which they run. The connecting arrows show how elements and processes are related to each other. The output of one process can be used as the input for another. You can select only the process that is ready to run by right clicking on it and selecting run.

Click Model in the menu bar, select run Entire Model for running the entire model.



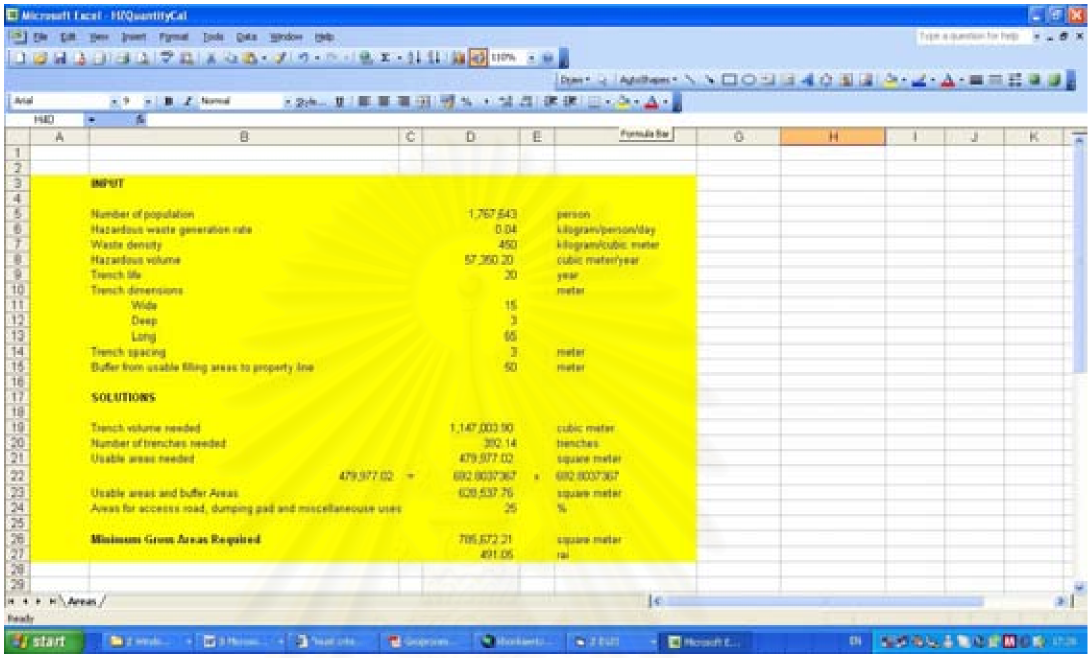
If all the elements in a process are colored, this means the tool has everything it needs and the process is ready to run. When tools and outputs display with a dropshadow, which means the process has run successfully.



Run all of models in 1 Screeen out unsuitable areas toolbox, and then run Identify potential areas model in 2 Identify potential areas toolbox, you will get a map showing potential areas for secured landfill.

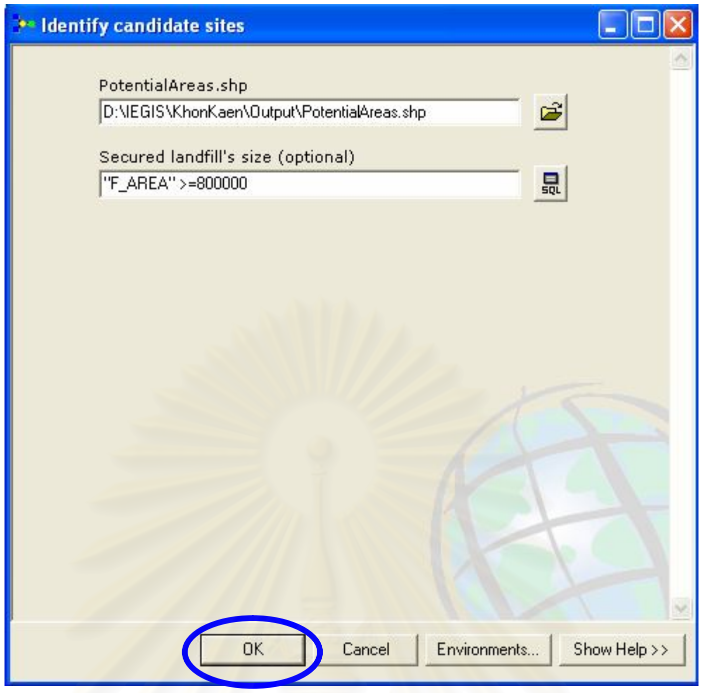
4. Identifying candidate sites for secured landfill

Then open file: HZQuantityCal under IEGIS folder to calculate the appropriate size of secured landfill site.



INPUT			
Number of population		1,767,643	person
Hazardous waste generation rate		0.04	kilogram/person/day
Waste density		450	kilogram/cubic meter
Hazardous volume		57,350.20	cubic meter/year
Trench life		20	year
Trench dimensions			meter
Wide		15	
Deep		3	
Long		65	
Trench spacing		3	meter
Buffer from usable filling areas to property line		50	meter
SOLUTIONS			
Trench volume needed		1,147,003.90	cubic meter
Number of trenches needed		392.14	trenches
Usable areas needed		479,977.02	square meter
	479,977.02 =	692.8037367 x	692.8037367
Usable areas and buffer Areas		628,537.76	square meter
Areas for access road, dumping pad and miscellaneous uses		25	%
Minimum Gross Areas Required		785,672.21	square meter
		491.05	rai

Activate ArcMap, and run Identify candidate sites model. In secured landfill' size box, type the minimum gross areas required which was obtained from the previous step after "F_AREA" >=. Click OK to run the model, you will get the candidate sites of secured landfill.



Run models in 4 Identify characteristic of candidate sites toolbox to identify characteristics of candidates sites based on the factors (eg. distance from the nearest water resource) derived from the considered criteria (eg. water resource) used in the screening process. In this step, it is recommended to run the model through the ModelBuilder. You can delete the process which you do not have GIS data by deleting all element of the process.

Then run models in 5 Import NRD2c Data to import and modify NRD2c data. through the modify NRD2c data model for deleting unwanted data and keeping only variables number Q1_3_1 and Q45_1b which are variables of number of population and employment rate, respectively.

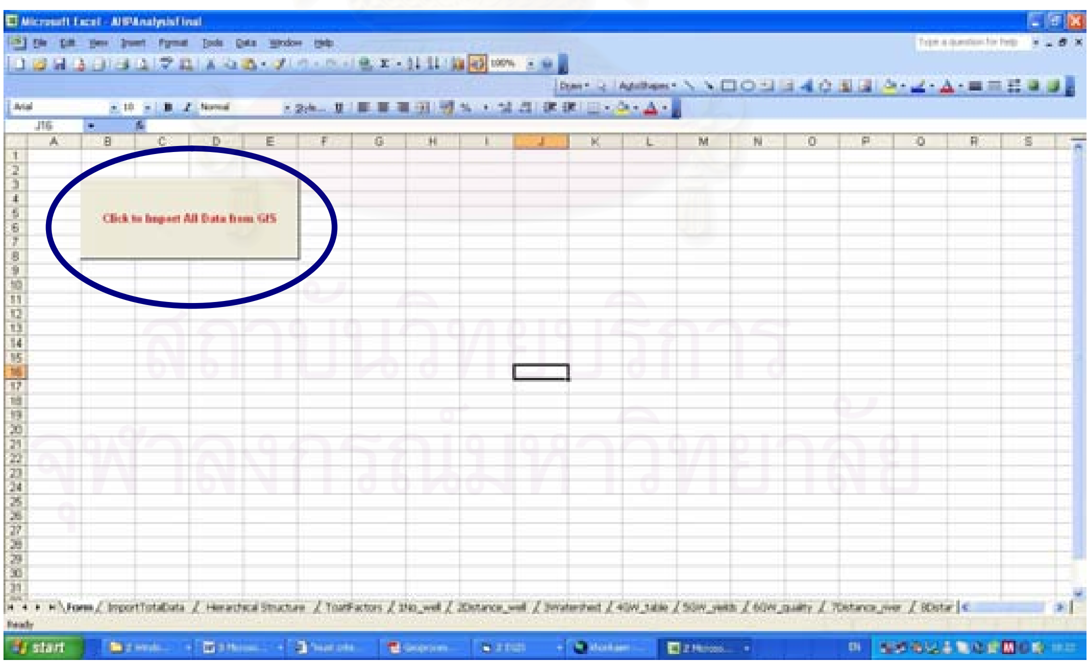
Run 6 Identify NRD2c of candidate sites to identify NRD2c of candidate sites.

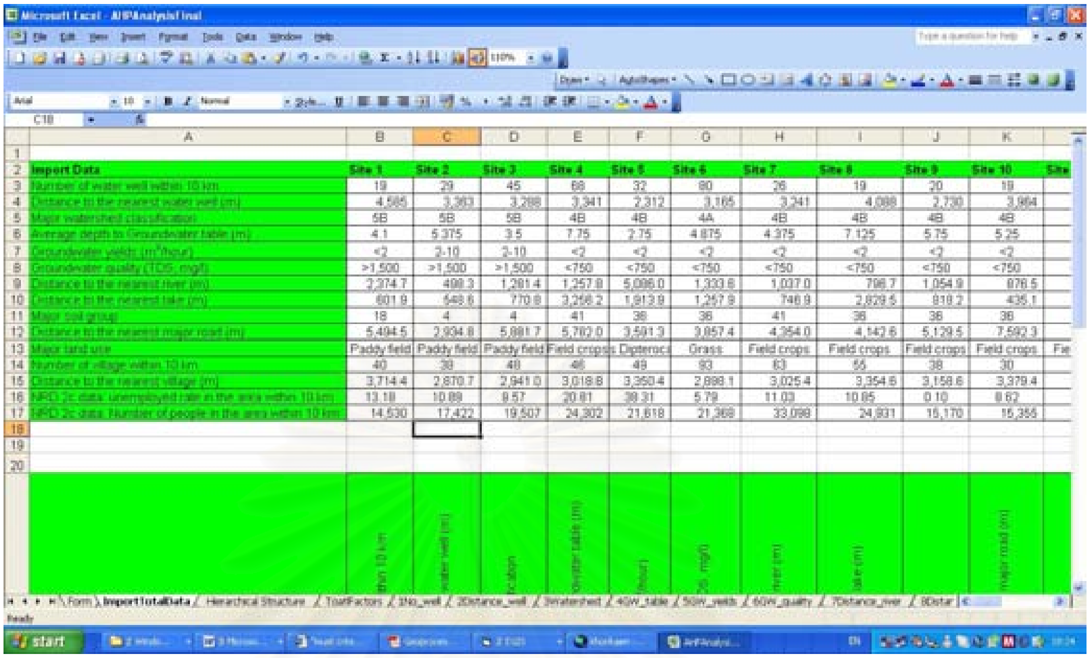
5. Ranking candidate sites

Open AHP folder and open the Microsoft excel files listed below:

AHPAnalysisFinal	1,017 KB	Microsoft Excel Worksheet	23/4/2551 8:54
DistLakerData	242 KB	Microsoft Excel Worksheet	24/4/2551 16:37
DistRiverData	209 KB	Microsoft Excel Worksheet	7/4/2551 9:42
DistRoadData	242 KB	Microsoft Excel Worksheet	7/4/2551 9:44
DistVillageData	209 KB	Microsoft Excel Worksheet	7/4/2551 9:45
DistWellData	235 KB	Microsoft Excel Worksheet	30/3/2551 21:49
GWQualityData	253 KB	Microsoft Excel Worksheet	7/4/2551 11:57
GWTableData	211 KB	Microsoft Excel Worksheet	30/3/2551 22:07
GWYiedData	253 KB	Microsoft Excel Worksheet	7/4/2551 11:57
HZQuantityCal	20 KB	Microsoft Excel Worksheet	4/4/2551 15:30
LandUseData	261 KB	Microsoft Excel Worksheet	7/4/2551 11:00
NoVillageData	368 KB	Microsoft Excel Worksheet	7/4/2551 10:07
NoWellData	254 KB	Microsoft Excel Worksheet	30/3/2551 21:40
NRD2cData	192 KB	Microsoft Excel Worksheet	7/4/2551 0:41
SoilGroupData	260 KB	Microsoft Excel Worksheet	7/4/2551 12:13
WatershedData	160 KB	Microsoft Excel Worksheet	7/4/2551 11:12
WeightAHP	836 KB	Microsoft Excel Worksheet	7/4/2551 14:49

Import .dbf files in to each file by clicking the [Click to Import All Data from GIS] button of each file. Activate [Microsoft Excel - AHPAnalysisFinal] file and Click [Click to Import All Data from GIS] to import all of GIS data generated by GIS models.

