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ในเขตพื้นที่กลุ่มอำเภอภูเวียง จังหวัดขอนแก่น

นายอายุวัฒ ธนาเศรษฐอังกูล

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EVALUATION FOR SOLID WASTES DISPOSAL SITE USING GEOGRAPHIC INFORMATION SYSTEM IN PHU WIANG DISTRICT CLUSTER KHON KAEN PROVINCE

Mr. Ayuwat Thanasate-angkool

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Thesis Title	EVALUATION FOR SOLID WASTES DISPOSAL SITE USING GEOGRAPHIC INFORMATION SYSTEM IN PHU WIANG DISTRICT CLUSTER KHON KAEN PROVINCE
By	Mr. Ayuwat Thanasate-angkool
Field of Study	Environmental Management
Thesis Advisor	Associate Professor Wanpen Wirojanagud, Ph.D.
Thesis Co-advisor	Assistant Professor Rungruang Lertsirivorakul, Ph.D.

Accepted by the Graduate school, Chulalongkorn University, in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Graduate School
(Assistant Professor M.R. Kalaya Tingsabadh, Ph.D.)

THESIS COMMITTEE

.... Chairman
(Manaskorn Rachakornkij, Ph.D.)

....Thesis Advisor
(Associate Professor Wanpen Wirojanagud, Ph.D.)

....Thesis Co-advisor
(Assistant Professor Rungruang Lertsirivorakul, Ph.D.)

....Member
(Assistant Professor Somsak Pitaksanurat, Dr.Tech.)

....Member
(Surachai Sompadung, M.Sc.)

อายุวัฒ ธนาเศรษฐอังกูล: การประเมินพื้นที่ดำเนินการกำจัดขยะมูลฝอยโดยระบบสารสนเทศภูมิศาสตร์ ในการคัดเลือกในเขตพื้นที่กลุ่มอำเภอภูเวียง จังหวัดขอนแก่น (EVALUATION FOR SOLID WASTES DISPOSAL SITE USING GEOGRAPHIC INFORMATION SYSTEM IN PHU WIANG DISTRICT CLUSTER KHON KAEN PROVINCE) อ.ที่ปรึกษา: รศ.ดร.วันเพ็ญ วิโรจนกูฏ, อ.ที่ปรึกษาร่วม: ผศ.ดร. รุ่งเรือง เลิศศิริวรกุล. 123 หน้า ISBN: 974-14-3545-2

งานวิจัยนี้มีวัตถุประสงค์เพื่อทำการศึกษาพื้นที่เหมาะสมสำหรับกำจัดขยะมูลฝอยในเขตพื้นที่กลุ่มอำเภอภูเวียง จังหวัดขอนแก่น โดยใช้ระบบสารสนเทศภูมิศาสตร์เป็นเครื่องมือ โดยการหาพื้นที่ที่เหมาะสมนั้นทำโดยใช้เกณฑ์การคัดเลือกพื้นที่ที่เหมาะสมของหลุมฝังกลบขยะ เตาเผาและโรงหมักปุ๋ย โดยมีเกณฑ์คัดพื้นที่จัดทำโดยกองควบคุมมลพิษ พร้อมกับได้นำเกณฑ์ในการคัดเลือกสถานที่กำจัดขยะประเภทขยะและของเสียอันตรายโดยกรมควบคุมมลพิษเช่นกันมาประยุกต์ใช้อีกด้วย จากการหาปริมาณประชากร โดยใช้อัตราการเติบโตร้อยละห้าภายใน 20 ปี ประชากรได้เท่ากับ 1,536,650 คนและด้วยปริมาณการผลิตขยะ 1 กก./คน/วัน ปริมาณขยะซึ่งเกิดขึ้นประมาณ 7,500 ตันและด้วยสัดส่วนของปริมาณขยะที่เป็นขยะเหมาะสมที่จะเผา ทำปุ๋ยและฝังกลบเท่ากับ 53.28, 30.38 และ 16.34% ตามลำดับ ซึ่งได้ขนาดพื้นที่เท่ากับ 0.51, 0.086 และ 0.0579 ตารางกิโลเมตร สำหรับหลุมฝังกลบขยะ เตาเผาและพื้นที่หมักปุ๋ยจากขยะ ในขั้นตอนการประมวลผลโดยระบบสารสนเทศภูมิศาสตร์ พื้นที่14 แห่งได้ถูกคัดเลือกว่ามีคุณสมบัติเหมาะสมสำหรับจัดตั้งสถานที่กำจัดขยะมูลฝอยของกลุ่มอำเภอนี้ พื้นที่แต่ละแห่งมีขนาดของพื้นที่มากกว่า 1.18 ตารางกิโลเมตร ซึ่งมากกว่าที่ต้องการจากการคำนวณ และในขั้นตอนการให้คะแนน พื้นที่ที่มีความเหมาะสมมากที่สุดได้แก่พื้นที่ที่ 14 ซึ่งตั้งอยู่ในเขตบ้านโคกม่วง อำเภอชุมแพ งานวิจัยนี้สามารถสรุปได้ว่า ระบบสารสนเทศภูมิศาสตร์เป็นระบบที่มีความเหมาะสมในการคัดเลือกสถานที่กำจัดขยะมูลฝอย และระดับน้ำใต้ดินรวมทั้งคุณสมบัติของดินและหินเป็นเกณฑ์ที่สำคัญอย่างหนึ่งในการคัดเลือกพื้นที่ที่เหมาะสมทำสถานที่ฝังกลบขยะ

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AYUWAT THANASATE-ANGKOOL: EVALUATION FOR SOLID WASTES DISPOSAL SITE USING GEOGRAPHIC INFORMATION SYSTEM IN PHU WIANG DISTRICT CLUSTER KHON KAEN PROVINCE. THESIS ADVISOR: ASSOC. PROF. WANPEN WIROJANAGUD, Ph.D., THESIS CO-ADVISOR: ASST. PROF. RUNGRUANG LERTSIRIVORAKUL, Ph.D., 123 pp. ISBN: 974-14-3545-2

This study aimed at an evaluation of the potential area for disposal site in Phu Wiang District Cluster in Khon Kaen province by using Geographic Information System (GIS) computer program. Initially, the potential area of disposal sites were mapped based on the criteria for selecting landfill, incineration and composting site designated by Pollution Control Department (PCD) and the additional guideline for selecting the potential area for hazardous waste disposal site designated by PCD. By using the growth rate of 5%, number of population forcasted for the year 20^{th} would be 1,536,650 persons. With the solid waste generation rate of 1 kg/capita/day, the amount of solid waste generation for the year 20^{th} would be 7,500 tons. In according with the ratio component of solid waste types as 53.28%, 30.38% and 16.34% for incineration, composting and landfill, the area of land requirement for each type are 0.51, 0.086 and 0.579 square kilometers respectively. Total area required for disposal of solid wastes is 1.18 square kilometers. By GIS approach, there are 14 potential disposal sites disposal site. Under the consideration of location and distance to the communities by field survey, 4 sites were screened to be the appropriate potential sites. After using the weight rating technique, the most appropriate potential area for disposal site is site number 14, which is in the area of Ban Khok Muang, Chum Phae District. It could be concluded that GIS is the meaningful tool to facilitate the disposal siting. Significantly, groundwater level and soil properties are ones of the major criteria for selecting site for disposal.

Field of Study: Environmental Management Student's signature: ....
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NOMENCLATURES

AAS	=	Atomic Absorption Spectrophotometry
EC	=	Electrical Conductivity
GIS	=	Geographic Information System
GMW	=	Groundwater Monitoring Well
GW	=	Groundwater
IC	=	Ion chromatography
K	=	Hydraulic conductivity
MSL	=	Mean Sea Level
PCD	=	Pollution Control Department
TDS	=	Total Dissolved Solids

Chapter I

Introduction and Background

1.1 Statement of Problem

In the past 10 years in Thailand, the amount of wastes generation has been increased from 30,640 tons per day in 1993 to 39,225 tons per day in 2002. The rate of waste generation is about 1.2% per year. Waste management is still being the major problem in Thailand. The amount of waste has been increasing and the collection services do not cover all areas. In the year 2002 only 79 communities has accessed with sanitary landfill. The rest of wastes have been improperly disposed by open dumping and burning. Moreover, the problem of solid waste in Thailand is lacking of waste separation. It is the mixed waste of non-hazardous and hazardous wastes. Hazardous wastes from many activities in the municipal such as household, photo shop, laundry shop and laboratory have been generated more than 300,000 tons per year with annually increasing. Examples of such hazardous wastes are fluorescence lamp containing mercury, ballast having Polychlorinated Biphenyls (PCB), cleaning product having acidic effect, battery containing manganese, paint and thinner (Pollution Control Department (PCD), 2004).

In Khon Kaen Province, where the study area of this study was taken place, the amount of waste generation per day both of the municipal area and out side of the municipal area is 813 tons per day. Only 276 tons per day are collected and the rest of it is left over. Equivalently, approximately 34% of wastes is disposed into the landfill and 66% is unsanitary disposed by open dumping and burning at the abandoned area. Similarly to other municipalities, inadequacy of waste collection and disposal equipment/tools and difficulty to finding the appropriate disposal sites could cause adverse impacts to environment and human health (Thaiyatham H., 2005).

The study area was at Phu Wiang District Cluster located in Khon Kaen Province. This district cluster is consisted of Si Chomphu, Phu Wiang, Nong Rua, Chum Phae, Nong Na Kham and Phu Pa Man Districts. Phu Wiang district cluster situates in the west part of Khon Kaen province. The total area of the district cluster is about 3,125.3 square kilometers. The area (Figure 1.1) is bounded by Sri Boonruang and Phu Kradung districts in Nong Bua Lam Pu and Loei Provinces, respectively to the north. In the southern part it is bounded by Phu Kiew and Ban Tan districts in Chaiyabhum Province. Whereas, in the west is bounded by Petchabun Province.

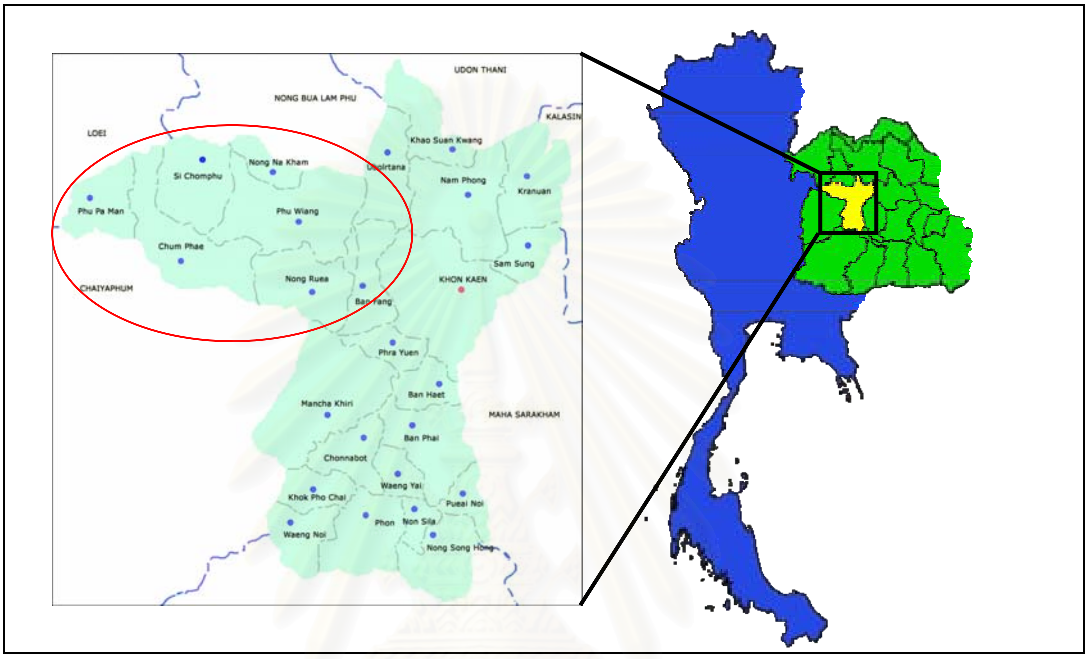

Figure 1.1 Phu Wiang District Cluster Study Area

The topography of the area is characterized by highland plain and plateau. In the western region of the study area is occupied with Phu Kradung and Petchabun mountains. The elevations of the area range from 180 to 880 meters above mean sea level (m.ASL). The temperature varies from 22.35-32.75^{o}C with the average of 26^{o}C. The annual rainfall in this district cluster is about 1,300 mm.

Regarding the potential development of the district cluster, each district has different perspectives according to their potentiality. Phu Pa Man was planned to develop for the national park and eco-tourism area. Chum Phae will be the center for economic zone along the east-west economic corridor. Phu Wiang will be developed for the Science Park and a hub for the higher technology in this region. Si Chomphu will be reserved as the area for agro-tourism and agriculture. Nong Rua will be provided for industrial park and industrial zone. Nong Na Kham will remain as agricultural area.