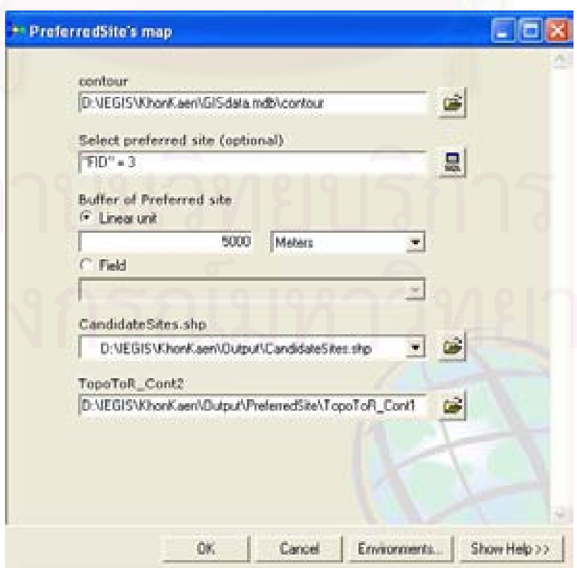




Open the ExpertInput folder, then open 1AHPAnalysis file to implement AHP for ranking candidate sites. The outputs of this step are the relative weights of factors and ranking of candidate sites.

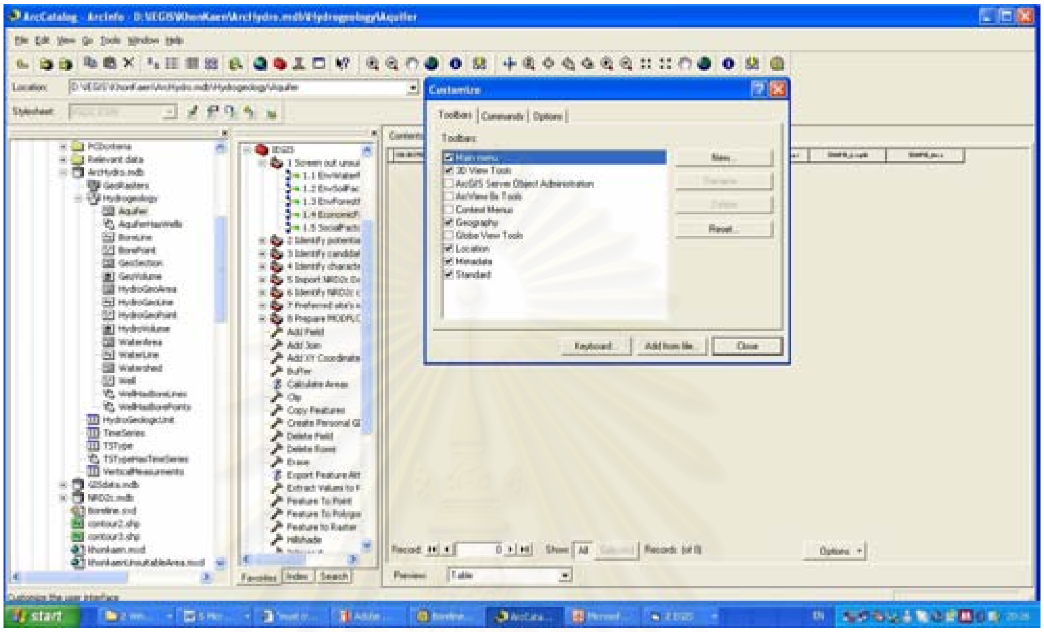
6. Presenting planning maps of preferred site by GIS models

Run PreferredSite's map model to present the map of preferred site.

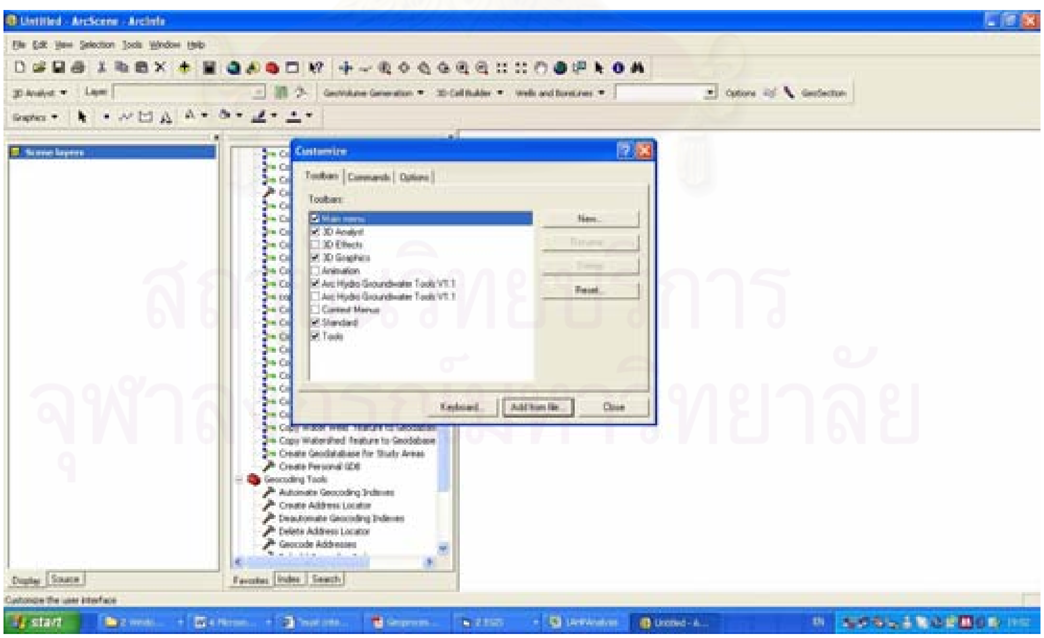


7. Preparing Visual MODFLOW Model's input by GIS models

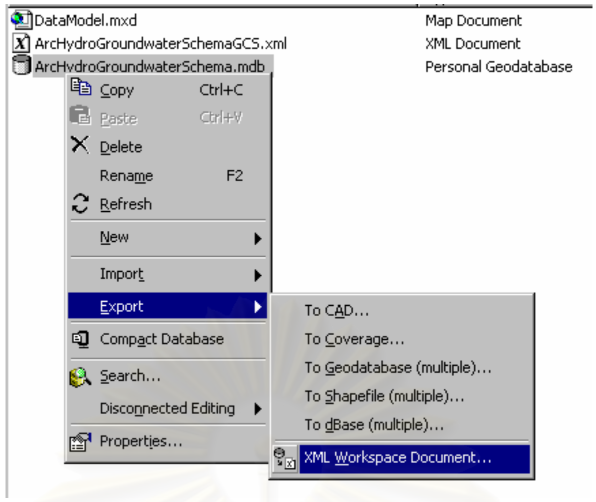
Add the Change XML Spatial Reference toolbar to ArcCatalog by importing the ChangeXMLSpatialRef.dll file through the customize option.



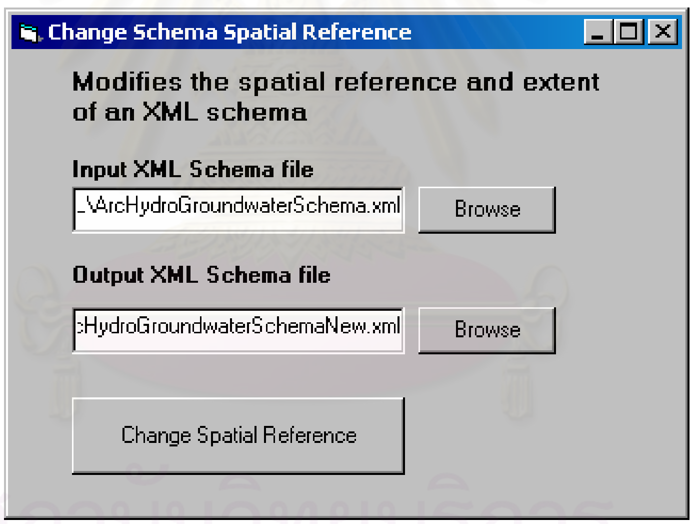
Adding Arc Hydro groundwater toolbar into the toolbar menu of ArcScene by customizing and adding the GroundwaterToolbar09192005.dll file through the customize option



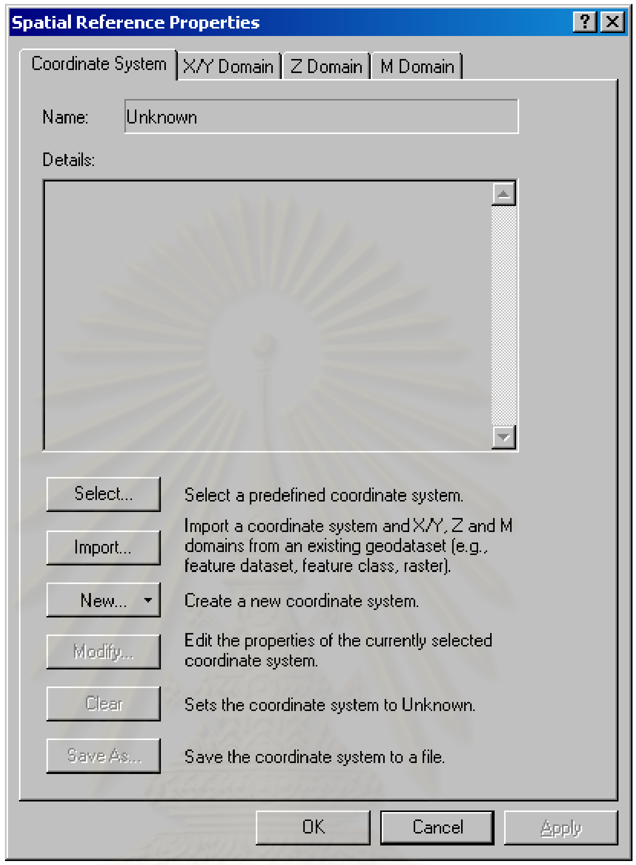
Create an XML schema from the ArcHydroGroundwater_Schema.mdb by using the Export to XML Workspace Document tool in ArcCatalog.



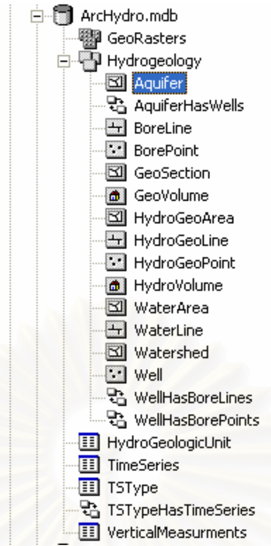
Open the Change XML Spatial Reference toolbar and specify the input and output XML files by browsing to the input XML schema and specifying the output location for the new XML file. Then, change the spatial reference of the schema to GCS_Indian_1975 through the spatial reference dialog and run the tool.



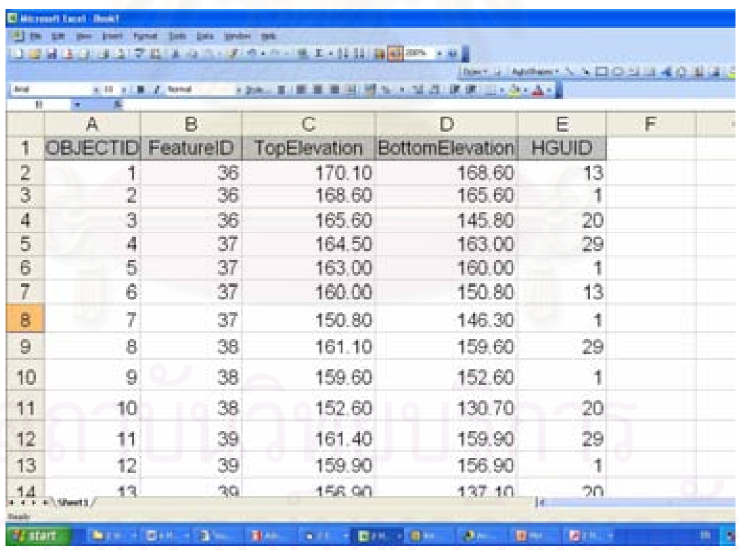
Select the change spatial reference button to start the spatial reference dialog.



Import the new schema to the created geodatabase through the import XML workspace document by selecting the schema only option and specify the schema with the new spatial reference as the XML source. Once the tool has run the geodatabase will contain all the feature datasets, feature classes, and relationships defined in the XML schema



Create the feature dataset and the relationships between feature classes and tables fit to the schematic of the model. The necessary data in this step is lithology data which can be obtain from the Department of Groundwater Resources. The lithology file is in PDF format and must be converted to DBF format for further analysis in ArcMap and ArcScene. The needed format of DBF file is shown below.



	A	B	C	D	E	F
1	OBJECTID	FeatureID	TopElevation	BottomElevation	HGUID	
2	1	36	170.10	168.60	13	
3	2	36	168.60	165.60	1	
4	3	36	165.60	145.80	20	
5	4	37	164.50	163.00	29	
6	5	37	163.00	160.00	1	
7	6	37	160.00	150.80	13	
8	7	37	150.80	146.30	1	
9	8	38	161.10	159.60	29	
10	9	38	159.60	152.60	1	
11	10	38	152.60	130.70	20	
12	11	39	161.40	159.90	29	
13	12	39	159.90	156.90	1	
14	13	39	156.90	137.10	20	

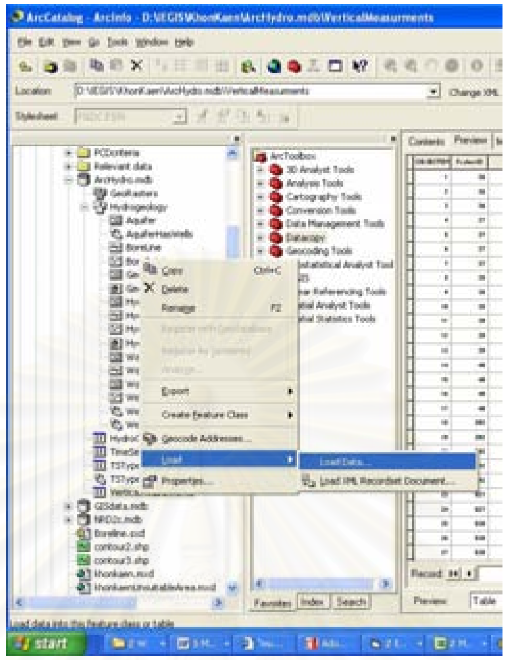
FatureID = ID of well feature

TopElevation = Top elevation of the hydrostratigraphic

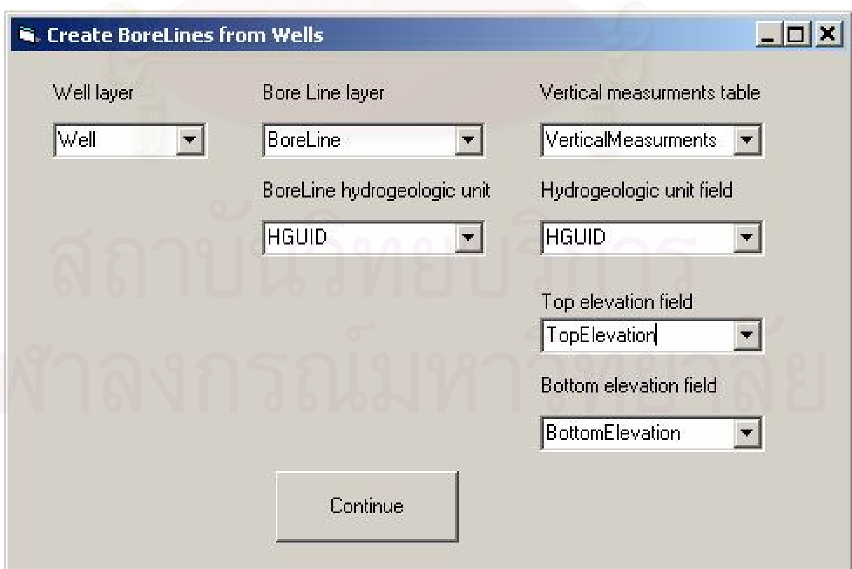
BottomElevation = Bottom elevation of the hydrostratigraphic

HUGI = Hydrostratigraphic

Load the prepared DBF file in to Verticalmeasurments table.

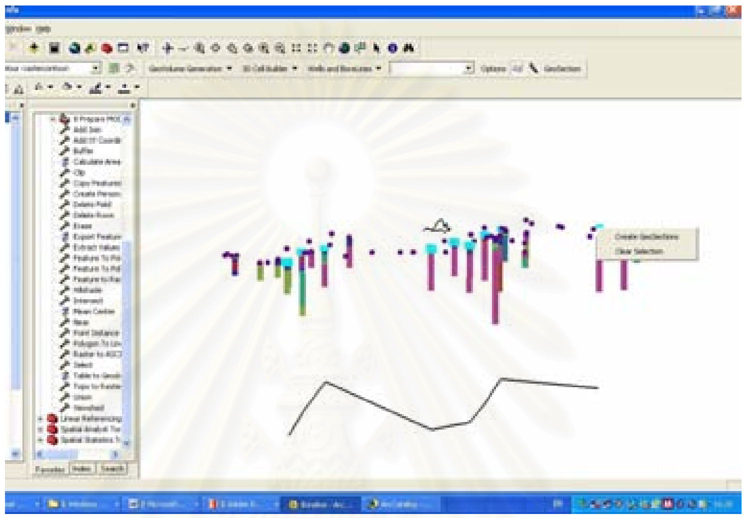


Create BoreLines by running Make BoreLines from Wells Tool. Choose Well for Well layer, BoreLine for Bore Line Layer, HGUID for BoreLine hydrogeologic unit, VerticalMeasurements for Vertical measurements table, HGUID for Hydrogeologic unit field, TopElevation for Top elevation field, and BottomElevation for Bottom elevation field as shown below:



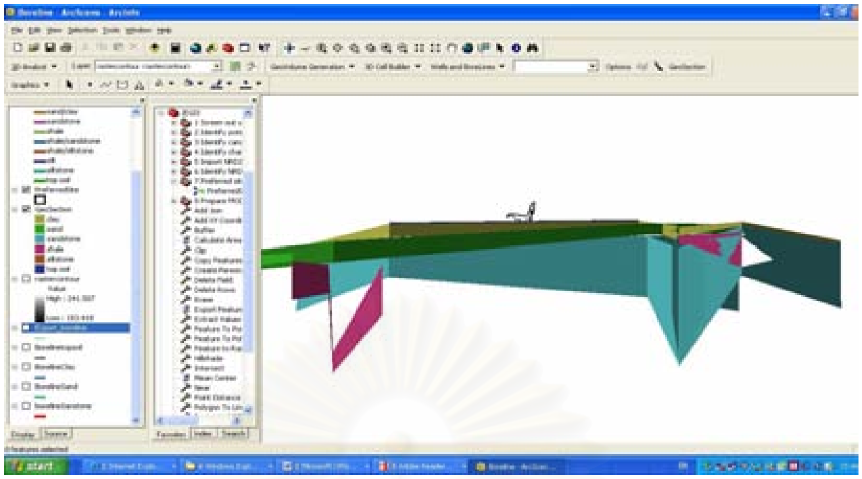
Create GeoSections from BoreLines by activating the BoreLine GeoSection tool and selecting the BoreLine GeoSection button as shown below:

Use the cursor to specify a cross section by selecting a number of wells along the desired section line

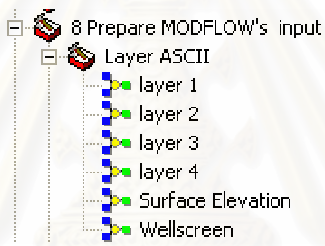


Click on Create GeoSections. The tool will prompt you to specify a name for the GeoSection. Name the section as GeoSection1 as shown below:

Click OK. A GeoSection will be created and added to the map.



Run all models listed below to generate ASCII files which will be used as input parameters of Visual MODFLOW model.



The outputs of this step are as follow:

- Surface Elevation model - produces surface elevation in ASCII format.
- Layer 1 model - produces bottom elevation of layer 1 in ASCII format.
- Layer 2 model - produces bottom elevation of layer 3 in ASCII format.
- Layer 3 model - produces bottom elevation of layer 3 in ASCII format.
- Layer 4 model - produces bottom elevation of layer 4 in ASCII format.
- Well model – produces pumping wells and observation wells files in ASCII format.

SurfaceElevation.asc - WordPad

File Edit View Insert Format Help

264021.505801	1792188.594344	200.0
266641.068939	1791520.890501	210.0
266171.131514	1790893.548003	210.0
264267.312573	1791402.874988	190.0
261317.005176	1791391.162610	170.0
266511.613432	1790641.072962	210.0
262588.498052	1791214.408343	180.0
265435.876065	1791061.786855	200.0
269923.944219	1790626.644541	220.0
266895.917398	1790666.463627	200.0
268287.218822	1790085.000050	200.0
269455.258267	1789531.805800	220.0
264865.719443	1790402.312049	190.0
261304.468820	1789738.875063	170.0
268467.531010	1790523.771812	210.0
269260.882927	1788984.224729	220.0
262265.525209	1788881.977425	180.0
257251.875941	1788943.493881	160.0
264109.468811	1789572.500030	180.0
260992.765630	1787732.874946	190.0
270867.150801	1787905.712326	200.0
268109.153882	1787192.950402	210.0
270142.042942	1788114.383886	210.0
267742.110873	1786713.702701	210.0
268782.000054	1787800.874972	210.0
267394.515032	1787979.535068	200.0
262512.045473	1786596.307191	200.0
268772.715856	1785993.677755	210.0
269904.615458	1785758.358557	210.0
258735.262989	1788040.374416	170.0
265631.781254	1787499.750063	190.0
266411.997766	1785328.867974	190.0
270334.812528	1785223.500011	210.0
267816.485688	1786216.553075	200.0
264118.593760	1786898.875049	180.0
255470.025960	1784673.131998	170.0
262180.754039	1783864.907444	200.0

An example of ASCII files of surface elevation

APPENDIX E

Publication

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Analysis of Integrated Expert Geographic Information Systems for Secured Landfill Sites

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Abstract: Siting of secured landfill is difficult because of the complexity of technical and social aspects. Technically, the appropriate tool for secured landfill sites analysis should be applied in the siting procedure. This study aims at developing a comprehensive tool to facilitate the analysis of secured landfill sites. It integrates Geographic Information System (GIS), Expert System (ES) and Analytic Hierarchy Process (AHP) into a packaged tool. The GIS represents spatial data, ES represents a knowledge base about secured landfill siting. AHP was applied for ranking of candidate sites and a user interface was developed to make this tool a user-friendly graphical system. The use of this tool was illustrated by identifying suitable sites for secured landfill in Khon Kaen Province, Thailand.

Key words: Geographic information system, expert system, analytic hierarchy process, secured landfill

INTRODUCTION

The improper management of hazardous waste may pose a serious threat to human health and environment (soil, air, water). Typically, hazardous waste management consists of collection, transportation, treatment and disposal of waste. Disposal of the waste is the final process and a key issue in overall hazardous waste management programs (Millano, 1996). There are several methods used for ultimate disposal of hazardous waste such as incineration, immobilization, landfill and off-shore and underground storage. Landfill is the option used in many countries and a major portion of wastes is disposed of through this rustic method. It is also technologically considered as an unsophisticated disposal method (Visvanathan, 1996). However, siting of landfills has become increasingly difficult since communities typically respond to plans to build a secured landfill or other hazardous waste disposal facilities with the view of Not in My Back Yard (NIMBY) or Locally Unwanted Land Uses (LULUs). It means that in general, a new facility for treating or disposing hazardous waste is desirable, but at the same time every community refuses to accept the facility (Minehart and Neeman, 2002).

There are two basic approaches to facility siting: open and closed. Closed siting approach often fails because social and political considerations are not given adequate attention, not because of environmental or technical mistakes. The open approach supports more effective public involvement and shares decision-making power (Kuhn and Ballard, 1998). In order to achieve the open approach, the appropriate tool for siting analysis should be applied in the siting procedures. In addition, this tool should be effective and easy to use for the general public, planners and decision makers. Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) such as Analytic Hierarchy Process (AHP) have been used in a number of studies in site selection (for example, Lindquist, 1991; Siddiqui *et al.*, 1996; Koo *et al.*, 1997; Lin and Koo, 1998; Badri, 1999; Badri *et al.*, 2001; Chuang, 2001; Kontos *et al.*, 2003). However, the research about the integration between GIS and MCDA as a public participation tool is still needed (Higgs, 2006). An Expert System (ES), a computer program which comprises a software technology that can replicate

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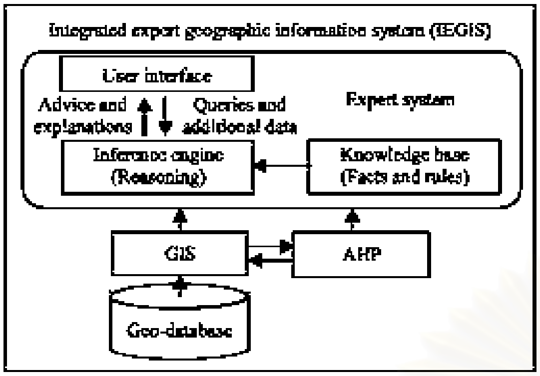

Fig. 1: Components of the integrated expert geographic information system

certain aspects of expertise and can manipulate both qualitative and quantitative knowledge, has also been indicated as a tool in site selection by various authors (Arentze *et al*., 1995; Eldrandaly *et al*., 2003; Way, 2005). The basic components of expert systems include (1) user interface which allows users to communicate with the system and to provide necessary data to the system (2) an inference engine, which solves given problems using input data from users and knowledge from a knowledge base, through its own reasoning methods and (3) a knowledge base, which contains the knowledge obtained from a domain expert, including facts and rules (Kim *et al*., 1990). Even though the GIS, MCDA and ES are useful for siting analysis there has been no attempt to integrate all of them for the comprehensive of secured landfill sites analysis. Therefore, the aim of this study is to develop a comprehensive tool to facilitate the analysis of secured landfill sites. It integrates ES, GIS and AHP into a packaged tool, called an Integrated Expert Geographic Information System (IEGIS).

The components of IEGIS are shown in Fig. 1. The developed system was used to identify the suitable sites for secured landfill in Khon Kaen Province located in the Northeast region of Thailand and there is no licensed hazardous waste disposal site in the region.

MATERIALS AND METHODS

This study was conducted at Khon Kaen University, Khon Kaen Province, Thailand during June 2006 to August 2007.

Materials: The computer used in this study is a standard Windows computer with ArcMap 9, Microsoft Visual Studio.Net 2003, Microsoft Excel 2003 and Visual Basic for Application (VBA).

Developing an Expert System for siting of secured landfill analysis: The ES for siting of secured landfill analysis was developed by using Microsoft Visual Studio. Net 2003. The system has capability to provide the information and suggestions about siting of secured landfill sites taking into account relevant laws, regulations and technical knowledge and allowing users to specific data layers for GIS analysis based on data they have in hand.