In accordance with the potential development, the infrastructure and utilities have to be prepared to accommodate with such growth. In terms of environmental pollution management, a solid waste disposal facility is one of the necessity infrastructures to be provided for the community. As mentioned earlier, most of municipality as well as the study areas, the wastes are mixed wastes of municipal solid wastes and household hazardous wastes. Without the separation of wastes and improper disposal, the leachate of such mixed wastes could be leaked into the environment particularly to the groundwater, that cause contamination of toxic substances which would be harmful to human health and surrounding area. This study is therefore to find the suitable disposal site to alleviate such problems.

1.2 Objective

The main objective is to investigate disposal site for integrated solid waste management using Geographic Information System at Phu Wiang District Cluster, Khon Kaen Province. The sub objectives are:

1) To estimate the existing quantity of solid wastes and predict solid waste quantity for the next 20 years.
2) To review the characteristics of solid wastes for calculating the amount of solid waste to be disposed by composting, incineration and landfill.
3) To calculate the total land requirement for integrating landfill, composting and incineration facilities.
4) To identify the candidate disposal sites using Geographic Information System based on the criteria of solid and hazardous waste disposal site selection from Pollution Control Department.
5) To rank the potential site using weighting system according to its relative importance.
6) To confirm the ranked disposal site with soil and groundwater characteristics taken by field investigation.

1.3 Hypothesis

1) Soil properties, groundwater quality and quantity, depth to water table and size of the suitable area are criteria selection for disposal site.
2) Modified criteria with hazardous waste siting criteria to prevent the impact of municipal solid waste contamination.

1.4 Scope of study:

Phuwiang, a district in Khon Kaen Province, is locates about 70 km northwest of the province. There are many sectors occupied within the district including industrial zone, agricultural, tourism, residential and construction areas. Most of the municipal solid wastes are mixed wastes of non-hazardous and household hazardous wastes. The disposal site should accommodate such mixed wastes. Accordingly, the selection of disposal site was studied based on the criteria of general solid wastes and hazardous wastes. The major tool of this study was application of Geographic Information System (GIS).The scopes of study were dealt with following steps:

(1) Reviewing the siting criteria of landfill, incineration and composting facilities.
(2) Calculating amount of solid wastes based on the number of population living in the study area with the population growth to 20 years.
(3) Selecting the potential areas according to the geological criteria for disposal site in the study area using GIS application.
(4) Assessing the selected disposal sites based on soil characteristics and groundwater level.
(5) Selecting disposal site used for waste disposal at least 20 years.
(6) Discussing and making conclusion of the findings.

1.5 Expected result

To be able to select the potential area for the disposal site where is the most suitable site for mixed wastes of solid and hazardous wastes generated from the communities in the study area.

Chapter II

Theory and Literature Review

2.1 Theoretical background

2.1.1 Characteristics of solid wastes

Solid wastes in municipal area generally are the mixed wastes of nonhazardous and hazardous wastes. Nonhazardous wastes can be defined as any unwanted or discarded material that is not in liquid or gaseous form. These wastes include municipal garbage and industrial refuse as well as sewage, agricultural refuse, demolition wastes and mining residues. Hazardous waste can be defined as wastes that cause or significantly contribute to an increase in mortality or in serious irreversible or incapacitating reversible illness or pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of or otherwise managed (Buchholz, 1998). Sources of solid wastes are presented in Table 2.1.

From the sources and types of solid wastes, solid wastes can be defined by its characteristic as solid, liquid or contained gaseous material that is discarded by being disposed of, burned or incinerated, or recycled. While hazardous wastes in municipal solid wastes are solids, semisolids or liquids. In addition, trace chemical compounds can exist as a solute within a liquid solvent, as a gas adsorbed onto solid or as a component of the gaseous emissions from Municipal Solid Waste (MSW), particularly MSW placed in landfills. Also in Thailand, the Ministry of Industry (MOI) categorizes the hazardous substances into 4 types being used as a correctly and appropriately control, and formulates Hazardous Substances Information Center to coordinate with other government agencies in part of hazardous substances information and stipulation of the criteria and methods to register hazardous substances. According to this, the Department of Industrial Work (DIW), Ministry of Industry of Thailand had describe that hazardous substance is the substance that can be explode, flammable, oxidizing agent and peroxide, toxic, substance causing diseases, radioactive, mutant causing, corrosive, irritate, and other substance either chemicals or otherwise which may cause injury to the persons, animals, plants, property or environments (DIW, 1992).

Table 2.1 Sources of Solid Wastes within the Community

Sources	Typical facilities, activities or locations where wastes are generated	Types of solid wastes
Residential	Single family and multifamily detached dwellings, low-, medium-, and high-rise apartment, etc.	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, tin cans, aluminum, other metals, ashes, street leaves, special wastes (including bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires), household hazardous wastes
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, print shops, service stations, auto repair shops, etc.	Paper, cardboard, plastics, wood, food waste, glass metals, special wastes (see above), hazardous wastes, etc.
Institutional	Schools, hospitals, prisons, governmental centers	As above in commercial
Construction and demolition	New construction sites, road repair/renovation sites, razing of buildings, broken pavement	Wood, steel, concrete, dirt, etc.
Municipal services (excluding treatment facilities)	Street cleaning, landscaping, catch basin cleaning, parks and beaches, other recreational areas	Special wastes, rubbish, street sweepings, landscape and tree trimmings, catch basin debris, general wastes from parks, beaches, and recreational areas

Sources: Tchobanoglous, et. al., 1993

Table 2.1 ***(cont.)*** Sources of solid wastes within community

Sources	**Typical facilities, activities or locations where wastes are generated**	**Types of solid wastes**
Treatment plant sites; municipal incinerators	Water, wastewater, and industrial treatment processes, etc.	Treatment plant wastes, principally composed of residual sludges
Municipal solid waste	All of above	All of above
Industrial	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power plants, demolition, etc.	Industrial process wastes, scrap materials, etc. Non-industrial wastes including food wastes, rubbish, ashes, demolition and construction wastes, special wastes, hazardous wastes
Agricultural	Field and row crops, orchards, vineyards, dairies, feedlots, farms, etc.	Spoiled food wastes, agricultural wastes, rubbish, hazardous wastes

Sources: Tchobanoglous, et. al., 1993

Due to the solid wastes mixed with hazardous waste, separation of the mixed wastes is required. Disposal facilities of each type of solid wastes depend on types of waste characteristics. Solid wastes for composting should be the organic waste which the ratio of carbon to nitrogen and carbon to phosphorus equals to 30-35: 1 and 75-100: 1 respectively. The characteristics related to compost are consisted of size of waste which equals to 0.5-1.5 inches, moisture content equals to 50-60%, air quantity equals to 10-30 ft^3/day/lb and temperature equals to 55 ^oC. The characteristics of waste for incineration should have calorific value at least 800 kcal/ kg, 15-20% of incinerable compound, lower than 15% of ash and 15-35% of the moisture content. The rest of wastes that are not matched the characteristics for composting and incineration would be disposed to the landfill. The criteria for determining the potential area for disposal site will be described in the next topic.

2.1.2 Disposal site

Disposal site means a site used for the store up of waste with the purpose of disposing or treatment of such waste (Environmental Conservation Act, 1989). Disposal site can be consisting of many facilities; each of the facility is used for different objectives. Usually, the solid wastes management facilities can be separated into 5 categories; transfer station, material recovery facility, incineration facility, composting facility and landfill facility. Pollution Control Department also compares three different kinds of waste disposal as shown in Table 2.2.

Table 2.2 Comparison of three different waste disposal methods (PCD, 1993)

Items	Incineration	Composting	Sanitary Landfill
Operation& maintenance	- almost high technology - need skillful staff	- medium technology - need semi-skillful staff	- low technology - need normal skillful staff
Effective disposing	- 60-65% volume reduction - eradicate infection 100%	- 30-35% volume reduction - eradicate infection 70%	- 100% volume reduction - eradicate a small number infection
System flexibility	low	low	High
Environmental effects on **- surface water** **- groundwater** **- air** **-odors, insects and carrier of disease germs**	 None None some none	 Possible Possible none possible	 Most possible Most possible possible some

Table 2.2 ***(cont.)*** Comparison of three different waste disposal methods (PCD, 1993)

Items	Incineration	Composting	Sanitary Landfill
Characteristics of wastes	- combustible, heat value not less than 4500 kcal/kg and moisture less than 40%	Able to be composted and moisture 50-70%	Everything except infection and hazardous wastes.
Land size	small	moderate	large
Capital cost	very high	rather high	rather low
Operation & maintenance cost	very high	rather high	rather low
By products	heat energy	compost	methane productivity

In the year 1998, Pollution Control Department of Thailand had set up the principle dealing with the municipal solid wastes and the guideline for landfill site selection as follows (Pollution Control Department, 2004):

(1) Within the watershed areas class 1 and class 2 as defined under the Cabinet Resolution on May 28, B.E. 2528 in setting up the watershed classification.

(2) Within the 1- kilometer distance from the property boundary of any ancient monuments as defined under the Ancient Monuments, Relics, Antiques and National Museum Act.

(3) Within the 5-kilometer distance from property boundary of any licensed and operating airport runway.

(4) Within 700 meters of existing potable water well or existing community water treatment plant.

(5) Within 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.

(6) In an area where geological formations or other subsurface features will not provide support for the solid wastes.

(7) Unless in the high land area. In an area subject to frequent and periodic flooding unless flood protect measures are in place.

(8) Unless in area where the normal waters table is sufficiently low. In high water level area unless special designed is provide.

(9) Unless in stretch of sufficient large area which can be land filled at least 20 years.

Moreover, the PCD has also set the principle for selecting the compost and incineration site as follow:

(1) Within the watershed areas class 1 and class 2 as defined under the Cabinet Resolution on May 28, B.E. 2528 in setting up the watershed classification.

(2) Within the 1- kilometer distance from the property boundary of any ancient monuments as defined under the Ancient Monuments, Relics, Antiques and National Museum Act.

(3) Within the 2-kilometer distance from property boundary of any licensed and operating airport runway.

(4) The location of the incinerator should be in the open air area.

For hazardous waste landfill, the additional factors used for consideration of the suitable site, for example, the potential migration of leachate to groundwater is a consideration with land disposal facilities, it is therefore desirable that a land disposal site have one or more of the following characteristics: the permeability of the uppermost formation is low, the depth to groundwater is high and the thickness of the clay deposits is high. Table 2 lists some exampling factors frequently used.

Table 2.3 Example of hazardous waste facility siting criteria (LaGrega, et. al., 2001)

Categories	Example of siting factors
Surface Water	Flood hazard areas, drinking water supplies, reservoirs
Groundwater	Hydraulic conductivity, depth to groundwater, thickness of clay deposits, aquicludes/aquitards, recharge areas, proximity to wells, karst area, groundwater flow direction
Environmentally sensitive lands	Wetlands, habitat for endangered species, parks
Population	Proximity to dwelling units, proximity to schools, population density
Industry/waste generation	Proximity to major waste generators

Furthermore, the Pollution Control Department also states the guideline for hazardous waste disposal facilities siting as follows:

(1) Distance from major highway more than 100 meters and less than 10 kilometers.

(2) Distance from communities, residential areas more than 3 kilometers.

(3) Distance from river or water resources more than 300 meters, not be located in upstream of originated water areas

(4) Groundwater table more than 1.5 meters.

(5) Not be located in flood-prone areas, low permeability soils

(6) Not be located in religious or historic sites

(7) Not be located in mining areas, far from fractures areas more than 100 meters.

For disposal of the mixture of solid and hazardous wastes, the criteria on waste disposal site should be integrated with criteria of hazardous waste facility site to find out the potential disposal area. From the entire solid and hazardous waste characteristics and the criteria for disposal site selection, geographical information system was employed for selecting the suitable disposal site.

2.1.3 Geographic information systems (GIS) application

A site selection process usually proceeds through a phased approach. It begins with the use of regional screening techniques to reduce a large study area, such as an entire country or region, to a manageable number of discrete search areas. Computerized GIS are available to assist in this task.

Database Management System is a part of computer knowledge, which is very useful in establishment database structure and database collection. This brings the systematic in to the data input process and data processing. By using this method, the cost expending in the data collection process should be brought down. Meanwhile, the data collection and data processing of the GIS is more effective.

ArcView is commercial GIS software which had been developed by Environment System Institute Inc. (ESRI). This program is used to present the data and to query the data from the Arc/Info program or another program. ArcView is very effective and user friendly. This program runs on Windows operating system which can display many menus and can open many windows in the same time.

The first version (V1.0) of the ArcView program can only display the map. After the development processes until it reaches ArcView 3.1 which is very powerful and similar to the PC Arc/Info. Beside of the presentation, query data and making a map, ArcView can perform the data edition and data correction both of the spatial data and database. Furthermore, it accepts the data in the form of AutoCAD and Image even do the spatial analysis by writing a script or using the applied program (Jirakajonkul S., 2001).

The applications of GIS for landfill management can be considered from two different perspectives: locating a site for a new landfill and maintaining existing landfills. The process of locating a new landfill must follow regulatory criteria for fatal laws, which for a large part is dependent upon soils. Land use and geology are also important as key considerations from a natural resources point of view. Economic considerations may include analysis for hauling and site characterization, both of which may be derived to a large extent using GIS (Etris R., 2005).