Integrating the GIS and ES: The integration of GIS and ES was developed by using Microsoft Visual Studio.Net 2003. It enables the data flow between the ES and the GIS to move back and forth flexibly based on users needs. The system has capacity to allow users to create their own buffer area according to relevant laws, regulations and technical knowledge. The outputs of this step are the suggestion about screening criteria which should be used in the GIS analysis, optimum size of secured landfill and candidate sites.

Integrating the GIS and AHP: Microsoft-Excel and Visual Basic for Application (VBA) were used to develop an Excel application to implement the AHP technique. The integration of GIS and AHP was developed by using Microsoft Visual Studio. Net 2003. The characteristics of candidate sites analyzed by GIS is reported and used as ranking factors in AHP analysis. The system allows users to weight the criteria for candidate sites ranking. After ranking of candidate sites, the preferred site is visualized in the GIS. The process of AHP in this study comprises the following steps (Saaty, 1980; Badiru and Cheung, 2002):

- **Develop the hierarchical structure for the decision problem:** The top level of the hierarchy is the overall objective of the decision problem and the competing alternatives are at the bottom of the hierarchy. The attributes of alternatives such as selection criteria and factors, on which the final objective depends, are listed between the top and the bottom of the hierarchy. The number of levels in the hierarchy depends on the complexity of the problem
- **Determine the relative weights of each alternative with respect to the characteristics and sub characteristics in the hierarchy:** After the hierarchy has been constructed, the users must undertake a subjective prioritization procedure to determine the weight of each element at each level of the hierarchy. Pairwise comparisons are performed at each level to determine the relative importance of each element at that level with respect to each element at the next-higher level in the hierarchy.

- Determine the relative weights of each attribute with respect to the objective

Develop Matrix of Pairwise Comparison of attributes: The matrix of pairwise comparisons can take the following form

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & & \ddots & \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix}$$

The attribute of the matrix A (m by m matrix) in the i^{th} row and j^{th} column is denoted by a_{ij}. The a_{ij} values represent the relative degree of importance of attribute i over attribute j. The possible assessment value of a_{ij} with the corresponding interpretation is shown below:

- Attribute i and j are equally important, insert 1
- Attribute i is weakly more important than attribute j, insert 3
- Attribute i is strongly more important than attribute j, insert 5
- Attribute i is demonstrably or very strongly more important than attribute j, insert 7
- Attribute i is absolutely more important than attribute j, insert 9

Intermediate numbers (2, 4, 6 and 8) are used as appropriate to indicate intermediate levels of importance. For all i and j, it is necessary that $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$.

Compute normalized relative weights of attributes: The entries of the matrix of pairwise comparisons are then normalized by dividing each entry in a column by the sum of all the entries in that column. This yields a new matrix A_w, in which the sum of the entries in each column is 1.

$$A_w = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}} \\ \vdots & & \ddots & \\ \frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}} \end{bmatrix}$$

Compute w_i as the average of the entries in row i of A_w to yield column vector W.

$$W = \begin{bmatrix} w_1 \\ \vdots \\ w_m \end{bmatrix} = \begin{bmatrix} \dfrac{\frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} + \cdots + \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}}}{m} \\ \vdots \\ \dfrac{\frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} + \cdots + \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}}}{m} \end{bmatrix}$$

Where, w_i represents the normalized average rating associated with each attribute. These averages represent the relative weight of the attributes that are being evaluated. The attribute which has highest value of w_i is considered to be the most important factor in the selection of a decision aid for productivity improvement.

Compute consistency ratio of pairwise comparison of attributes: Since the initial pairwise comparisons of the attributes are done based on subjective opinions of the people involved in the decision making, it is quite possible that some elements of bias and inconsistency will be present in the evaluations. Saaty (1980) proposed a procedure for calculating the Consistency Ratio (CR) to determine reasonable consistency and to minimize bias. The consistency ratio is calculated as follows:

$$\text{Consistency ratio (CR)} = \text{CI/RI}$$

Where:

CI = $(\lambda_{max} - m)/(m-1)$

λ_{max} = The average consistency measure for all alternatives

$$\frac{1}{m}\sum_{i=1}^{m} \frac{i^{th} \text{ entry in } A \cdot W}{i^{th} \text{ entry in } W}$$

m = No. of element

RI The appropriate random index of m, which is shown below

m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

If CR is sufficiently small, the decision maker's comparisons are probably consistent enough to give useful estimates of the weights for the objective function. In general, a consistency ratio of 0.10 or less is considered acceptable:

- Determine the relative weights of each alternative with respect to the attribute. After the relative weights of the attributes are obtained, the next step is to evaluate the alternatives on basis of the attributes. In this step, relative evaluation rating is

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obtained for each of alternative with respect to each attribute. The procedure for the pairwise comparisons of the alternatives is similar to the procedure for the attributes. Then each matrix is analyzed and normalized by using the procedure showed previously.

Compute overall desirability weight of each alternative: The attribute weights are then combined with the system weights to obtain the final AHP analysis by using the following equation

$$\alpha_j = \Sigma_i (w_i k_{ij})$$

Where

- α_j = Overall weighted evaluation for alternative j
- w_i = Relative weight for attribute i
- k_{ij} = Evaluation rating for alternative j with respect to attribute i
- $w_i k_{ij}$ = A measure representing the global weight of alternative j with respect to attribute i. The sum of the global weights associated with an alternative represents the overall weight α_j of that alternative

Make a final decision based on the results: The alternative which has the highest weighted ranking should be selected as the preferred alternative.

After ES, GIS and AHP were integrated, the user interface was developed to allow users to interact with either system through graphic menu-based tools. The operations and outcomes are dependent upon users. The conceptual framework of this study is shown in Fig. 2.

RESULTS AND DISCUSSION

The results of this study were illustrated based on the application of IEGIS in Khon Kaen Province, Thailand. Fig. 3 shows the location of Khon Kaen Province.

Developing an expert system for siting of secured landfill analysis: The first page of the ES is a welcome page Fig. 4. When users entered the system, they were asked to check all the environmental sensitive areas in the province (Fig. 5) and to check all GIS data they had in hand (Fig. 6). Then the ES copied the GIS data in to geo-database and proposed the screening criteria based on siting criteria from the Notifications No. 1 and No. 7 of Anonymous (2003), the Anonymous guidelines (2006a, b) and the existing GIS data provided by users. The screening criteria of Khon Kaen Province proposed by the ES consist of three main factors which are environmental factors, economic factors and social factors as shown in Table 1.

Integrating the GIS and ES: Based on the screening criteria proposed by the ES as shown in Table 1, ArcMap models of water factors, soil factors, forest factors, economic factors and social factors were built to screen out unsuitable areas for secured landfill sites. These models have capability to automate the GIS analysis and allow users to create their own buffer area. An example of models and the interface for inputting buffer values are shown in Fig. 7a, b, respectively.

Next the models were run to screen out unsuitable areas and identify potential areas for secured landfill sites. Figure 8a, b represent unsuitable areas and potential areas

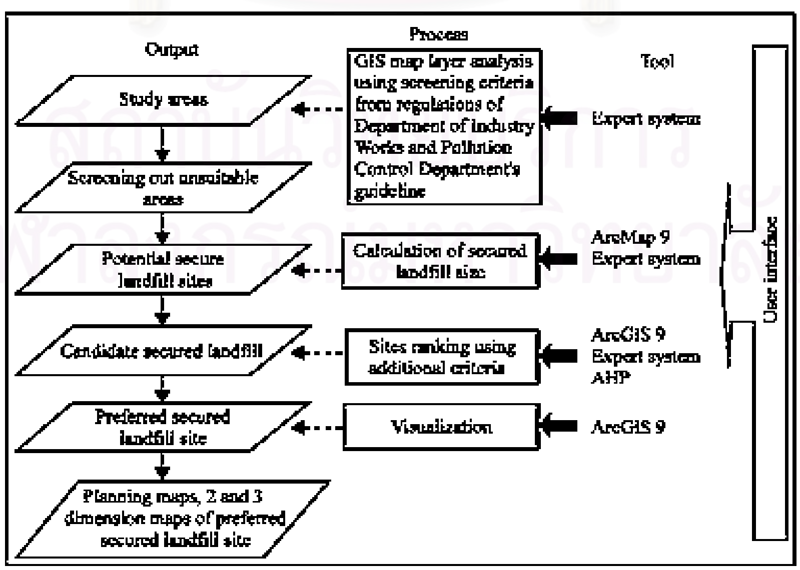

Fig. 2: Conceptual framework of this study

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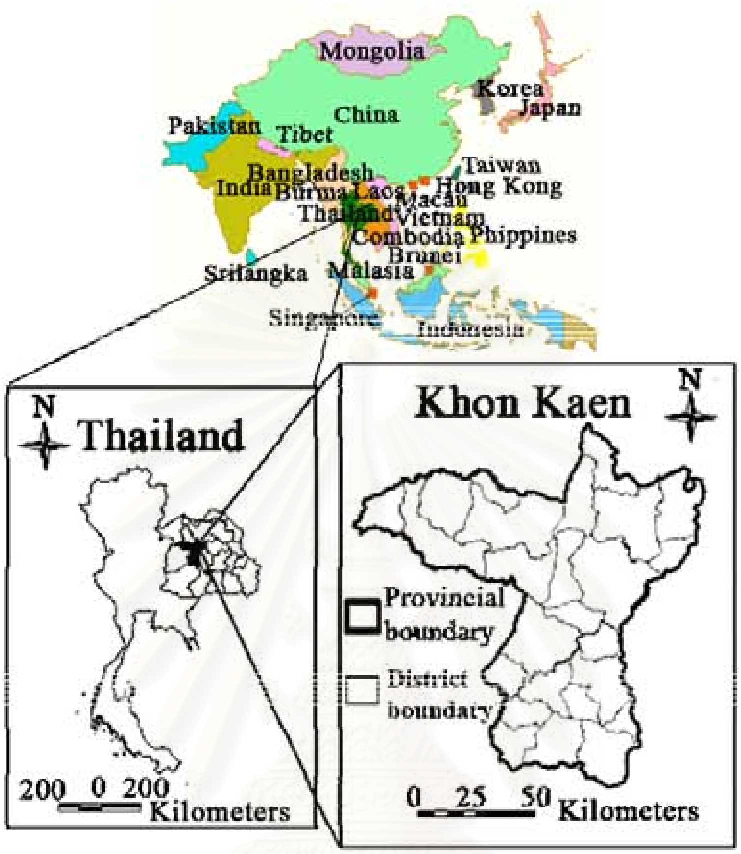

Fig. 3: Location map of Khon Kaen Province, Thailand

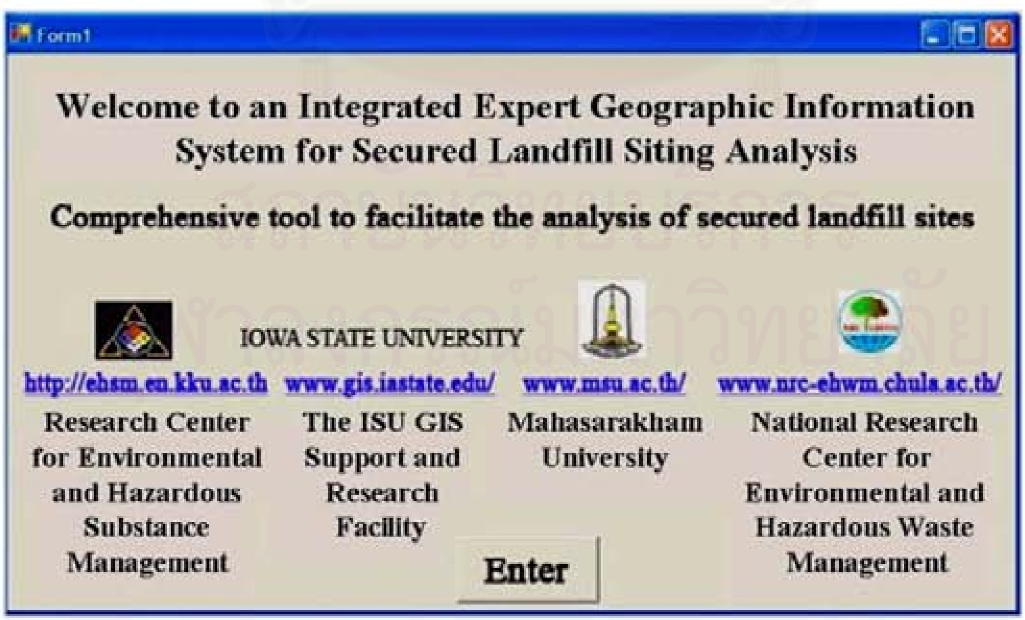

Fig. 4: First page of the expert system

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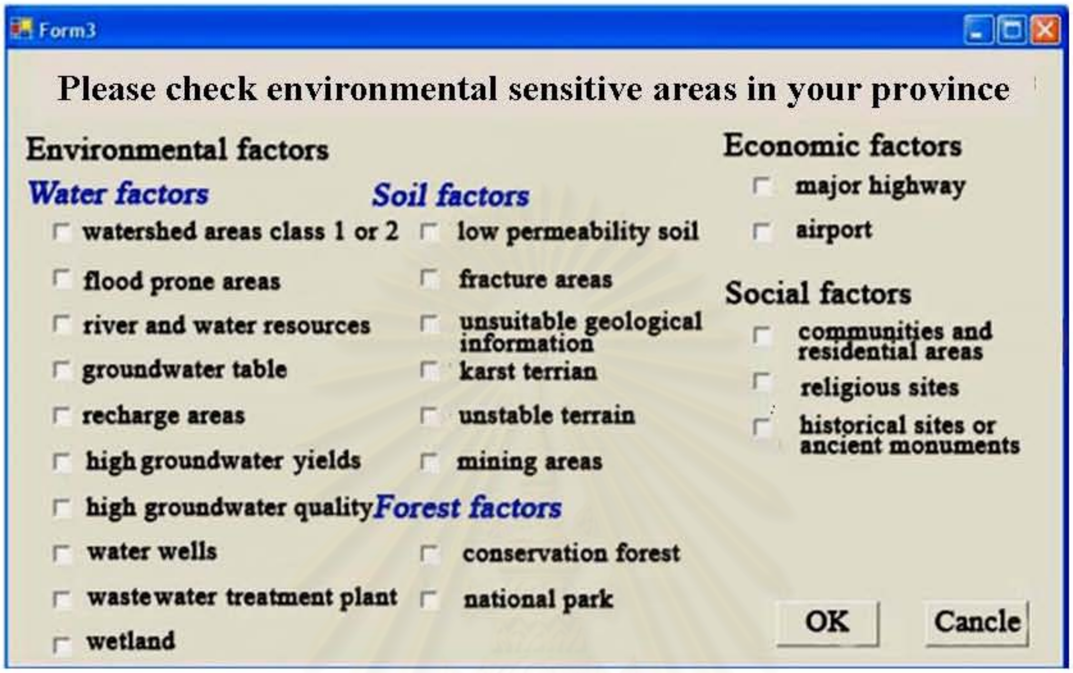