2.2 Relevant study

There are many researches related with Geographic Information System (GIS) application. For example, Utanawan Boonruang (2001) employed the GIS as a tool in determining the area for landfill site selection. By using criteria such as slope, surface water, groundwater, geology, geomorphology, possibility flood-prone area, soil characteristics, forest, land use, intensive area/urban, heritage and area where could accept waste for at least 20 years. Kamolporn Kerdput (1999) applied GIS for finding the potentiality area used as landfill site in Pathumthani province. An area of 1,500 square kilometers was selected by considering the relevant environmental factors using Arc/Info and ArcView program. Surasak Boonlue (1998) analyzed for suitable landfill site for solid waste using GIS application at Chasengsao Province. The research procedure was divided into five steps; using the GIS overlay techniques to select the preliminary potential areas, examining the preliminary potential area by field investigation, outlining the ranking of preliminary potential areas using the weight rating method, monitoring by reconnaissance site investigation and two boreholes for the highest ranking of the area, performing the soil resistivity of 7 sites at 80-100 metre-depth. Geotechnical borehole drilled at 15 metre-depth and 12 groundwater wells in the area and surrounding area were constructed to be used for monitoring in the future. It should be noted that the study of Boonlue's research was considered only for solid waste. While the project presented herein was considered for solid waste and hazardous waste. However, the study approach of both researches is similar. Chonticha Disathien (1992) brought GIS application and general solid waste criteria to determine the potentially landfill site selection at Saraburi municipality by dividing the analytical into 2 parts. Firstly, the weight rating technique was used to rate the criteria for slope, soil suitability, soil characteristics, topographic features, groundwater, and land uses for potential landfill site. Secondly, other criteria were determined for more efficiency of the potential landfill site. The criteria are including road and rail way, river, surface water and the haul distance. Mayura Prabpan (2001) applied the GIS to evaluate land suitability for sanitary landfill in community's public land areas in Tumbon Savathee, Khon Kaen province. This research was included three steps; using the GIS application to evaluated only the secondary data for land suitability as a first step. Step two used the field survey to assess the adequacy of the secondary data necessary for evaluations. The land suitability used the secondary data together with the data from field survey to evaluate for sanitary landfill site selection. The result shows that Pa Dum Saen Prayot area was highly promising for the research. Haruethai Thaiyathum (2005) used the GIS application and Visual Hydrologic Evaluation of Landfill Performance (HELP) computer program to evaluate for the potential sites for sanitary landfill in Khon Kaen province. From the criteria of Pollution Control Department (PCD) together with some additional criteria from Changwat (province) Action Plan for Environmental Quality Management (CAPEQM) project and by adding more specific on groundwater criteria had made the medium to low sensitive area of the existing landfill planning map created by CAPEQM project significantly decreased from 2,689.78 square kilometers to 572 square kilometers, which was approximately 79%.

Comparing the study presented in this document to the relevant researches mentioned above, this study had focused on the disposal site selection for mixed wastes. The criteria application was based on integration of criteria of general solid waste and hazardous wastes. While other studies had considered only for general solid wastes.

Chapter III

Materials and Methodology

3.1 Materials

This research focused on investigation of the disposal site for integrated solid waste management using Geographic Information System in Phu Wiang District Cluster, Khon Kaen Province. Materials employed for data analyzing to find the potential area for disposal site are topographic maps of the study area and the Geographic Information System program (ArcView 3.11).

The topographic maps of the study area were obtained from the Royal Thai Survey Department which is in the series L 7017 and scale of the map is 1:50,000. The specified maps are as follows.

Table 3.1 Map sheets of the topographic map

Map sheets	Map names
5342 I	Phu Kradung District
5342 II	Khon San District
5441 I	Nong Rua District
5441 IV	Phu Khieo District
5442 I	Si Bunruang District
5442 II	Phu Wiang District
5442 III	Chum Phae District
5442 IV	Si Chomphu District

The computer software used in this research was ArcView GIS Version 3.11 program (Environmental Systems Research Institute, ESRI). The additional programs including Autodesk Map 2004 (Microsoft Corporation) and Surfer Version7 were employed in this research.

3.2 Methodology

The methodology consisted of 2 phases; waste generation and land requirement, step of analyzing as shown in the flowchart of Figure 3.1 and described below.

3.2.1 Waste generation and land requirement

To estimate for solid waste quantity, the parameters consisting of number of population in the next 20 years and the solid waste generation rate were required. Estimation of the number of population in the next 20 years employed the formula expressed as:

$$P_{(t+n)} = (1+r)^n \, x \; P_t \tag{3.1}$$

where P_t is the population at time t - the base year (person),

$P_{(t+n)}$ is the population to be forecast at time t+n (person),

n is the number of years between t and t+n (year),

r is the annual growth rate.

In this equation, the annual growth rate was assumed to be five percent of the population in each year. The annual growth rate is calculated from the number of population that born in each year minus with the number of death population in each year. The result is divided by the number of population.

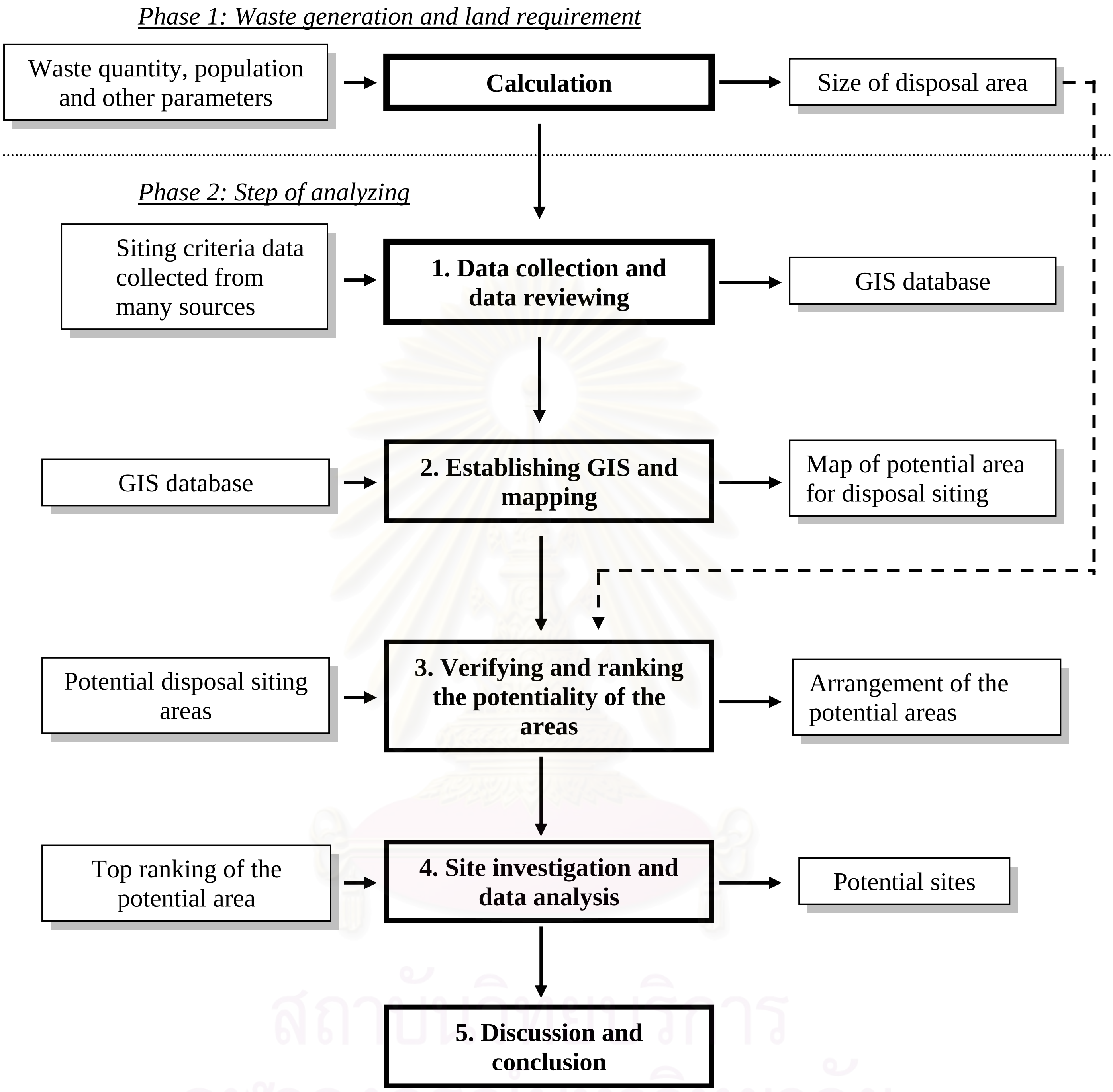

Figure 3.1 Flow Chart Showing Procedure and Results of Each Step

From equation (3.11), the number of population forecasted at time t+n was used for calculating the quantity of solid waste in each year. The calculating formula is expressed as:

$$Q_w = P \ x \ R_w \tag{3.2}$$

where Q_w is the quantity of solid waste time t+n (kg),

P is the population to be forecast at time t+n (person),

R_w is the solid waste generation rate (kg/capita/day).

The total amount of solid waste calculated at time t+n was then used for determining the size of disposal site. The quantities of solid waste calculated for each of disposal method depend on the characteristics of the solid waste. The parameters used to calculate the land requirement of the disposal facilities are quantity of solid waste and compacted specific weight of solid wastes. Moreover, the actual site requirements are greater than the value computed from these two parameters. The additional land is required for buffer zone, office and service building, access roads, utility access, and so on.

These results of this phase were then used as criteria for disposal site selection in the next phase.

3.2.2 Step of analyzing

Methodology of the step of analyzing (see Figure 3.1) can be divided into four main steps including data collection and data reviewing, establishing GIS and mapping, verifying and ranking the potentiality of the areas, site investigation and data analysis, which are subsequently explained.

3.2.2.1 Data collection and data reviewing

Firstly, the basic data acquisition, library researches, and literature studies are collected and arranged into data system. The raw data collected from various sources were reviewed and evaluated for the areas. Data collected include secondary and primary data.

(1) Secondary data is the data taken from papers, documents, reports and maps obtained from the government agencies or the others. Examples of the secondary data are as follows:

- Topographic map
- Land use map
- Geological map
- Drill log of wells
- Record of wells
- Etc.

(2) Primary data is the data carried out by the researcher. The examples of the primary data are as follows:

- Groundwater quality map
- Groundwater level map
- Aquifer characteristic map
- Etc.

3.2.2.2 Establishing GIS and mapping

In this step the preparation of the GIS database and evaluation for the potential areas for disposal site by using GIS, which can be divided into 2 categories:

a) To import the data into the geographical information system.

Data of the geographical system is consisted of 2 parts which are spatial data and attribute data. Spatial data consist of maps, while the attribute data is the data explained for all of the spatial data.

b) Data analysis

In the preliminary analysis for potential disposal site, these data were manipulated by using the geological criteria. The combination of municipal disposal facilities criteria and hazardous waste disposal siting criteria as presented in Table 3.2 were used in GIS application to determine for the suitable disposal site.

Table 3.2 Criteria for selecting site of waste disposal methods

Criteria	**Landfill**	**Incineration**	**Compost**	**Hazardous waste**
Within the watershed areas class 1 and class 2	√	√	√	
Within the 1- kilometer distance from the property boundary of any ancient monuments	√	√	√	**√(not located)**
Within the 5-kilometer distance from property boundary of any licensed and operating airport runway.	√	-	-	-
Within 700 meters of existing potable water well or existing community water treatment plant.	√	-	-	
Within 300 meters of any natural or man-made body of water, including wetlands, except bodies of water contained within the disposal site.	√	-	-	√
In an area where geological formations or other subsurface features will not provide support for the solid wastes.	√	-	-	-

Table 3.2 ***(cont.)*** Criteria for selecting site of waste disposal methods

Criteria	Landfill	Incineration	Compost	Hazardous waste
Unless in the high land area. In an area subject to frequent and periodic flooding unless flood protect measures are in place.	√	-	-	√
Unless in area where the normal waters table is sufficiently low. In high water level area unless special designed is provide.	√	-	-	-
Unless in stretch of sufficient large area which can be land filled at least 20 years.	√	-	-	-
Within the 2-kilometer distance from property boundary of any licensed and operating airport runway.	-	√	√	-
The location of the incinerator should be in the open air area.	-	√	-	-

Table 3.2 ***(cont.)*** Criteria for selecting site of waste disposal methods

Criteria	**Landfill**	**Incineration**	**Compost**	**Hazardous waste**
Distance from communities >3-kilometer	-	-	-	√
Distance from major highway >100 m.,<10-kilometer	-	-	-	√
Not be located in mining area	-	-	-	√

In this analyzing step, the positive area and the negative area were overlaid and analyzed. The positive area is defined as the area that is suitable for the disposal site which is considered by the suitable characteristics of soil and rock. The negative area is defined as the environmental sensitive receptors to be impacted from the disposal site such as watershed class 1 and 2, forestry, national park, wetland, stream, water wells, community, etc. The GIS of these positive maps and negative maps were established by reclassification and constructing the buffer zone of negative areas. After that, the negative areas were intersected with the positive areas by overlaying technique. The non-intersected positive area is the potential area for disposal site. The disposal site should have area for at least 20 years capacity.