Fig. 5: Expert system asking users to input the sensitive factors in their area

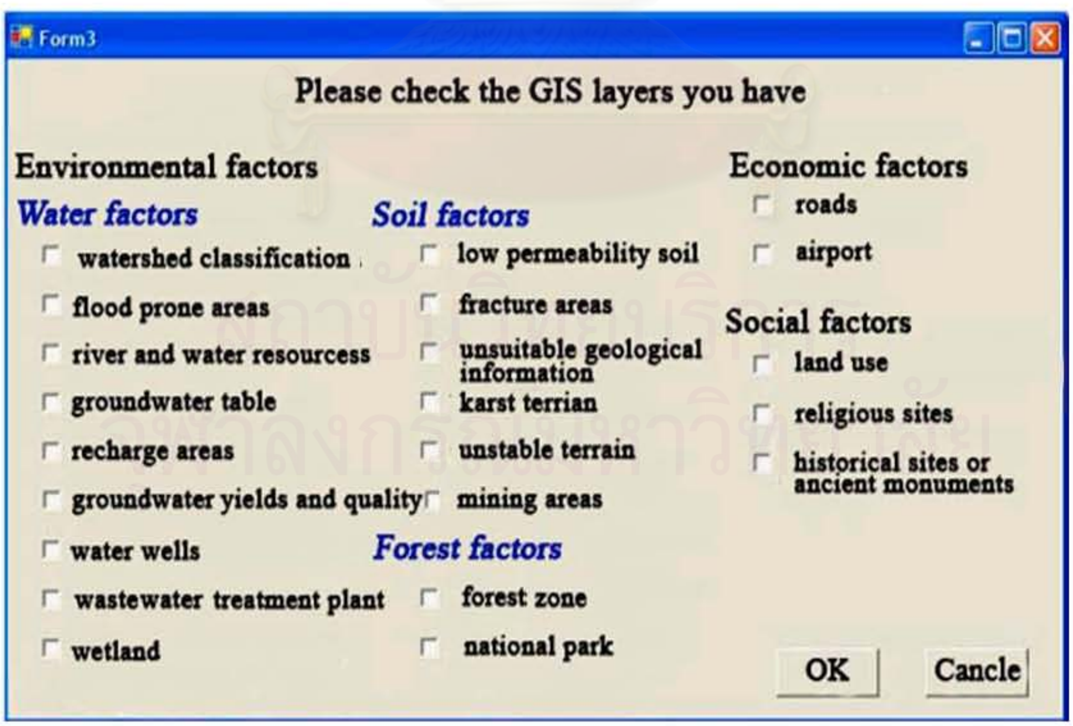

Fig. 6: Expert System asking users to input the GIS layers they have

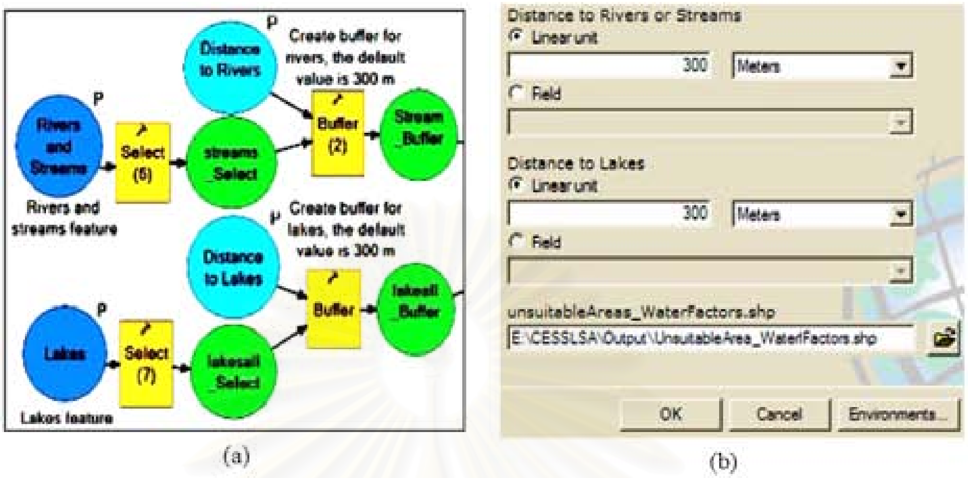

Fig. 7: (a) Example of ArcMap model, (b) Example of an interface for inputting buffer values

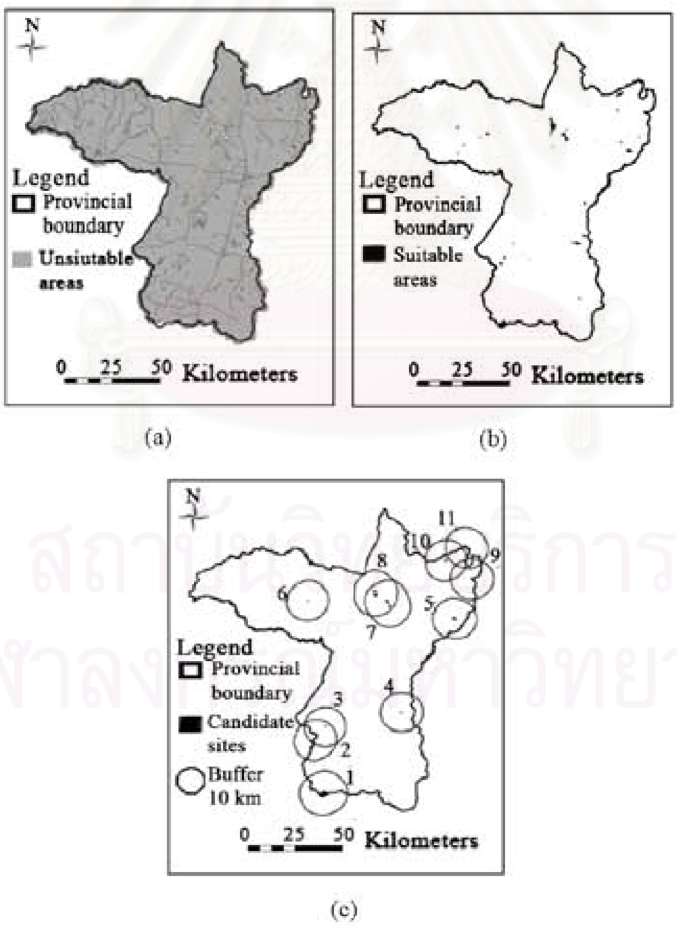

Fig. 8: (a) Unsuitable areas for secured landfill sites, (b) Potential areas for secured landfill sites and (c) Candidate sites for secured landfill and their 10 km buffer

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Table 1: Screening criteria of Khon Kaen Province proposed by the Expert System

No.	Factors	Default values of buffer areas
1	**Environmental factors**	
	Water	
	Watershed areas class 1 and 2	-
	Flood prone areas	-
	River and water resources	300 m
	Groundwater table	<1.5 m
	Recharge areas	-
	High yields and high quality of groundwater	-
	Existing water wells	700 m
	Wastewater treatment plant	700 m
	Wetland	300 m
	Soil	
	Low permeability soil	
	Forest	
	Conservation forest	-
	National park	-
2	**Economic factors**	
	Major highway	>100 m - 10 km
	Airport	5 km
3	**Social factors**	
	Communities and residential areas	2 km
	Religious areas	-
	Historical sites or ancient monuments	-

Table 2: Characteristics of candidate sites based on additional criteria

Candidate site	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Factor 12	Factor 13
Sites 1	19	4.6	5B	4.10	>2	>1500	2.4	0.6	18	5.5	Paddy field	48	3.7
Sites 2	29	3.1	5B	5.40	2-10	<1500	0.5	0.5	4	2.9	Paddy field	42	2.9
Sites 3	15	3.5	5B	5.50	2-10	>1500	1.5	0.8	4	5.9	Paddy field	55	2.9
Sites 4	68	3.3	4B	7.50	<2	<750	1.3	3.3	11	5.8	Field crops	58	3.0
Sites 5	52	2.5	4B	2.75	>2	>750	5.1	1.9	36	3.6	Forest	60	3.4
Sites 6	80	3.2	1A	1.90	<2	<750	1.3	1.3	36	3.9	Grass	93	2.9
Sites 7	26	3.5	4B	4.40	>2	>750	1.5	0.7	41	4.4	Field crops	68	3.0
Sites 8	19	4.1	4B	7.10	<2	<750	0.8	2.8	36	4.1	Field crops	56	3.1
Sites 9	20	2.7	4B	5.80	>2	>750	1.1	0.8	36	5.1	Field crops	45	3.2
Sites 10	19	4.0	4B	5.30	<2	<750	0.9	0.1	36	7.6	Field crops	30	3.1
Sites 11	6	4.9	4A	4.00	>2	>750	1.2	3.2	18	2.0	Field crops	13	3.1

Factor 1: No. of water well within 10 km, Factor 2: Distance to the nearest water well (km), Factor 3 : Major watershed classification, Factor 4: Average depth to water table (m), Factor 5: Groundwater yields (m^3 h^{-1}), Factor 6: Groundwater quality (TDS, mg L^{-1}), Factor 7: Distance to the nearest river (km), Factor 8: Distance to the nearest lake (km), Factor 9: Distance to the nearest major road (km), Factor 10: Major land use, Factor 11: No. of village within 10 km, Factor 12: Distance to the nearest village (km)

for secured landfill sites, respectively. After that, The ES calculated the appropriate size of secured landfill site and the result of the calculation was used as an input in a GIS analysis to identify the candidate sites for secured landfill. The results of GIS analysis show that there are eleven candidate sites for secured landfill in Khon Kaen province as shown in Fig. 8c.

Integrating the GIS and AHP: After the candidate sites were identified, the additional criteria were developed by considering factors used in screening process. In this case, there were 13 criteria which should be used as factors for ranking of candidate sites. Then ArcMap models automated GIS analysis and provided the characteristics of each candidate site based on the 13 criteria. The results of GIS analysis for characteristics of candidate sites are shown in Table 2. In The AHP application, the hierarchical structure for the decision problem was established and the overall objective of the analysis was to identify the suitable site for secured landfill in Khon Kaen Province as shown in Fig. 9. The result of determining the relative weights for the thirteen factors with respect to the objective of the analysis is shown in Table 3. The entries in Table 3 were then normalized to obtain the normalized average rating associated with each factor or the relative weights of factors as shown in the last column in Table 4. The relative weight shows that the average depth to groundwater table has the highest important rating, 0.218. It means that this factor is considered to be the most important factor in the selection of secured landfill sites. The consistency ratio of this step is 0.012 which is considered as acceptable. The relative weights of the candidate sites with respect to each factor were evaluated by using the similar procedure to the procedure for comparing the factors. The result of this step is presented in Table 5, which all consistency ratios are considered as acceptable. The relative weight showed earlier in Table 4 were combined with the relative weight of the candidate sites contained in Table 5 to obtain the overall relative

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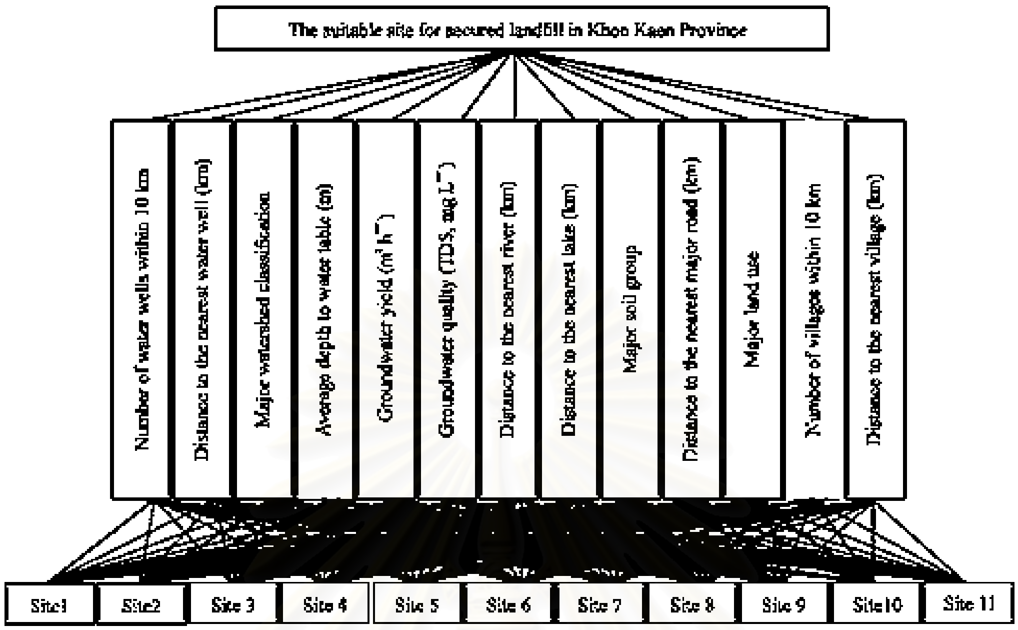

Fig. 9: Hierarchical structures for the decision problem

Table 3: Matrix of pairwise comparisons of the thirteen additional factors

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1.00	0.25	1.00	0.17	0.33	0.33	0.20	0.20	1.00	1.00	1.00	0.50	0.33
2	4.00	1.00	4.00	0.33	2.00	2.00	0.50	0.50	4.00	4.00	4.00	3.00	2.00
3	1.00	0.25	1.00	0.17	0.33	0.33	0.20	0.20	1.00	1.00	1.00	0.50	0.33
4	6.00	3.00	6.00	1.00	4.00	4.00	2.00	2.00	6.00	6.00	6.00	5.00	4.00
5	3.00	0.50	3.00	0.25	1.00	1.00	0.33	0.33	3.00	3.00	3.00	2.00	1.00
6	3.00	0.50	3.00	0.25	1.00	1.00	0.33	0.33	3.00	3.00	3.00	2.00	1.00
7	5.00	2.00	5.00	0.50	3.00	3.00	1.00	1.00	5.00	5.00	5.00	4.00	3.00
8	5.00	2.00	5.00	0.50	3.00	3.00	1.00	1.00	5.00	5.00	5.00	4.00	3.00
9	1.00	0.25	1.00	0.17	0.33	0.33	0.20	0.20	1.00	1.00	1.00	0.50	0.33
10	1.00	0.25	1.00	0.17	0.33	0.33	0.20	0.20	1.00	1.00	1.00	0.50	0.33
11	1.00	0.25	1.00	0.17	0.33	0.33	0.20	0.20	1.00	1.00	1.00	0.50	0.33
12	2.00	0.33	2.00	0.20	0.50	0.50	0.25	0.25	2.00	2.00	2.00	1.00	0.50
13	3.00	0.50	3.00	0.25	1.00	1.00	0.33	0.33	3.00	3.00	3.00	2.00	1.00
Column sum	36.00	11.08	36.00	4.12	17.17	17.17	6.75	6.75	36.00	36.00	36.00	25.50	17.17

Table 4: Normalized AHP matrix of paired comparisons

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	Row sum	Row average (relative weights of factors)
1	0.028	0.023	0.028	0.040	0.019	0.019	0.030	0.030	0.028	0.028	0.028	0.020	0.019	0.339	0.026
2	0.111	0.090	0.111	0.081	0.117	0.117	0.074	0.074	0.111	0.111	0.111	0.118	0.117	1.342	0.103
3	0.028	0.023	0.028	0.040	0.019	0.019	0.030	0.030	0.028	0.028	0.028	0.020	0.019	0.339	0.026
4	0.167	0.271	0.167	0.243	0.233	0.233	0.296	0.296	0.167	0.167	0.167	0.196	0.233	2.835	0.218
5	0.083	0.045	0.083	0.061	0.058	0.058	0.049	0.049	0.083	0.083	0.083	0.078	0.058	0.874	0.067
6	0.083	0.045	0.083	0.061	0.058	0.058	0.049	0.049	0.083	0.083	0.083	0.078	0.058	0.874	0.067
7	0.139	0.180	0.139	0.121	0.175	0.175	0.148	0.148	0.139	0.139	0.139	0.157	0.175	1.974	0.152
8	0.139	0.180	0.139	0.121	0.175	0.175	0.148	0.148	0.139	0.139	0.139	0.157	0.175	1.974	0.152
9	0.028	0.023	0.028	0.040	0.019	0.019	0.030	0.030	0.028	0.028	0.028	0.020	0.019	0.339	0.026
10	0.028	0.023	0.028	0.040	0.019	0.019	0.030	0.030	0.028	0.028	0.028	0.020	0.019	0.339	0.026
11	0.028	0.023	0.028	0.040	0.019	0.019	0.030	0.030	0.028	0.028	0.028	0.020	0.019	0.339	0.026
12	0.056	0.030	0.056	0.049	0.029	0.029	0.037	0.037	0.056	0.056	0.056	0.039	0.029	0.557	0.043
13	0.083	0.045	0.083	0.061	0.058	0.058	0.049	0.049	0.083	0.083	0.083	0.078	0.058	0.874	0.067
Column sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	13.00	1.00

CR: Consistency Ratio = 0.012

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weights of the candidate sites as shown in Table 6. The overall weighted evaluation (α_j) contained in Table 6 shows that site 4 should be selected as the suitable site for secured landfill since it has the highest weight rating, 0.221. The Preferred site were then visualized in two and three dimension to present the characteristics of the site and surrounding areas within 5 kilometers as shown in Fig. 10 and 11, respectively.

The results from the application of IEGIS in Khon Kaen Province indicated that IEGIS can effectively facilitate the siting process of secured landfills. It provides decision support to users in selection of a suitable secured landfill site which means the objective of this study was achieved. The advantage of IEGIS compared to previous studies (Kontos *et al*., 2003; Eldrandaly *et al*., 2003; Way, 2005) is that it is friendly to users and even though

Table 5: Relative weights of the candidate sites with respect to each factor

Candidate site	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Factor 12	Factor 13
Site 1	0.043	0.188	0.038	0.040	0.067	0.020	0.161	0.027	0.077	0.053	0.036	0.066	0.198
Site 2	0.052	0.062	0.038	0.077	0.200	0.020	0.021	0.027	0.154	0.151	0.036	0.050	0.047
Site 3	0.108	0.055	0.038	0.032	0.200	0.020	0.061	0.038	0.154	0.047	0.036	0.079	0.054
Site 4	0.217	0.058	0.109	0.281	0.067	0.118	0.061	0.234	0.077	0.049	0.067	0.091	0.063
Site 5	0.068	0.020	0.109	0.021	0.067	0.118	0.421	0.103	0.077	0.117	0.119	0.097	0.118
Site 6	0.308	0.042	0.191	0.062	0.067	0.118	0.068	0.063	0.077	0.110	0.368	0.298	0.048
Site 7	0.048	0.049	0.109	0.051	0.067	0.118	0.044	0.037	0.077	0.090	0.067	0.128	0.063
Site 8	0.043	0.130	0.109	0.225	0.067	0.118	0.030	0.180	0.077	0.090	0.067	0.086	0.118
Site 9	0.044	0.027	0.109	0.095	0.067	0.118	0.044	0.038	0.077	0.061	0.067	0.055	0.085
Site 10	0.043	0.114	0.109	0.074	0.067	0.118	0.031	0.022	0.077	0.024	0.067	0.031	0.122
Site 11	0.024	0.255	0.038	0.040	0.067	0.118	0.058	0.231	0.077	0.208	0.067	0.020	0.085
CR	0.011	0.032	0.002	0.017	0.000	0.000	0.035	0.032	0.000	0.011	0.006	0.014	0.019

Table 6: Final AHP analysis for decision

Candidate sites	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10	Factor 11	Factor 12	Factor 13	Overall weighted evaluation (α_j)
Site 1	0.001	0.019	0.001	0.009	0.004	0.001	0.024	0.004	0.077	0.001	0.001	0.003	0.013	0.160
Site 2	0.001	0.006	0.001	0.017	0.013	0.001	0.003	0.004	0.154	0.004	0.001	0.002	0.003	0.212
Site 3	0.003	0.006	0.001	0.007	0.013	0.001	0.009	0.006	0.154	0.001	0.001	0.003	0.004	0.209
Site 4	0.006	0.006	0.003	0.061	0.004	0.008	0.009	0.036	0.077	0.001	0.002	0.004	0.004	0.221
Site 5	0.002	0.002	0.003	0.005	0.004	0.008	0.064	0.016	0.077	0.003	0.003	0.004	0.008	0.198
Site 6	0.008	0.004	0.005	0.014	0.004	0.008	0.010	0.010	0.077	0.003	0.010	0.013	0.003	0.169
Site 7	0.001	0.005	0.003	0.011	0.004	0.008	0.007	0.006	0.077	0.002	0.002	0.005	0.004	0.136
Site 8	0.001	0.013	0.003	0.049	0.004	0.008	0.005	0.027	0.077	0.002	0.002	0.004	0.008	0.203
Site 9	0.001	0.003	0.003	0.021	0.004	0.008	0.007	0.006	0.077	0.002	0.002	0.002	0.006	0.141
Site 10	0.001	0.012	0.003	0.016	0.004	0.008	0.005	0.003	0.077	0.001	0.002	0.001	0.008	0.141
Site 11	0.001	0.026	0.001	0.009	0.004	0.008	0.009	0.035	0.077	0.005	0.002	0.001	0.006	0.184

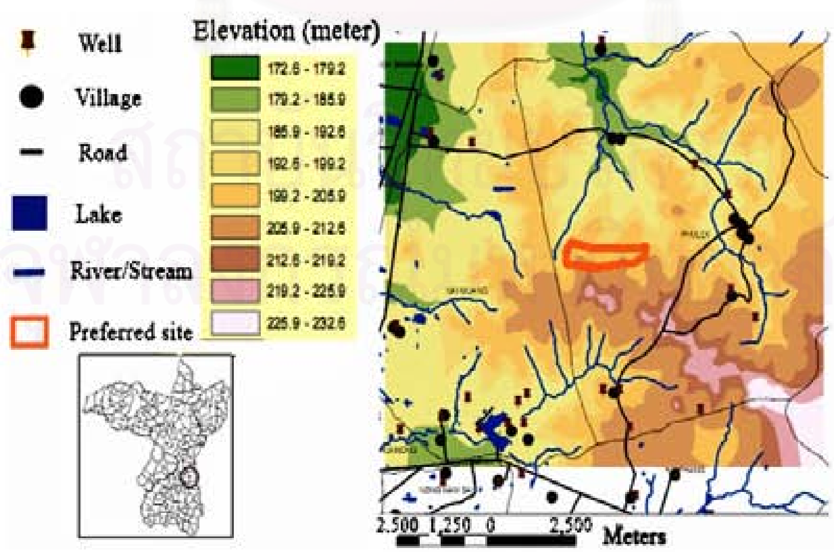

Fig. 10: 2-dimensional map of preferred site (Site No. 4)

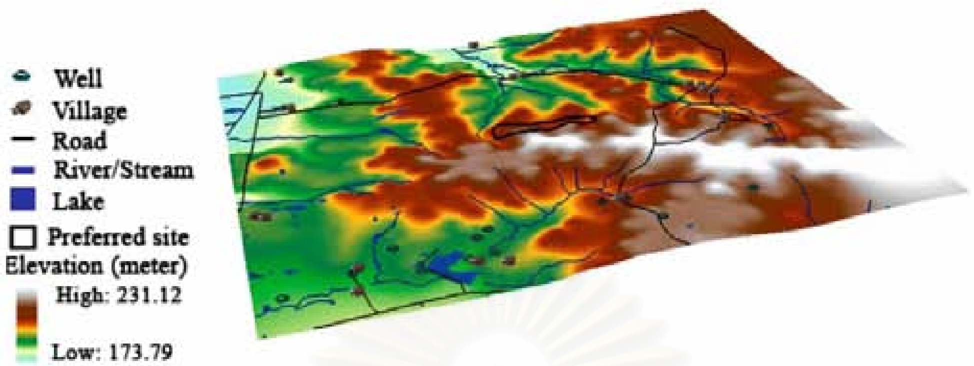

Fig. 11: 3-dimensional map of preferred site (the convection factor to place heights is 10)

they are not GIS experts, they just follow the guidance of the ES to identify the suitable secured landfill. In addition, the IEGIS could be particularly useful in situations where there are a large number of candidate sites, where there are a large number of additional criteria to be taken into consideration in the sites ranking process or where the determination of relative weights by different stakeholders is needed. Thus it could be used as a public participation tool to identify the suitable sites of secured landfill which could increase transparency in the siting procedures and improve the speed of the site selection process by incorporating public opinions at the outset of the decision-making process (Higgs, 2006). The criteria used in this study were developed according to Thai legislation and guidelines. However, the developed system is flexible thus it is not difficult to take other criteria into account.