For the overlaying technique, Pattarapunchai P. (2006) stated that the overlaying technique or overlay analysis use the buffer and the spatial overlay to create the database for GIS. Buffer can be defined as the area created to cover the selected area in an arrangement of the distance. This selected area can be even point, line or area for both of the vector and raster data. For spatial overlay, this analysis uses the overlay of several data layers, which are different in attribute but also locating in the same area to create a new data layer as shown in the Figure 3.2.

The input databases into the GIS are table and mapped format. Sources of the database are shown in Figure 3.2. Data for GIS were collected to create map of each criteria. Consequently, these databases were aiming to present the potential area for disposal site.

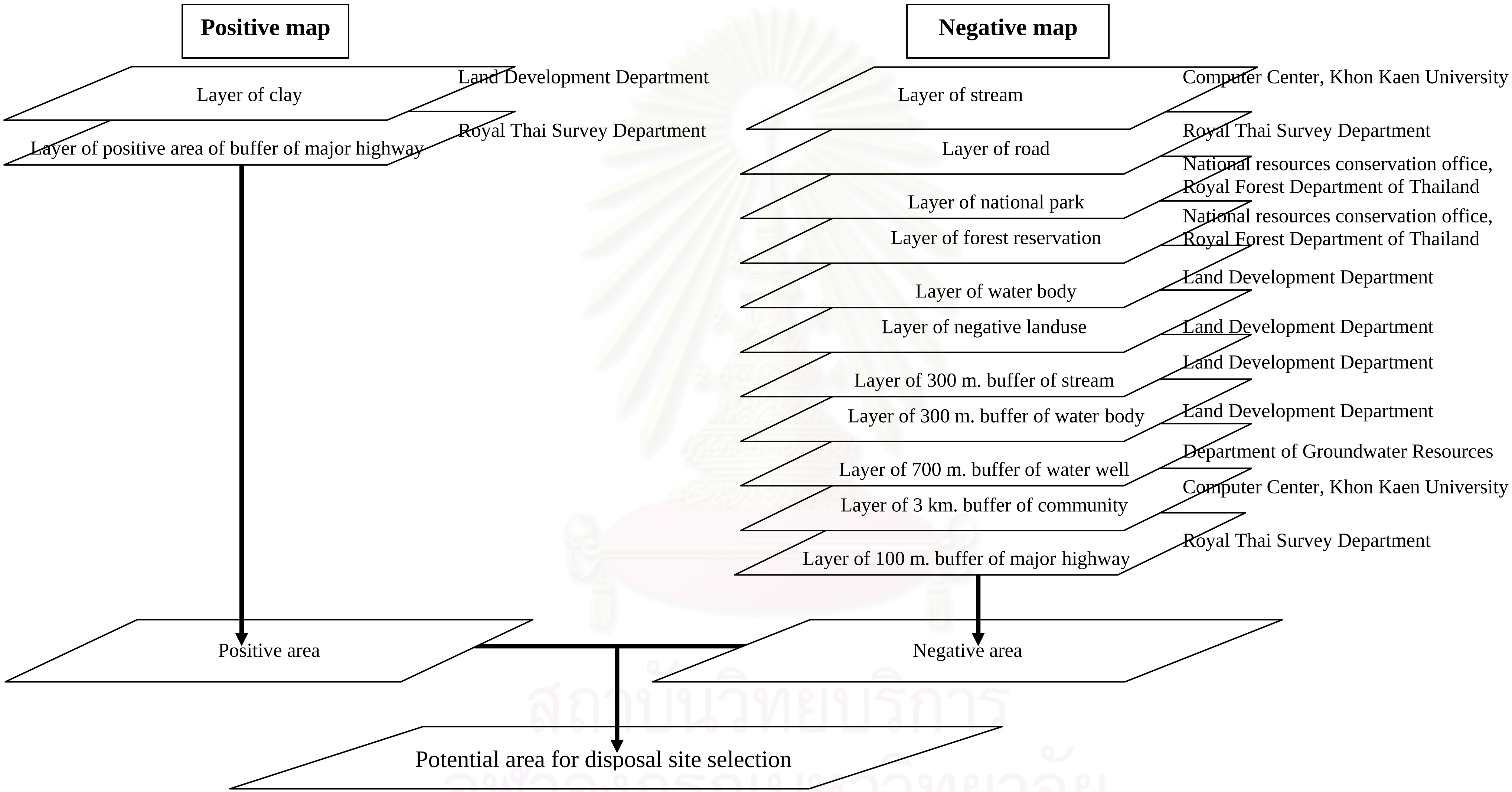

Figure 3.2 GIS Overlaying Technique for Screening Potential Area for Disposal Site

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3.2.2.3 Verifying and ranking the potentiality of the areas

The potential areas obtained from the above steps were chosen for the most suitable potential area for disposal site by integration of the following factors. Factors have to be considered for evaluating the potential sites for the long-term disposal of solid wastes (Tchobanoglous, et. al., 1993) include:

(1) Haul distance: The haul distance is one of the important variables in the selection of a disposal site. It is clear that the length of the haul can significantly affect of the overall design and operation of the waste management system. A disposal site should have accessibility to roads or temporary roads to unloading areas. The transportation of wastes should not pass through any central business or residential area. For this criteria, haul distance of each community to disposal site is calculated from AutoCAD application.

(2) Location restrictions: Location restrictions refer to where landfills can be located. Restrictions now apply with respect to siting landfills near airports, in floodplains, in wetlands, in areas with known faults, in seismic impact zones, and in unstable areas.

(3) Available land area: In selecting potential land disposal sites, it is important to ensure that sufficient land area is available. Although there are no fixed rules concerning the area required, it is desirable to have sufficient area, including an adequate buffer zone. The minimum land requirement should be equal to the size of the required land area which calculated from the land requirement of each disposal facilities. The weight will be given at 1 for the area

(4) Site accessibility: Because land areas of suitable size are often not near existing roadways and cities, construction of access roadways and the use of long haul equipment have become a fact of life and an important part of landfill siting. The persistency of the course used for transporting waste into the disposal area is considered as criteria for site accessibility of the disposal site. The lower persistency of the course may generate cost on reconstructing the road for accessing the disposal site.

(5) Soil condition and topography: Because it is necessary to cover the solid wastes placed in the landfill each day and to provide a final cover layer after the landfilling operation is completed, data must be obtained on the amounts and characteristics of the soils in the area. The topography of the area is important on designing the drainage system from the disposal site.

(6) Surface water hydrology: The local surface water hydrology of the area is important in establishing the existing natural drainage and runoff characteristics that must be considered. Other conditions of flooding must also be identified.

(7) Geologic and hydrogeologic conditions: These factors may be the most important factors in establishing the environmental suitability of the area for a landfill site. Data on these factors are required to assess the pollution potential of the proposed site and to establish what must be done to the site to ensure that the movement of leachate or gases from the landfill will not impair the quality of local groundwater or contaminate other subsurface or bedrock aquifers.

(8) Local environmental conditions: Although it has been possible to build and operate landfill sites in close proximity to both residential and industrial developments, they must be operated very carefully if they are to be environmentally acceptable with respect to traffic, noise, odor, dust, airborne debris, visual impact, vector control, hazards to health, and property values.

(9) Potential ultimate uses for the completed site: One of the advantages of a landfill is that, once it is completed, a sizable area of land becomes available for other purposes. Because the ultimate use affects the design and operation of the landfill, this issue must be resolved before the layout and design of the landfill is begun.

Therefore, the potential areas have to be ranked by using the rating scores of all the above factors. The weight of each criterion must be determined according to its relative importance. Each weight would be given by the experts. Once the weighting is accomplished, each candidate site can be rated according to how it compares to the other candidates. The total score for each site is then determined according to the following formula:

$$S_A = (W_1 \ x \ R_1) + (W_2 \ x \ R_2) + (W_3 \ x \ R_3) + ... \quad (3.3)$$

where SA = Total score for site A

W1 = Weight of first criterion

R1 = Rating of first criterion

The area which is the first ranking would be chosen for the potential area for disposal site in this research.

3.2.2.4 Site investigation and data analysis

After choosing the potential area for disposal site, the field investigation including preliminary soil investigation and groundwater determination were conducted in order to confirm the field data with the one obtained from GIS and to be the background data for designing the environmental preventive measures as well as for the monitoring in the future.

Preliminary soil investigation for the soil layer characteristics was carried out using resistivity imaging and sounding method, which is the method that uses the difference of earth materials electrical resistivity. Normally, the conductivity of the rock is an electrolytic conduction induced by the free-ion in the electrolyte. Each type rock has a different amount of free-ion which accordingly makes different resistivity. The resistivity survey was employed to identify the subsurface layers. The resistivity meter is IRIS series SYSCAL R-1^{+} (Figure 3.3). The resistivity imaging method was conducted by using the dipole-dipole configuration, whereas sounding method was arranged by Schlumberger configuration.

Figure 3.3 Resistivity Meter

Groundwater monitoring well was installed at the selected disposal site. Soil and groundwater samples at the monitoring well were collected to be analyzed for the basic properties in the laboratory. Soil permeability by infiltration test was carried out. Whereas, pumped test was conducted to determine the hydraulic conductivity of the aquifer. In addition, groundwater samples from the existing wells upstream and downstream of the selected disposal site were also analyzed for their chemical properties. Groundwater quality and analysis method are summarized in Table 3.3.

Table 3.3 Groundwater quality and analysis method

Basic characteristics	Equipment
pH	pH meter
Total Dissolved Solid (TDS)	Filtration and evaporation
Electrical Conductivity (EC)	EC meter
Total Hardness	Erichrome Black-T Titration
Cupper (Cu)	Atomic Absorption Spectrophotometry (AAS)
Chromium (Cr)	Atomic Absorption Spectrophotometry (AAS)
Cadmium (Cd)	Atomic Absorption Spectrophotometry (AAS)
Lead (Pb)	Atomic Absorption Spectrophotometry (AAS)
Zinc (Zn)	Atomic Absorption Spectrophotometry (AAS)
Chloride (Cl)	Ion chromatography (IC)
Potassium (K)	Ion chromatography (IC)
Sodium (Na)	Ion chromatography (IC)
Sulfate (SO_4)	Ion chromatography (IC)
Carbonate (CO3)	Indicator Titration
Bicarbonate (HCO3)	Indicator Titration

Chapter IV

Results and Discussions

4.1 Waste Generation and Land Requirement

As previous mentioned, the calculation for the area of disposal site was divided into two steps including waste generation and land requirement (lifespan at least 20 years). Then the calculated data was used as one of the GIS database. The details of calculation are described as follows:

4.1.1 Waste generation

There are three parameters used for calculating the waste generation including the number of population in the next 20 years, the waste generation rate and the physical characteristics of the solid waste.

4.1.1.1 Number of population during 2004-2024

In reference with the formula for calculating the number of population by the forecasting techniques for population prediction of Field and Mac Gregor (1992) as expressed by equation (3.1) in Chapter 3.

From the equation (3.1), P_t and $P_{(t+n)}$ were substituted by the number of population of each municipal/ sanitary in the study area during 2004 to 2024 and 2005 to 2025, year by year, respectively. In this study, Thanasateang-kool S. and Charoenchai A. (2003) suggested to use the annual growth rate at 5 percent of population in each year, which is proposed by the Department of National Economic and Social Development (see Table A-1 in Appendix A)

Therefore, the total number of population is approximately 1,536,650 persons. More details are presented in Table A-2 in Appendix A.

4.1.1.2 Solid waste generation

According to Pollution Control Department, the averaged solid waste generation rate is 1 kg/capita/day. Therefore, this waste generation rate was used for calculating the quantities of solid waste in the study area the formula for calculating the quantities of solid waste expressed as equation (3.2) in Chapter 3.

From the equation (3.2), P and R_w were substituted by the number of population in the study area and the solid waste generation rate, which are 1,536,650 persons and 1 kg/capita/day, respectively.

Consequently, the total quantities of solid waste in 20 years of the study area are 7,550,645 tons. The quantities of solid waste of each municipal/sanitary in the study area are presented in Table A-3 in Appendix A.

4.1.1.3 Physical characteristics of solid waste

The composition of the solid waste in the study area can be separated into three groups by their physical characteristics as:

- Composted solid waste: food waste or garbage, and leaf or branch of tree
- Combustible solid waste: paper, plastic, rubber, leather, and clothes
- Non-combustible solid waste: glass, metal, stone, fragment of ceramics, and others

The physical characteristics of solid waste in Khon Kaen province (Piyaprasit C., 1996) are summarized in Tables B-1 and B-2, indicated as by weight for 30.38% of composted solid waste, 53.28% of combustible solid waste and 16.34% of non-combustible solid waste. Therefore, the cumulative weight of solid waste during 2004-2024 is 7,550,645 tons could be divided into three categories including 2,293,886 tons of composted solid waste, 4,022,984 tons of combustible solid waste and 1,233,775 tons of non-combustible solid waste, respectively. However, the total amount of solid waste was used for land requirement calculation in the next step. Table 4.1 shows the quantities of each type of the solid waste generated in the study area.