CONCLUSION

Siting of secured landfill requires an extensive evaluation process to identify the suitable location. The integration of GIS, ES and AHP presented in this study could be a valuable tool for identifying the suitable sites for secured landfills. This system has the potential to expand the use and utility of GIS, ES and AHP and could benefit users in the secured landfill siting procedures. The development of ES and the integration of GIS, ES and AHP using Visual Studio.Net and Microsoft-Excel were successful. This study is regarded as the first step in the long term research agenda of the authors to develop the tool for facilitating secured landfill sites analysis. Since the major environment concern with secured landfill is groundwater contamination associated with infiltration of leachate (Misra and Pendey, 2005), the future research challenge is to integrate a groundwater model into the system for predicting the potential adverse impact from the preferred site to groundwater and also develop the ES to have capability to provide the measures for potential impacts from the preferred site.

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APPENDIX F

Proceeding papers

The proceeding of 6th National Environmental Conference

March 7-9, 2007 at Amarin Lagoon Hotel, Phitsanulok

ระบบผู้เชี่ยวชาญสารสนเทศภูมิศาสตร์แบบบูรณาการ สำหรับการวิเคราะห์หาพื้นที่ฝังกลบอย่างปลอดภัย

Integrated Expert Geographic Information System for Secured Landfill Sites Analysis

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บทคัดย่อ

การหาพื้นที่ฝังกลบของเสียอันตรายแบบปลอดภัยค่อนข้างมีความยุ่งยากทั้งด้านเทคนิคและสังคม ดังนั้นการหาพื้นที่ฝังกลบของเสียอันตรายจำเป็นต้องอาศัยเครื่องมือที่มีความเหมาะสม การศึกษานี้มีวัตถุประสงค์เพื่อพัฒนาระบบผู้เชี่ยวชาญสารสนเทศภูมิศาสตร์ในการวิเคราะห์หาพื้นที่ฝังกลบของเสียอันตรายโดยประยุกต์ใช้การวางแผนเชิงพื้นที่ซึ่งผสานปัจจัยด้านสิ่งแวดล้อม เศรษฐกิจและสังคมเข้าด้วยกัน และบูรณาการการทำงานร่วมกันระหว่างระบบผู้เชี่ยวชาญ ระบบสารสนเทศภูมิศาสตร์ กระบวนการลำดับชั้นเชิงวิเคราะห์ และแบบจำลองน้ำใต้ดิน ซึ่งระบบสารสนเทศภูมิศาสตร์จะทำหน้าที่ในการวิเคราะห์ข้อมูลเชิงพื้นที่ ระบบผู้เชี่ยวชาญทำหน้าที่ในการเก็บและประมวลผลความรู้ด้านการวางแผนเชิงพื้นที่และการวิเคราะห์หาพื้นที่ฝังกลบของเสียอันตราย และใช้กระบวนการลำดับชั้นเชิงวิเคราะห์ในการจัดลำดับความสำคัญของพื้นที่ที่ได้รับการคัดเลือกเพื่อระบุพื้นที่ที่มีความเหมาะสมมากที่สุด จากนั้นใช้แบบจำลองน้ำใต้ดินคาดการณ์ผลกระทบต่อน้ำใต้ดินที่อาจเกิดขึ้นจากการฝังกลบของเสียอันตราย แล้วจึงพัฒนาระบบให้ใช้งานได้ง่าย ทั้งนี้ระบบที่พัฒนาขึ้นนี้ได้ถูกใช้เพื่อหาพื้นที่ฝังกลบของเสียอันตรายในจังหวัดขอนแก่นเพื่อทดสอบประโยชน์ในการทำงานของระบบ

คำสำคัญ : การวางแผนเชิงพื้นที่; ระบบสารสนเทศภูมิศาสตร์; ระบบผู้เชี่ยวชาญ; กระบวนการลำดับชั้นเชิงวิเคราะห์; การฝังกลบแบบปลอดภัย

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Abstract

Siting of secured landfill is likely difficult because of the complexity of technical and social aspect. Technically, the appropriate tool for secured landfill sites analysis should be applied in the siting procedure. This study aims at developing a comprehensive tool to facilitate the analysis of secured landfill sites based on spatial planning method, which combines environmental factors, and socio-economic factors in site selection processes. It integrates Geographic Information System (GIS), Expert System (ES), Analytic Hierarchy Process (AHP) and groundwater contamination model into a packaged tool. The GIS represents a spatial data, ES represents a knowledge base about secured landfill siting including spatial planning, AHP is applied for ranking of candidate sites, groundwater contamination model is used to assess the possible groundwater impacts from the preferred site, and an user interface is developed to make this tool as an user-friendly graphic system. The use of this tool is illustrated by identifying suitable sites for secured landfill in Khon Kaen Province, Thailand.

Keywords : spatial planning; geographic information system (GIS); expert system (ES); analytic hierarchy process (AHP); secured landfill

Introduction

The improper management of hazardous waste may pose a serious threat to human health and environment (soil, air, water). The typical hazardous waste management consists of component for the collection, transportation, treatment and disposal of waste. Disposal of the waste is the final process and a key issue in overall hazardous waste management programs [1]. There are several methods used for ultimate disposal of hazardous waste such as incineration, immobilization, landfill, off-shore and under ground storage. Landfill option is the one which is used in many countries, and major portion of wastes is disposed of through this rustic method. It is also technologically considered as an unsophisticated disposal method [2]. However, siting of landfills has become increasingly difficult because of communities typically respond to plans to build a secured landfill or the others hazardous waste disposal facilities with the view of "Not in My Back Yards (NIMBYs)" or "Locally Unwanted Land Uses (LULUs). It means that in general, a new facility for treating or disposing hazardous waste is desirable, but at the same time every community refuses to accept the facility [3]. There are two basic approaches to facility siting: open and closed. Closed siting approach often fails because social and political considerations are not given adequate attention, not because of environmental or technical mistakes. While the open approach supports more effective public involvement, and shares decision-making power [4]. In order to achieve the open approach, the appropriate tool for siting analysis should be applied in the siting procedures. In addition, this tool should be effective and easy to use for general public, planners, and decision makers. Siting of secured landfills should carefully consider various factors and regulation. Spatial planning is a method, which combines environmental factors, engineering factors and socio-economic factors and leads to suitability sites for secured landfills. Based on spatial planning, the candidate sites is identified by analyzing GIS map layers and data according to the siting criteria

The aim of this study is to develop a comprehensive tool to facilitate the analysis of secured landfill sites based on spatial planning method. It integrates Geographic Information System (GIS), Expert System (ES), Analytic Hierarchy Process (AHP), which was developed by Thomas L. Satty in 1980 [5] and groundwater model into a packaged tool, called Integrated Expert Geographic Information System (IEGIS). The component of IEGIS is shown in Figure 1. The GIS represents a spatial data, ES represents a knowledge base about secured landfill siting including spatial planning, AHP is applied for ranking of candidate sites, groundwater model is used to assess the possible groundwater impacts from the preferred site, and a user interface is developed to makes it as a user-friendly graphic system. The developed tool is used to identify the suitable sites for secured landfill in Khon Kaen Province located in the Northeast region of Thailand and there is no licensed hazardous waste disposal site in the region.

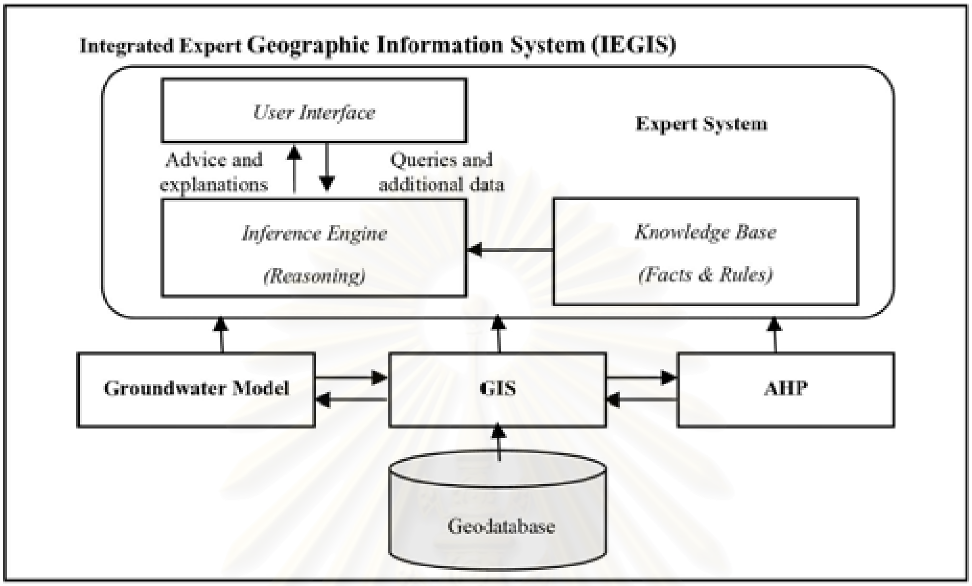


Figure 1 Components of the Integrated Expert Geographic Information System

Methodology

The methodology of this study was divided into two parts. The first part was developing the IEGIS for siting of secured landfill analysis. The second part was applying the IEGIS for secured landfill sites analysis in Khon Kaen Province, Thailand.

1. Developing IEGIS for siting of secured landfill analysis

1.1 Developing an expert system for siting of secured landfill analysis. The expert system has capability to: a) provide the information and suggestions about siting of secured landfill sites including relevant laws, regulations, and technical knowledge; b) allow the user to specific data layers for siting analysis based on data they have and also allows the user to create their own buffer area according to relevant laws, regulations, and technical knowledge; c) allow the users to weight the criteria for candidate sites ranking by themselves; and d) provide the measures for each potential impact from candidate sites and the preferred site.

1.2 Integrating the GIS and ES

The GIS used in this study is ArcGIS 9. The GIS and ES is interfaced at the level of dynamic integration, which enables the data flow between the decision tool and the GIS to move back and forth flexibly based on the user's needs.

1.3 Integrating the GIS and AHP

1.4 Integrating the GIS and groundwater model

The groundwater model will be used for monitoring and predicting the groundwater impacts from the preferred site. This model can be access by the user from the main menu of the system.

1.5 Developing the IEGIS user interface

2. **Applying the Expert GIS for secured landfill sites analysis in Khon Kaen Province, Thailand**

Results and Discussion

Developing an expert system for siting of secured landfill analysis

The expert system for siting of secured landfill was developed by Visual Basic language to provide the information and suggestions about siting of secured landfill sites including relevant laws, regulations, and technical knowledge for users. It also allows users to specific data layers for siting analysis based on GIS data they have in hand. Figure 2 shows examples of the expert system's interface screens.

(a) (b)

Figure 2 (a) First page of the Expert System (b) Expert System asking user to input the environmentally sensitive locations in their areas

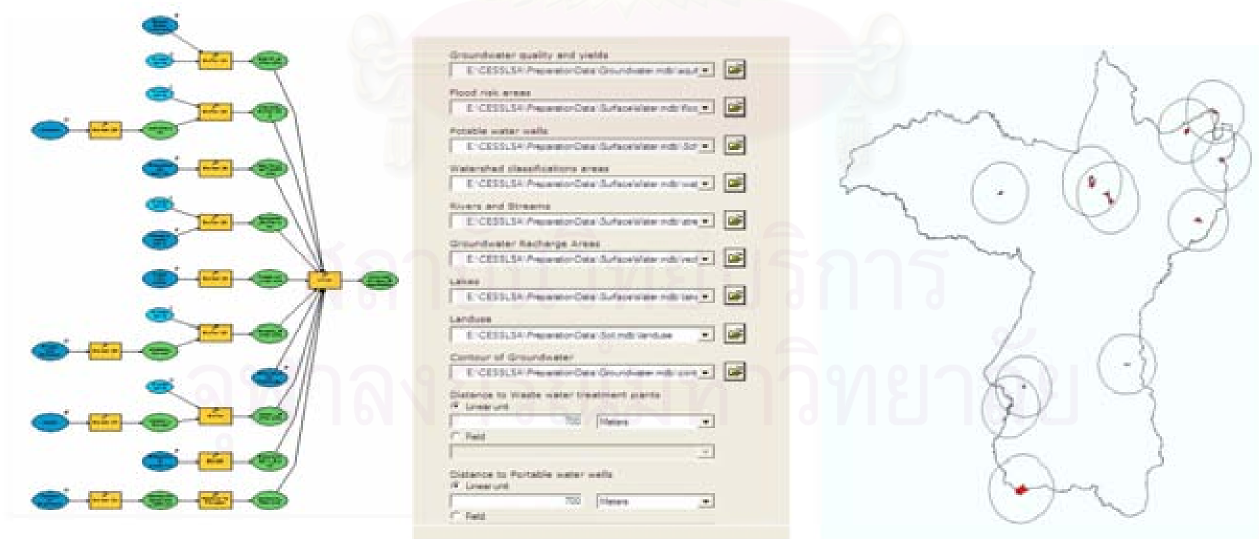
Integrating the GIS and ES

According to the siting criteria from the Notifications No. 1 and No.7 of Ministry of Industry [6], the Pollution Control Department's guidelines [7, 8], and the existing GIS data of Khon Kaen Province, the screening criteria were proposed by the expert system. The screening criteria proposed by the expert system consist of three main factors which are environmental factors, economic factors and social factors as showed in Table 1.

Due to the screening criteria in Table 1, ArcMap models, which are models of water factors, soil factors, forest factors, economic factors and social factors, were built to screen out unsuitable areas for secured landfill sites. These models have capability to automate the GIS analysis and allow users to create their own buffer area. An example of models and the interface for inputting buffer values are shown in Figures 3(a) and 3(b), respectively. Then the models were run to screen out unsuitable areas and identify candidate sites for secured landfills. The results of GIS analysis show that there are eleven candidate sites for secured landfill in Khon Kaen Province as showed in Figure 3(c).

Table 1 Screening criteria proposed by the expert system for Khon Kaen Province

No.	Factors		Default values of buffer areas
1	**Environmental factors**		
	Water	- watershed areas class 1 and 2	
		- flood prone areas	
		- river and water resources	300 m
		- groundwater table	<1.5 m
		- recharge areas	
		- high yields and high quality of groundwater	
		- existing water wells	700 m
		- wastewater treatment plant	700 m
		- wetland	300 m
	Soil	- low permeability soil	
		- mining areas	100 m
	Forest	- forest zone C (Conservation zone)	
		- national park	
2	**Economic factors**		
		- major highway	> 100 m < 10 km
		- airport	5 km
3	**Social factors**		
		- communities and residential areas	2 km
		- religious areas	
		- historical sites or ancient monuments	



(a) (b) (c)

Figure 3 (a) Example of ArcMap model (b) Example of an interface for inputting buffer values (c) Candidate sites for secured landfill in Khon Kaen Province

Integrating the GIS and AHP

After the candidate sites were identified by GIS, GIS models were built to automate GIS analysis and provide the characteristics of each candidate site based on the twelve criteria as showed in Table 2. Then Microsoft-Excel® and Visual Basic for Application (VBA) were used to develop an Excel application to import the required information from the geodatabases (.xls files) and implement the AHP analysis for ranking the candidate sites. The results of AHP analysis is shown in Table 3. The overall weighted evaluation (α_j) contained in Table 3 shows that site 4 should be selected as the suitable site for secured landfill since it has the highest weight rating, 0.146.

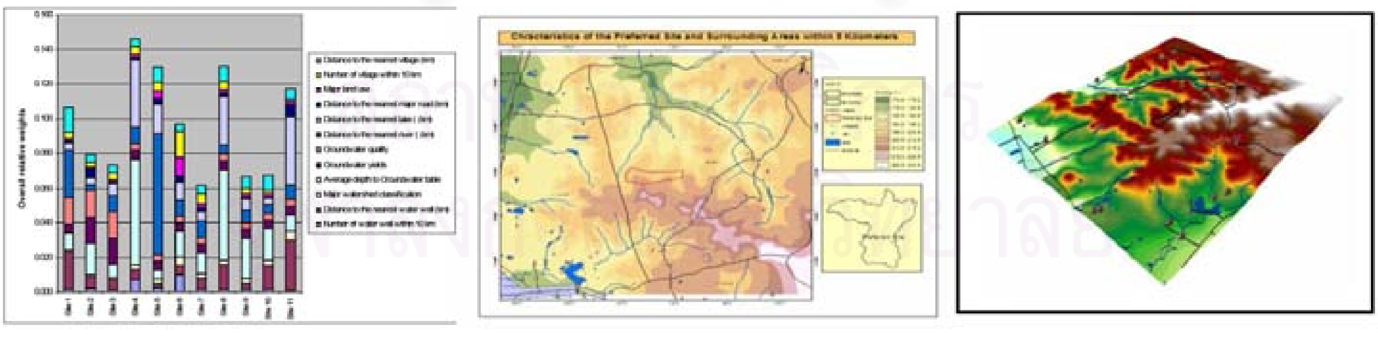
Figure 4(a) presents a bar chart of the relative weights of the eleven candidate sites. The segments in each bar represent respective rating of each candidate site with respect to each of the twelve factors. The Preferred site were then visualized in two and three dimension to show the characteristics of the site and surrounding areas within 5 kilometers as showed in Figure 4(b) and 4(c), respectively.

Table 2 Characteristics of candidate sites based on additional criteria

Criteria / Candidate site	Number of water well within 10 km	Distance to the nearest water well (km)	Major watershed classification	Average depth to Groundwater table (m)	Groundwater yields (m^3/hour)	Groundwater quality (TDS, mg/l)	Distance to the nearest river ((km)	Distance to the nearest lake ((km)	Distance to the nearest major road (km)	Major land use	Number of village within 10 km	Distance to the nearest village (km)
Sites 1	19	4.6	5B	4.1	<2	>1500	2.4	0.6	5.5	Paddy field	48	3.7
Sites 2	29	3.4	5B	5.4	2-10	>1500	0.5	0.5	2.9	Paddy field	42	2.9
Sites 3	15	3.3	5B	3.5	2-10	>1500	1.3	0.8	5.9	Paddy field	53	2.9
Sites 4	68	3.3	4B	7.5	<2	<750	1.3	3.3	5.8	Field crops	58	3.0
Sites 5	32	2.3	4B	2.75	<2	<750	5.1	1.9	3.6	Forest	60	3.4
Sites 6	80	3.2	4A	4.9	<2	<750	1.3	1.3	3.9	Grass	93	2.9
Sites 7	26	3.3	4B	4.4	<2	<750	1.3	0.7	4.4	Field crops	68	3.0
Sites 8	19	4.1	4B	7.1	<2	<750	0.8	2.8	4.1	Field crops	56	3.4
Sites 9	20	2.7	4B	5.8	<2	<750	1.1	0.8	5.1	Field crops	43	3.2
Sites 10	19	4.0	4B	5.3	<2	<750	0.9	0.4	7.6	Field crops	30	3.4
Sites 11	6	4.9	4A	4	<2	<750	1.2	3.2	2.0	Field crops	13	3.1

Table 3 Final AHP analysis for decision making

Factors / Candidate sites	Number of water well within 10 km	Distance to the nearest water well (km)	Major watershed classification	Average depth to Groundwater table (m)	Groundwater yields (m^2/hour)	Groundwater quality (TDS, mg/l)	Distance to the nearest river ((km)	Distance to the nearest lake ((km)	Distance to the nearest major road (km)	Major land use	Number of village within 10 km	Distance to the nearest village (km)	overall weighted evaluation (αj)
Site 1	0.001	0.022	0.001	0.010	0.005	0.015	0.027	0.005	0.001	0.001	0.003	0.015	0.106
Site 2	0.002	0.007	0.001	0.018	0.015	0.015	0.003	0.004	0.005	0.001	0.002	0.004	0.079
Site 3	0.001	0.006	0.001	0.008	0.015	0.015	0.009	0.007	0.001	0.001	0.004	0.004	0.073
Site 4	0.007	0.006	0.003	0.061	0.005	0.004	0.009	0.039	0.001	0.002	0.005	0.004	0.146
Site 5	0.002	0.002	0.003	0.005	0.005	0.004	0.070	0.017	0.003	0.004	0.005	0.009	0.130
Site 6	0.010	0.005	0.005	0.015	0.005	0.004	0.009	0.011	0.003	0.010	0.015	0.004	0.097
Site 7	0.002	0.006	0.003	0.012	0.005	0.004	0.009	0.006	0.002	0.002	0.006	0.004	0.062
Site 8	0.001	0.014	0.003	0.052	0.005	0.004	0.005	0.028	0.002	0.002	0.004	0.009	0.130
Site 9	0.001	0.003	0.003	0.023	0.005	0.004	0.007	0.006	0.001	0.002	0.003	0.007	0.067
Site 10	0.001	0.014	0.003	0.018	0.005	0.004	0.005	0.004	0.001	0.002	0.002	0.009	0.068
Site 11	0.001	0.029	0.005	0.010	0.005	0.004	0.009	0.038	0.008	0.002	0.001	0.006	0.117



(a) (b) (c)

Figure 4 (a) Histogram of overall weights of eleven candidate sites

(b) Two dimensions map of preferred site

(c) Three dimensions map of preferred site (the convection factor to place heights is 10)

Conclusion

Siting of secured landfill requires an extensive evaluation process to identify the suitable location. The integration of GIS, ES and AHP presented in this paper could be the valuable tool for identifying the suitable sites for secured landfills. This system has the potential to expand the use and utility of GIS, ES and AHP and could benefit planners, decision makers and general public in the secured landfill siting procedures. The development of integrating GIS, ES and AHP using Visual Basic and Microsoft-Excel® were success. However, this study has just finished the integration of ES, GIS and AHP. The next step of work is to integrate groundwater model into the system for predicting the potential adverse impact from the preferred site to groundwater.

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ทำเนียบวิทยากร

ชื่อบทความ	ระบบผู้เชี่ยวชาญสารสนเทศภูมิศาสตร์แบบบูรณาการสำหรับการวิเคราะห์หาพื้นที่ฝังกลบอย่างปลอดภัย Integrated Expert Geographic Information System for Secured Landfill Sites Analysis
ผู้นำเสนอบทความ	นายฤทธิรงค์ จังโกฏิ
สถานที่ทำงาน	ศูนย์วิจัยด้านการจัดการสิ่งแวดล้อมและสารอันตราย ภาควิชาวิศวกรรมสิ่งแวดล้อม คณะวิศวกรรมศาสตร์ มหาวิทยาลัยขอนแก่น
โทรศัพท์	081-717-1798
ประวัติการศึกษา	- ปัจจุบัน กำลังศึกษาหลักสูตร วิทยาศาสตรดุษฎีบัณฑิต สหสาขาวิชาการจัดการสิ่งแวดล้อม บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย - 2542 สาธารณสุขศาสตรมหาบัณฑิต (อนามัยสิ่งแวดล้อม) คณะสาธารณสุขศาสตร์ มหาวิทยาลัยขอนแก่น - 2538 วิทยาศาสตรบัณฑิต (วิทยาศาสตร์สุขาภิบาล) คณะสาธารณสุขศาสตร์ มหาวิทยาลัยขอนแก่น
ตำแหน่งหน้าที่ปัจจุบัน	ผู้ช่วยวิจัย ศูนย์วิจัยด้านการจัดการสิ่งแวดล้อมและสารอันตราย ภาควิชาวิศวกรรมสิ่งแวดล้อม คณะวิศวกรรมศาสตร์มหาวิทยาลัยขอนแก่น
ประวัติการทำงาน	- ม.ค.2549-ปัจจุบัน ผู้ช่วยวิจัย ศูนย์วิจัยด้านการจัดการสิ่งแวดล้อมและสารอันตราย ภาควิชาวิศวกรรมสิ่งแวดล้อม คณะวิศวกรรมศาสตร์ มหาวิทยาลัยขอนแก่น - ส.ค.2543-พ.ค.2545 ผู้ช่วยที่ปรึกษาด้านการจัดการสิ่งแวดล้อม ศูนย์การจัดการสิ่งแวดล้อม มหาวิทยาลัยขอนแก่น - ก.พ.2543-ก.ค.2543 อาจารย์ผู้ช่วยสอน ภาควิชาวิทยาศาสตร์สิ่งแวดล้อม คณะวิทยาศาสตร์ มหาวิทยาลัยขอนแก่น - ม.ค.2541-ม.ค.2543 นักวิทยาศาสตร์สิ่งแวดล้อม โครงการวิจัยมูลฝอย คณะสาธารณสุขศาสตร์ มหาวิทยาลัยขอนแก่น
ประสบการณ์	-
ผลงาน	-

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OB_10

Spatial Planning for Secure Landfill Using an Expert Geographic Information System

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Abstract

Siting of secure landfill has become increasingly difficult because of communities typically respond to plans to build a secure landfill with the view of "Not in My Back Yards (NIMBYs)" or "Locally Unwanted Land Uses (LULUs). The appropriate tool for secure landfill sites analysis should be applied in the siting procedure especially in the process of public participation to facilitate the siting of secure landfill. This study aimed at developing a comprehensive tool to facilitate the analysis of secure landfill sites based on spatial planning method, which combined environmental factors, engineering factors and socio-economic factors in site selection processes. It integrated Geographic Information System (GIS), Expert System (ES), and Analytic Hierarchy Process (AHP) into a packaged tool. The GIS represented a spatial data, ES represented a knowledge base about secure landfill siting including spatial planning, AHP was applied for ranking of candidate sites and an user interface was developed to makes it as a user-friendly graphic system. The developed tool was used to identify the suitable site for secure landfill in Khon Kaen province, Thailand. The results of GIS analysis indicated that there were eleven candidate sites for secure landfill due to the screening criteria and the calculation of landfills size. The candidate sites were then ranked by using AHP method based on twelve additional criteria. The candidate site number 4 was selected as the suitable site for secure landfill with the highest weight rating, 0.146. All consistency ratios of AHP analysis were considered as acceptable (<0.10).

BIOGRAPHY

Mr. Rittirong Junggoth was born on October 5, 1975 in Kalasin, Thailand. He obtained his B.Sc. (Sanitary Science) in 1997 and M.P.H (Environmental Health) in 2002 from Faculty of Public Health at Khon Kaen University. He started his Ph.D. degree in International Programs in Environmental Management, Chulalongkorn University in 2004 and completed the program in May 2008.