Table 4.1 Quantities of each type of solid waste generated in the study area

Year	Pop. Prediction (persons)	Rate of solid waste generation (kg/capita/day)	Waste generation (kg/d)	Incinerable (kg/d)	Composting (kg/d)	Landfill (kg/d)
2004	579,147	1	579,147	308,569.52	175,944.86	94,632.62
2005	608,105	1	608,105	323,998.34	184,742.30	99,364.36
2006	638,510	1	638,510	340,198.13	193,979.34	104,332.53
2007	670,435	1	670,435	357,207.77	203,678.15	109,549.08
2008	703,957	1	703,957	375,068.29	213,862.14	115,026.57
2009	739,155	1	739,155	393,821.78	224,555.29	120,777.93
2010	776,113	1	776,113	413,513.01	235,783.13	126,816.86
2011	814,918	1	814,918	434,188.31	247,572.09	133,157.60
2012	855,664	1	855,664	455,897.78	259,950.72	139,815.50
2013	898,447	1	898,447	478,692.56	272,948.20	146,806.24
2014	943,370	1	943,370	502,627.54	286,595.81	154,146.66
2015	990,538	1	990,538	527,758.65	300,925.44	161,853.91
2016	1,040,065	1	1,040,065	554,146.63	315,971.75	169,946.62
2017	1,092,068	1	1,092,068	581,853.83	331,770.26	178,443.91
2018	1,146,672	1	1,146,672	610,946.84	348,358.95	187,366.20
2019	1,204,005	1	1,204,005	641,493.86	365,776.72	196,734.42
2020	1,264,206	1	1,264,206	673,568.96	384,065.78	206,571.26
2021	1,327,416	1	1,327,416	707,247.24	403,268.98	216,899.77
2022	1,393,787	1	1,393,787	742,609.71	423,432.49	227,744.80
2023	1,463,476	1	1,463,476	779,740.01	444,604.01	239,131.98
2024	1,536,650	1	1,536,650	818,727.12	466,834.27	251,088.61

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4.1.2 Land requirement calculation

For this step, the amount of the solid waste generation was used as one of the parameter to calculate the land requirement of the disposal site. In this study, the land requirement is divided into 3 areas for incineration plant, composting facility and landfill, respectively.

4.1.2.1 Land requirement for incineration plant

Based on the calculated quantities of 4,022,984 tons of solid waste for incineration, the maximum of the solid waste generated per day is equal to 818.7 tons per day. In addition with the data of incineration plant (Mitsubishi-Martin) in Phuket Province that uses the total area of 43,000 m^2 for 250 tons per day incineration facility, consequently, the total area for incineration plant in this study is approximately 86,000 m^2.

4.1.2.2 Land requirement for landfill

From the guideline of land requirement for various landfill capacities (Pollution Control Department, 1998) are shown in Table 4.2.

Table 4.2 Guideline of land requirement for various landfill capacities

Wastes (tons/day)	Area (rai)
10-50	15-70
50-100	70-130
100-300	130-380
300-500	380-620

In this study, the maximum quantity of solid waste per day is at 251.09 tons/day. The land requirement of the landfill is equal to 318.75 rai or approximately at 510,000 m^2.

4.1.2.3 Land requirement for composting facility

The quantities of solid waste for composting are equal to 2,293,886 tons. To calculate the land requirement for composting facility, Boonruang U. (2001) suggested using the compacted specific weight of solid waste at 550 kg/m^3. With the windrow method and the cross section area of the windrow at 2.95 m^2, time for compost for 45 days, and 10% of the area for storing composted waste before further usage. The total area for composting facility is equal to 578,541.4 m^2. More details are presented in Table 4.3.

From the calculated land requirement for each facility, then it was summed up to be the total land area requirement of 1,174,541.40 m^2 or 1.17 km^2. This land requirement was not screening out the amount of waste for recycling in according to find the largest land area requirement for disposal siting.

This land area requirement would be used as a criterion for selecting an area for potential disposal site selection in the next step.

Table 4.3 Land requirement for composting facility calculation

Year	Population (persons)	Waste generation (ton/d)	Composting (kg/d)	Volume (m3/d)	Cross section area (m2)	Length (m) for waste/day	Composting area for 45 days (m2)	Composting area for 45 days plus spacing between row (m2)	Total area using for 1 year (m2)
2004	579,147	579.1	175,944.86	319.90	2.95	108.62	12,219.27	24,438.54	198,223.71
2005	608,105	608.1	184,742.30	335.90	2.95	114.05	12,830.25	25,660.49	208,135.12
2006	638,510	638.5	193,979.34	352.69	2.95	119.75	13,471.75	26,943.51	218,541.79
2007	670,435	670.4	203,678.15	370.32	2.95	125.74	14,145.33	28,290.66	229,468.71
2008	703,957	704.0	213,862.14	388.84	2.95	132.02	14,852.60	29,705.21	240,942.23
2009	739,155	739.2	224,555.29	408.28	2.95	138.62	15,595.24	31,190.47	252,989.40
2010	776,113	776.1	235,783.13	428.70	2.95	145.56	16,375.00	32,750.01	265,638.95
2011	814,918	814.9	247,572.09	450.13	2.95	152.83	17,193.74	34,387.48	278,920.68
2012	855,664	855.7	259,950.72	472.64	2.95	160.47	18,053.43	36,106.86	292,866.74
2013	898,447	898.4	272,948.20	496.27	2.95	168.50	18,956.10	37,912.19	307,510.01
2014	943,370	943.4	286,595.81	521.08	2.95	176.92	19,903.92	39,807.83	322,885.74
2015	990,538	990.5	300,925.44	547.14	2.95	185.77	20,899.10	41,798.20	339,029.85
2016	1,040,065	1,040.1	315,971.75	574.49	2.95	195.06	21,944.06	43,888.12	355,981.38
2017	1,092,068	1,092.1	331,770.26	603.22	2.95	204.81	23,041.26	46,082.51	373,780.36
2018	1,146,672	1,146.7	348,358.95	633.38	2.95	215.05	24,193.33	48,386.66	392,469.59
2019	1,204,005	1,204.0	365,776.72	665.05	2.95	225.80	25,402.98	50,805.97	412,092.86
2020	1,264,206	1,264.2	384,065.78	698.30	2.95	237.09	26,673.15	53,346.30	432,697.76
2021	1,327,416	1,327.4	403,268.98	733.22	2.95	248.95	28,006.80	56,013.60	454,332.55
2022	1,393,787	1,393.8	423,432.49	769.88	2.95	261.40	29,407.14	58,814.29	477,049.24
2023	1,463,476	1,463.5	444,604.01	808.37	2.95	274.47	30,877.49	61,754.99	500,901.58
2024	1,536,650	1,536.7	466,834.27	848.79	2.95	288.19	32,421.37	64,842.75	525,946.73

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4.2 GIS Database and Analysis

The procedure of GIS database and analysis was separated into two main categories. As described in the previous chapter, the first one was data collection consisting of primary data and secondary data. The second step was analyzed of the data using criteria of Pollution Control Department.

In the preliminary analysis for potential disposal site, the data was manipulated based on the geological criteria. Then, the combination criteria for municipal and hazardous waste disposal site were set forth by GIS application to determine for the suitable disposal site.

The result of the analysis using GIS was separated into positive maps and negative maps (details on layout in Appendix D).

4.2.1 Positive maps

As stated in Chapter 3, the positive maps are the maps presenting the areas that are available for disposal site The positive maps herein were consisted of the map of positive soil group, and the map of positive area within 100 meters but not more than 10 kilometers from the major highway. The map of positive soil group is the map of clay, which was conducted by using GIS application to select the soil group of clay out of the soil group map, and converting into a new shape file as shown in Figure 4.1 For the map of positive area from buffer of the major highway (within 100 meter and not more than 10 kilometers), the buffer areas were created by using GIS application and the criteria on distance from the major highway of the hazardous waste disposal facility is shown in Figure 4.2.

4.2.2 Negative maps

The samples of the negative maps were consisted of the forest reservation map (Figure 4.3), community with 3 kilometers-buffer map (Figure 4.4), national park map (Figure 4.5), water well locations with 700 meters-buffer map (Figure 4.6), natural or man-made water bodies with 300 meters-buffer map (Figure 4.7), negative land use map consisting of watershed area and residential area (Figure 4.8) and the stream with

300 meters-buffer map (Figure 4.9). Each of the map was the area that disposal site should not be located and all of these maps were conducted by using the GIS application as for the positive maps. For each of the negative map, forest reservation map and national park map were obtained the data from the National Resources Conservation Office, Royal Forest Department of Thailand. These two maps can be using as the negative maps directly. By using the GIS application, a new negative landuse map was generated by relocate watershed areas as well as residential areas. The rest of the negative map, which are the buffer maps of community, water well locations, natural or man-made water bodies and the stream, all of these maps were using the buffer selected feature function in the GIS-extension to create the buffer zones with the distance which were indicated in the criteria for disposal site selection of Pollution Control Department.

By using the overlaying technique in GIS application, positive maps and negative maps were intersected, and then the non-intersected positive areas are the suitable area for disposal site as illustrated in Figure 4.10.

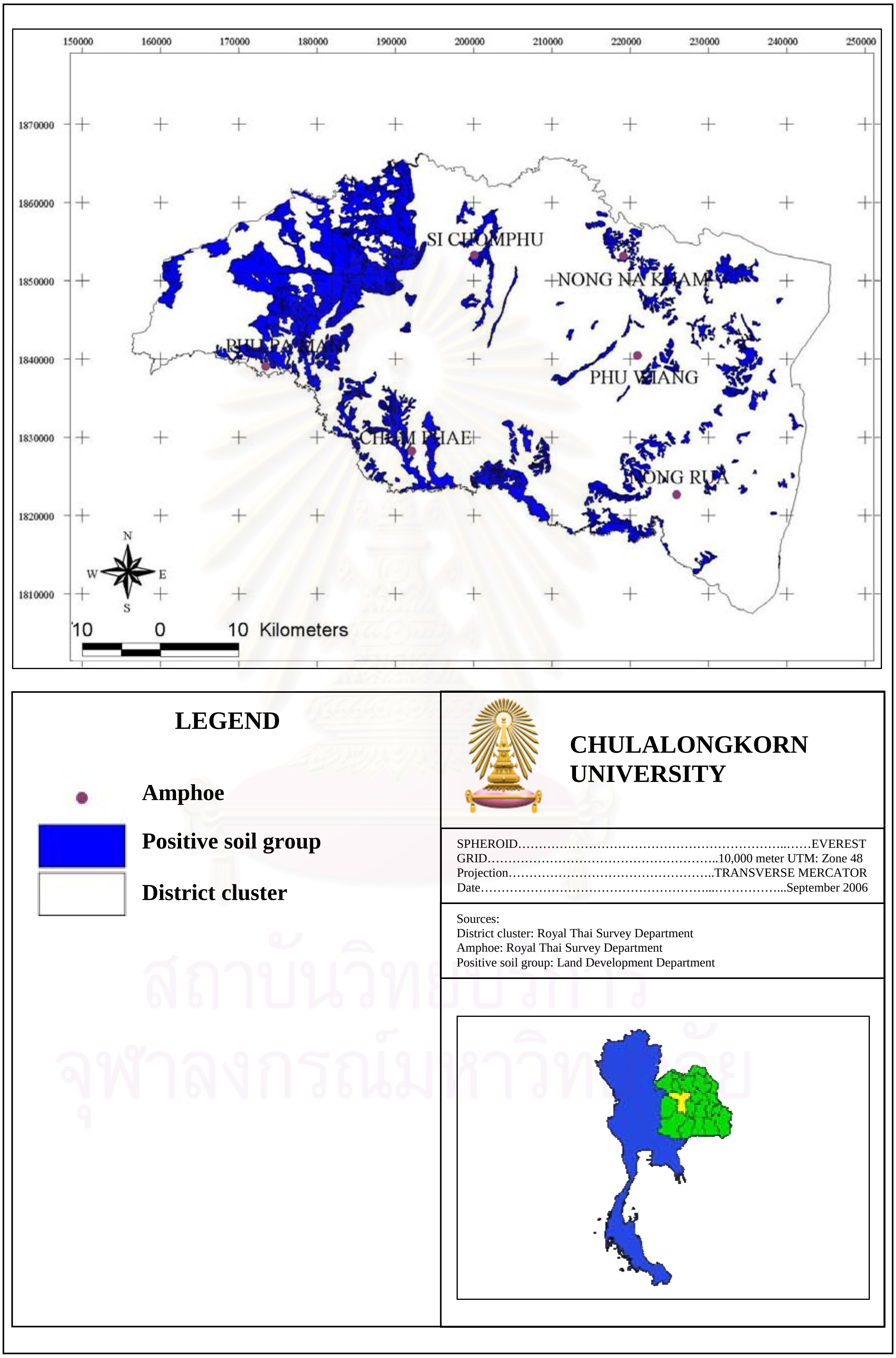


Figure 4.1 Map of Positive Soil Group

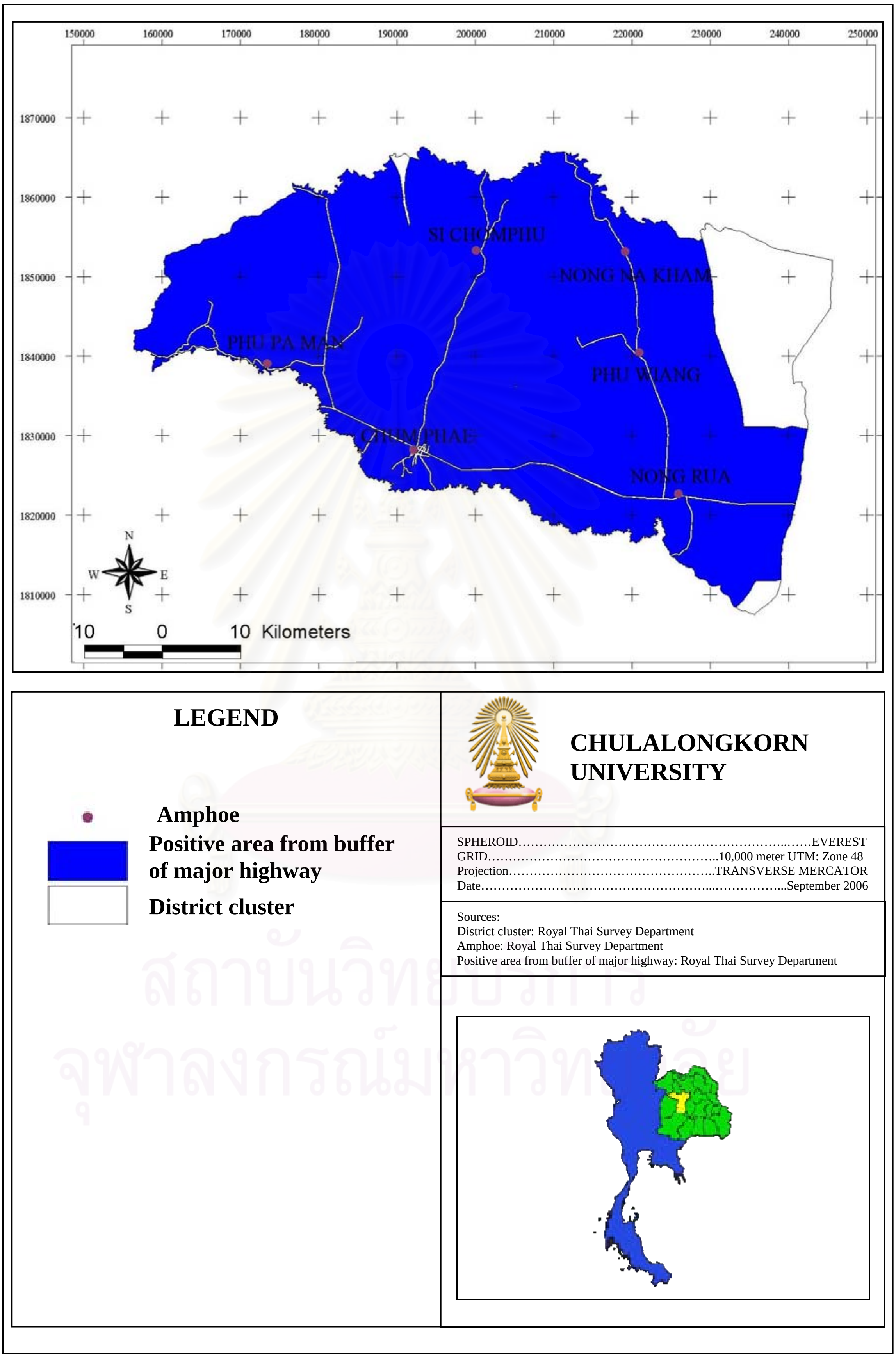


Figure 4.2 Map of Positive Area of Major Highway Buffer

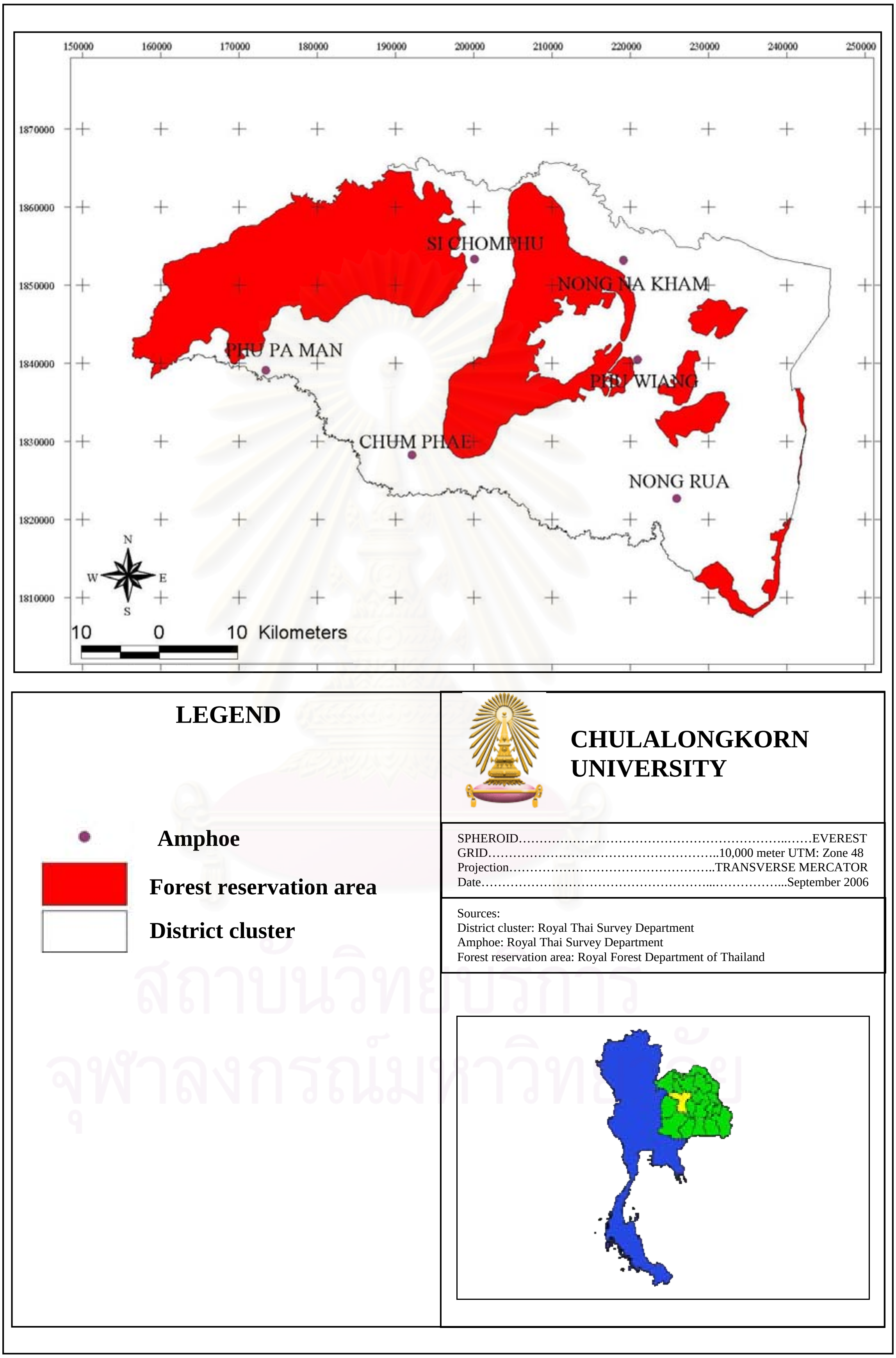


Figure 4.3 Forest Reservation Map

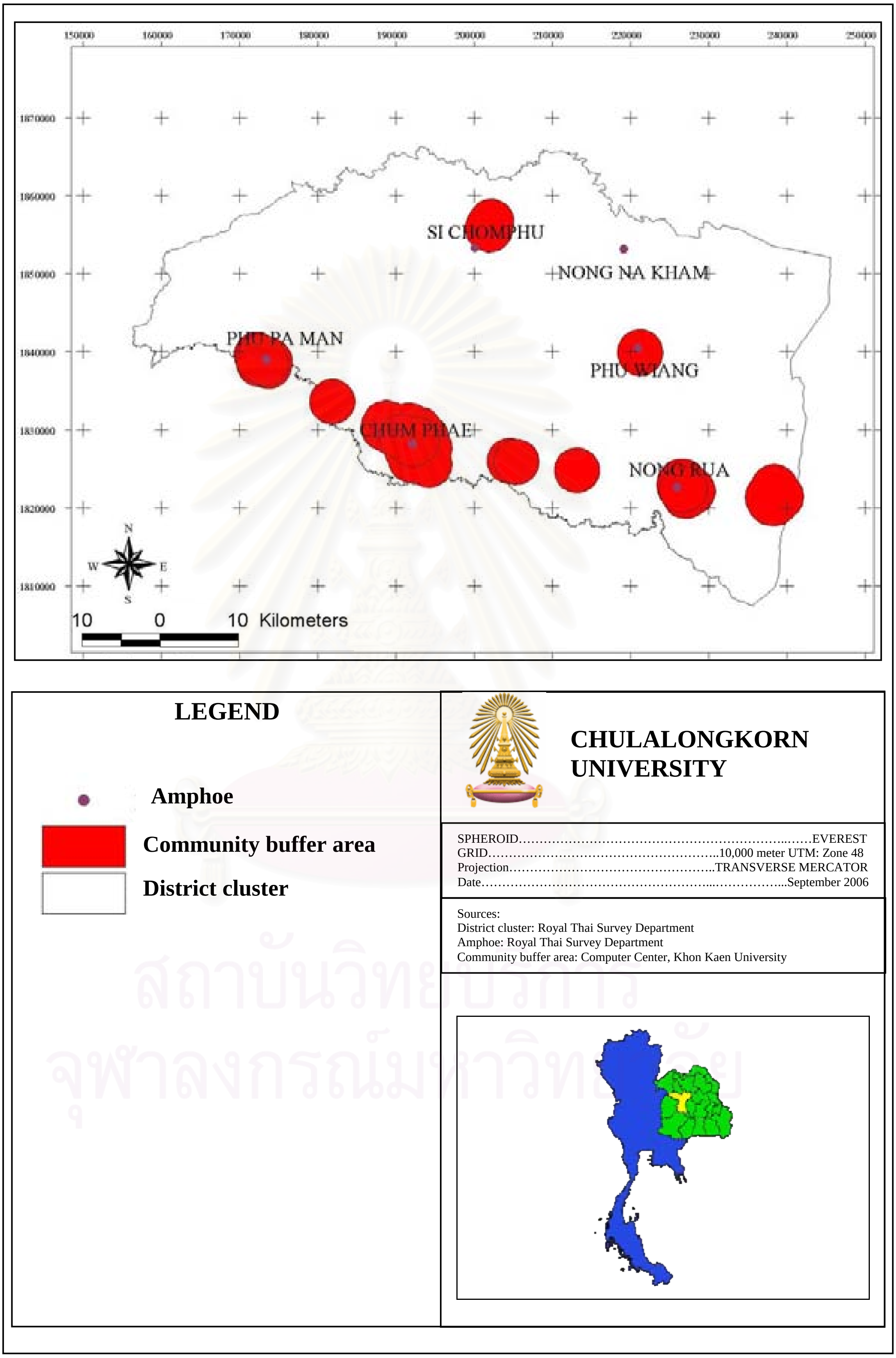


Figure 4.4 Map of Community Buffer Area

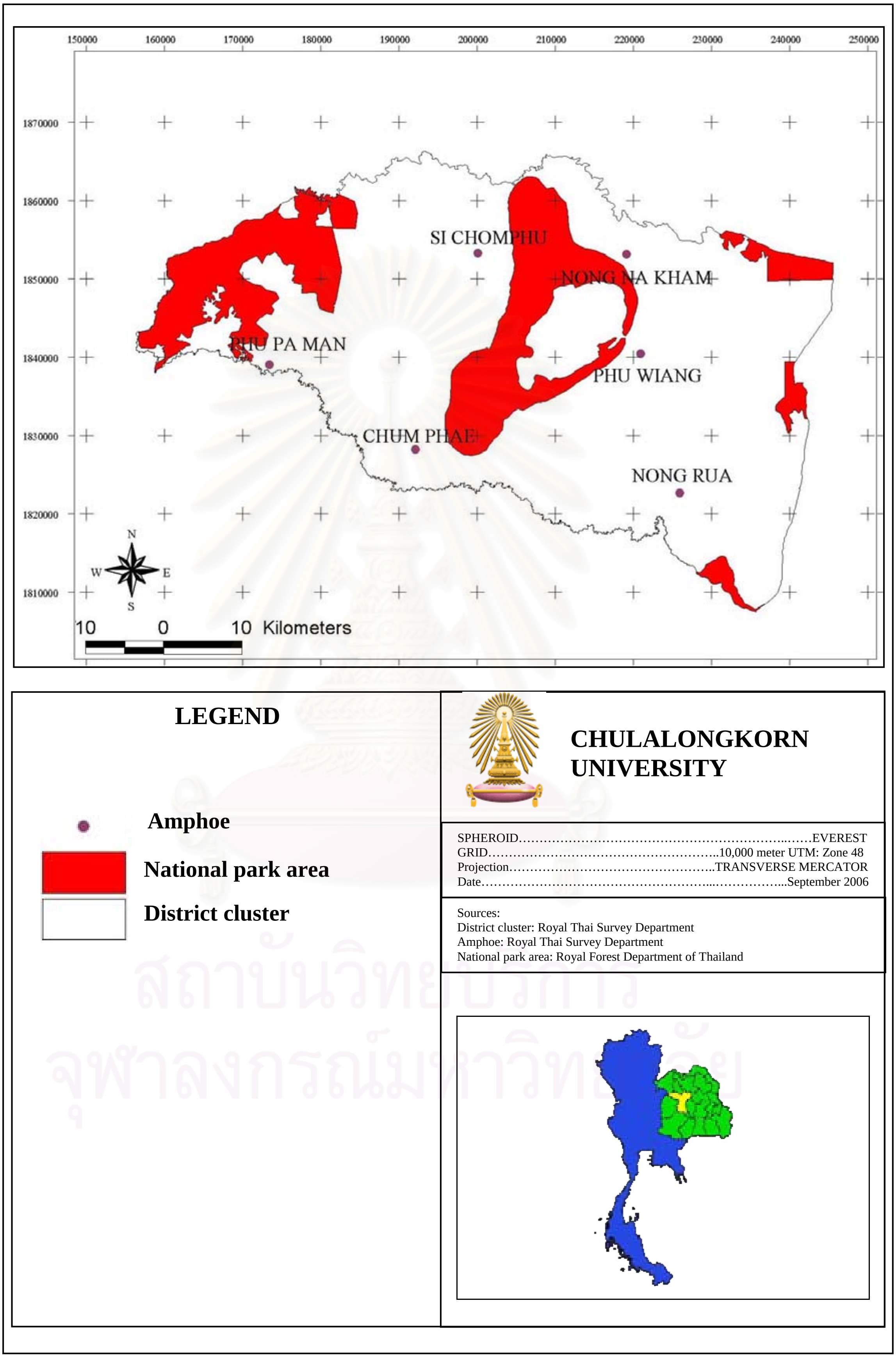
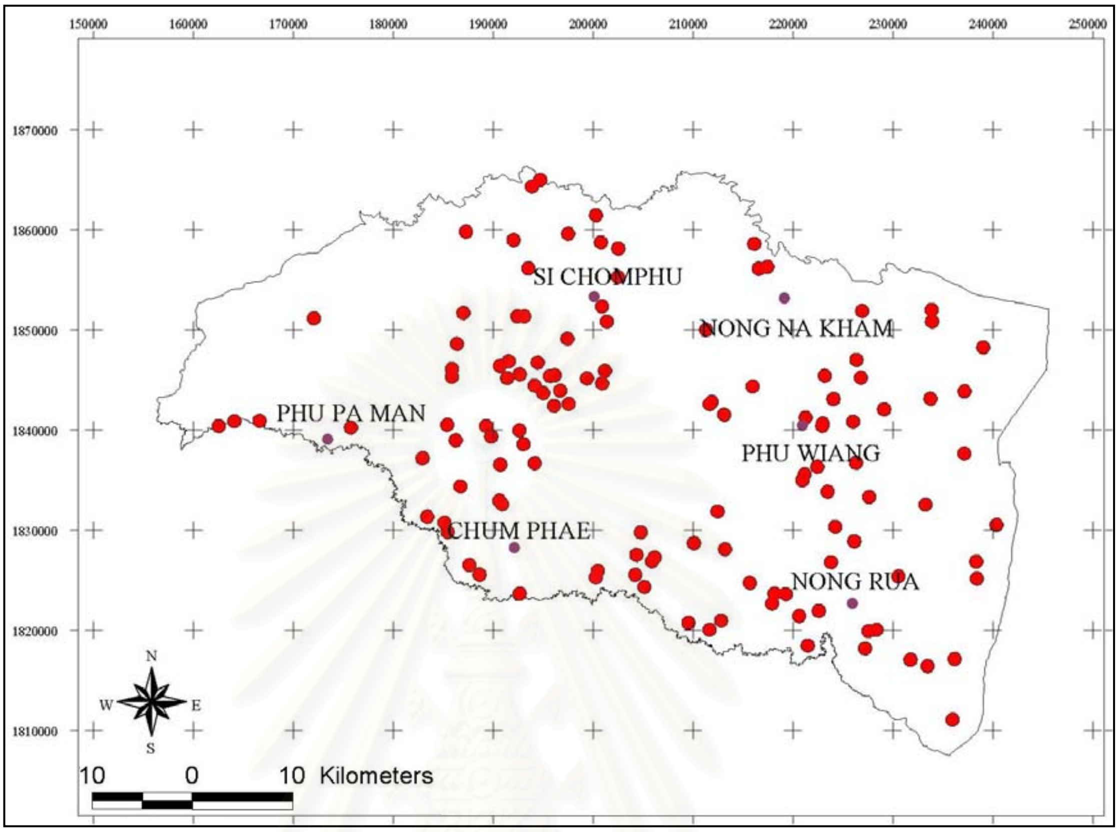


Figure 4.5 Map of National Park



LEGEND

Amphoe

Water well buffer area

District cluster

CHULALONGKORN UNIVERSITY

SPHEROID……………………………………………………………...……EVEREST
GRID…………………………………………………..10,000 meter UTM: Zone 48
Projection……………………………………………..TRANSVERSE MERCATOR
Date…………………………………………….....……………...September 2006

Sources:
District cluster: Royal Thai Survey Department
Amphoe: Royal Thai Survey Department
Water well buffer area: Department of Groundwater Resources

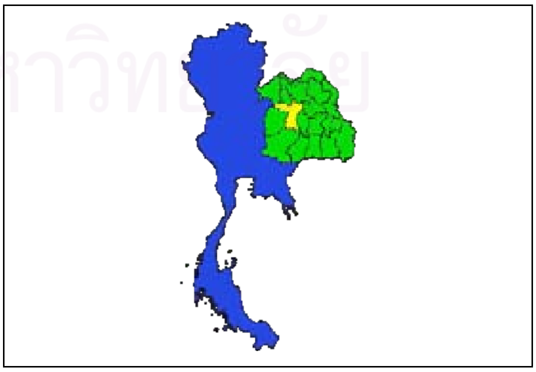


Figure 4.6 Map of Water Well with 700 Meters-radius Buffer

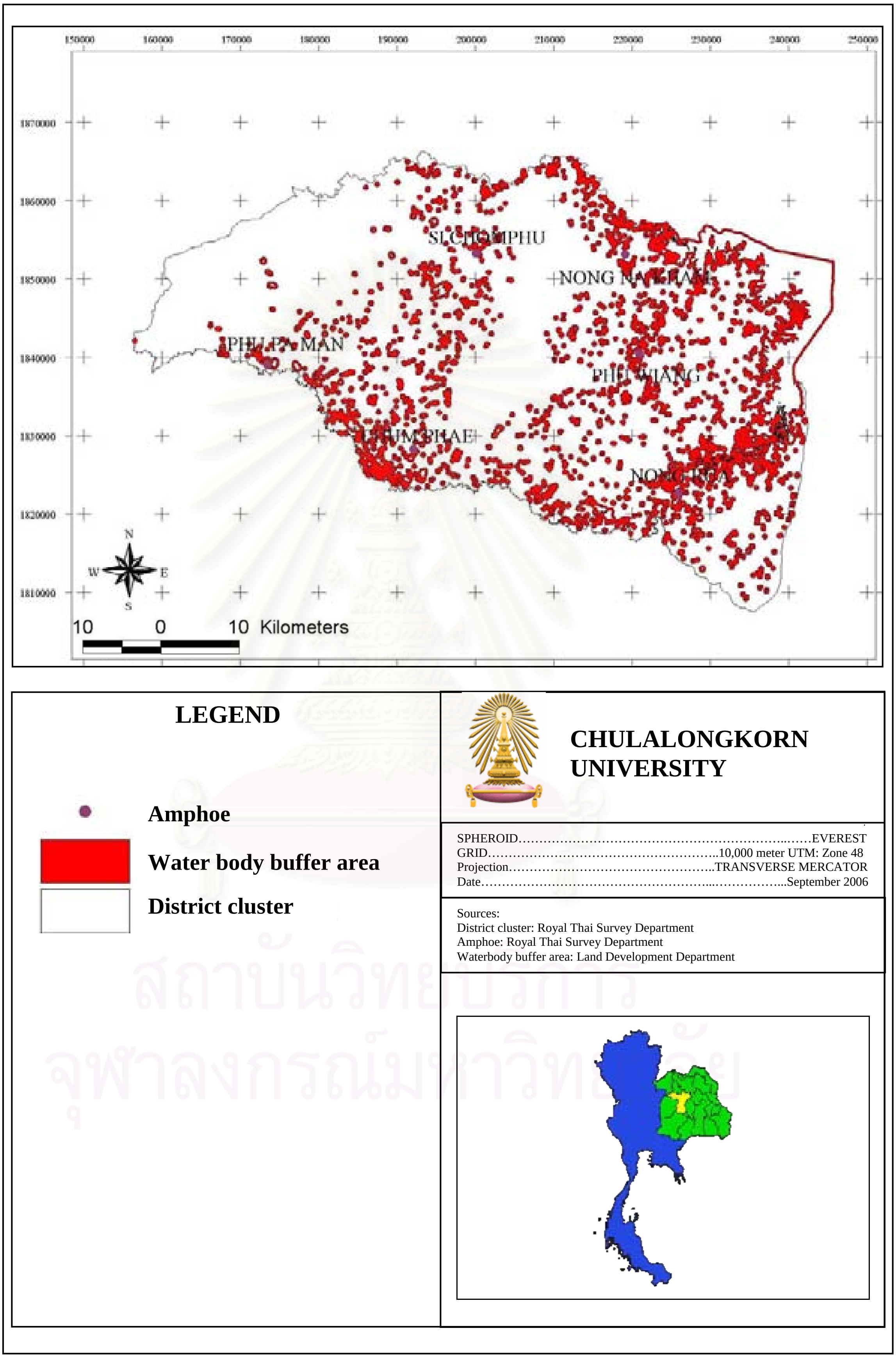


Figure 4.7 Map of Water Body with 300 Meters-radius Buffer

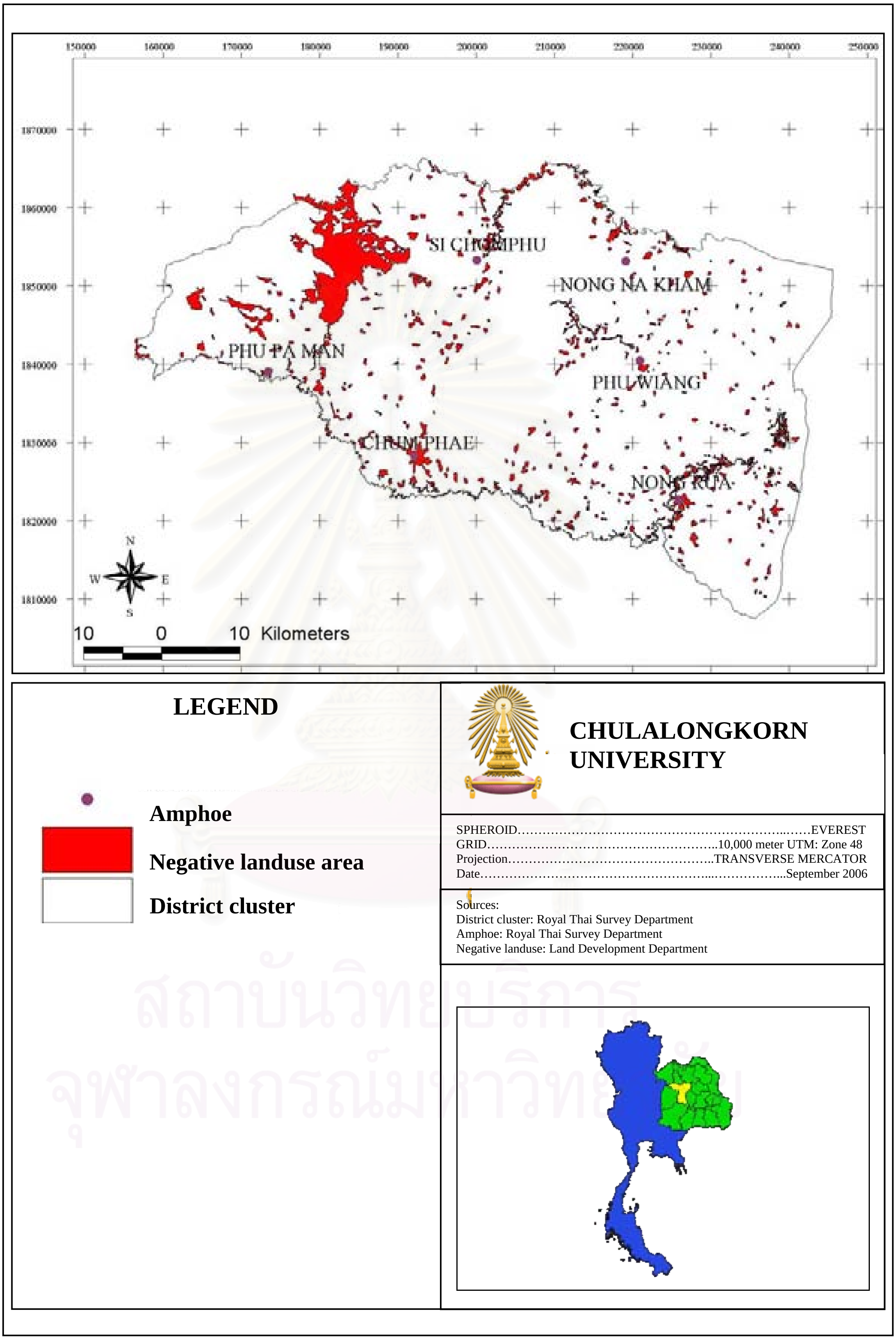


Figure 4.8 Negative Landuse Map

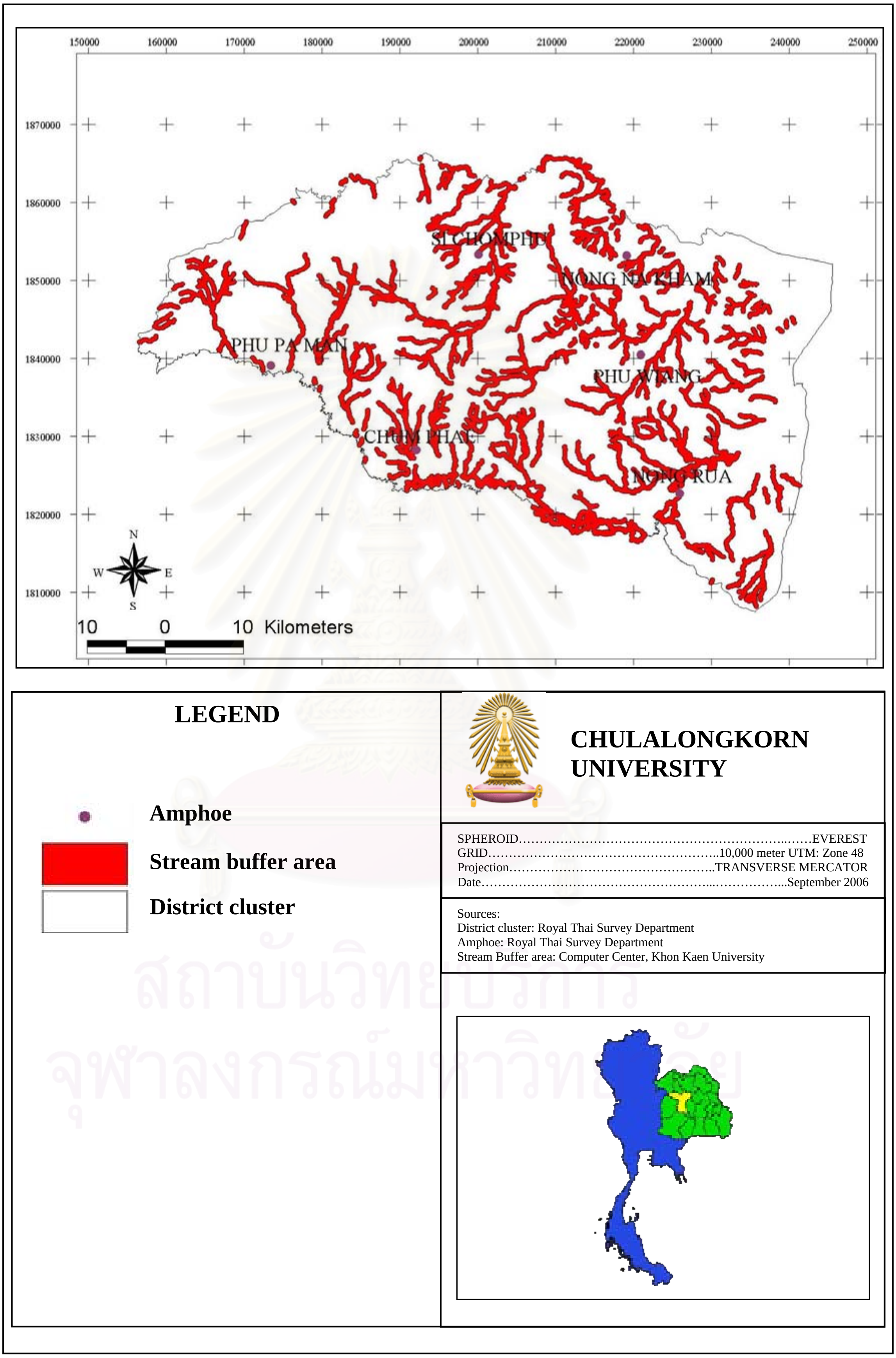


Figure 4.9 Map of Stream with 300 Meters Buffer

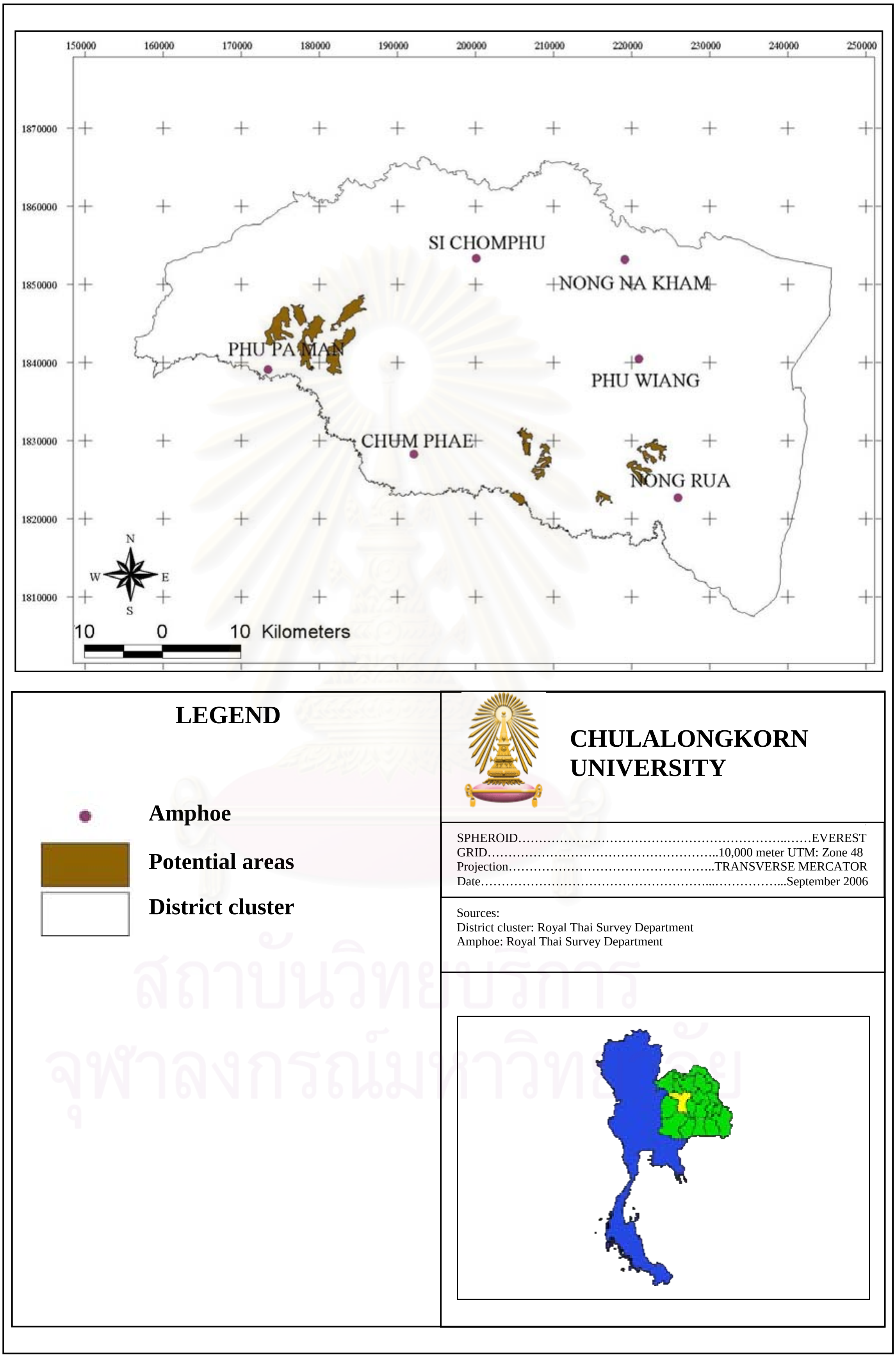


Figure 4.10 Map of Potential Areas for Disposal Site

4.3 Verifying and ranking for the potential disposal area

From the previous step, fourteen (14) areas in Nong Rua, Chum Phae, Phu Pa Man and Si Chomphu Districts are shown as the potential areas for disposal site selection. Then, the primary screening was made by field survey. The location of the disposal site and the distance between the disposal site and community were considerably concerned. Finally, four (4) areas were selected, while ten areas were cut out because these areas have some parts adjacent to or inside the village area (Details in Appendix D). After the primary screening by field survey, the criteria were used for ranking the selected potential areas for disposal site which were as follows.:

- Size of the area
- Site accessibility
- Land use
- Permeability of soil in the area
- Topography
- Hydrogeological condition and,
- Haul distance from the community.

All of these criteria were weighted by their respectability and reference from Siting Landfills and Other LULUs (Noble G., 1992), which are described as follows:

4.3.1 Size of the area

This criterion is one of the major criteria for selecting a potential area for disposal site. The weight of this criteria was given at 1 for area of 0-1 km^2, 3 for 1-2 km^2, and 5 for the area that larger than 2 km^2. From the step of land requirement calculation, 1.17 km^2 is needed. The score of each site will be given as 0 point for area that have an area between 1.17-2.34 km^2, 2 points for the area which is between 2.34 and 3.51 km^2, and 5 points for the area that is larger than 3.51 km^2.

4.3.2 Site accessibility

For site accessibility, this criterion is described as a persistency of the course used for transportation in the area. The weight of this criterion is giving from 1 to 5 for no-road, dirt road, gravel road, asphalt road and concrete road, respectively. Consequently the score for each type of the road is given at 0 for no-road because the road construction is generating the cost. Then, 2 and 3 points given for dirt and gravel road because of its persistency are low. Finally, 4 and 5 point given for asphalt and concrete road, respectively, because of their higher and highest persistency.

4.3.3 Land use

The weight for this criterion is giving at 0 for forest area, 2 for paddy field and field crop, and 5 for uncommercial forest and grass land. The score of each criterion is giving at 1 for forest because this area should be maintained conservative. Then, 3 points is assigned for field crop and paddy field because these areas are already own by the villager in the area. Finally, 5 points given for uncommercial forest and grass land because it is a public land.

4.3.4 Permeability of soil

As we know that if the permeability of soil is high, the leachate will be leaking into groundwater in a short period of time. Weighting of 5, 3 and 0 are given to the low, medium and high permeability, respectively as the score of 5, 3 and 1 point.

4.3.5 Topography

Boonruang U. (2001) suggested that the topography of the area has the suitable slope of 1-2% for drainage system and should not be more than 6%. The weight is given at 5 for 0-2% slope, 3 for 2-6% slope and 1 for more than 6% slope of the area. The score is given at 5 points for 0-8% slope, 3 points for 8-20% slope and 1 point for more than 20% slope as the suggestion of Disathien (1992), which classified as less than 8% slope is good class, 8-20% slope is medium class and more than 20% is poor class.

4.3.6 Hydrogeological condition

The criterion of hydrogeological condition is measured of the depth of water table below the ground surface. The deeper the groundwater level is the better for selecting the area for disposal site. The weight of 1 to 5 is given to the water table depth 1-2 m., 2-3 m., 3-4 m., 4-5 m., and more than 5 meters from the ground surface, respectively. The score is given at the same rate of weight of the criteria.

4.3.7 Haul distance

Pollution Control Department suggested that the haul distance from the community to the disposal area should not more than 20 kilometers. The length of the distance is affecting the cost of the transportation. The weight of the criteria is given at 1 for the length more than 20 kilometers, 2 for 15-20 kilometers, 3 for 10-15 kilometers, 4 for 5-10 kilometers, and 5 for 0-5 kilometers. The score is given at 5 points for every distance. For this data on the haul distance, the database of the road in GIS application was converting from the shape file to calculating the transportation length of the solid waste by using the Autodesk 2004, which is one of the AutoCAD application.

For each of the criteria, the total score is calculated by times weight with its score of each criterion. The results are summarized in Table and details are shown in Appendix C.

From this step, site 14 located near Khoksung Samphan in Chum Phae district was selected as a potential disposal site as shown in Figure 4.11.

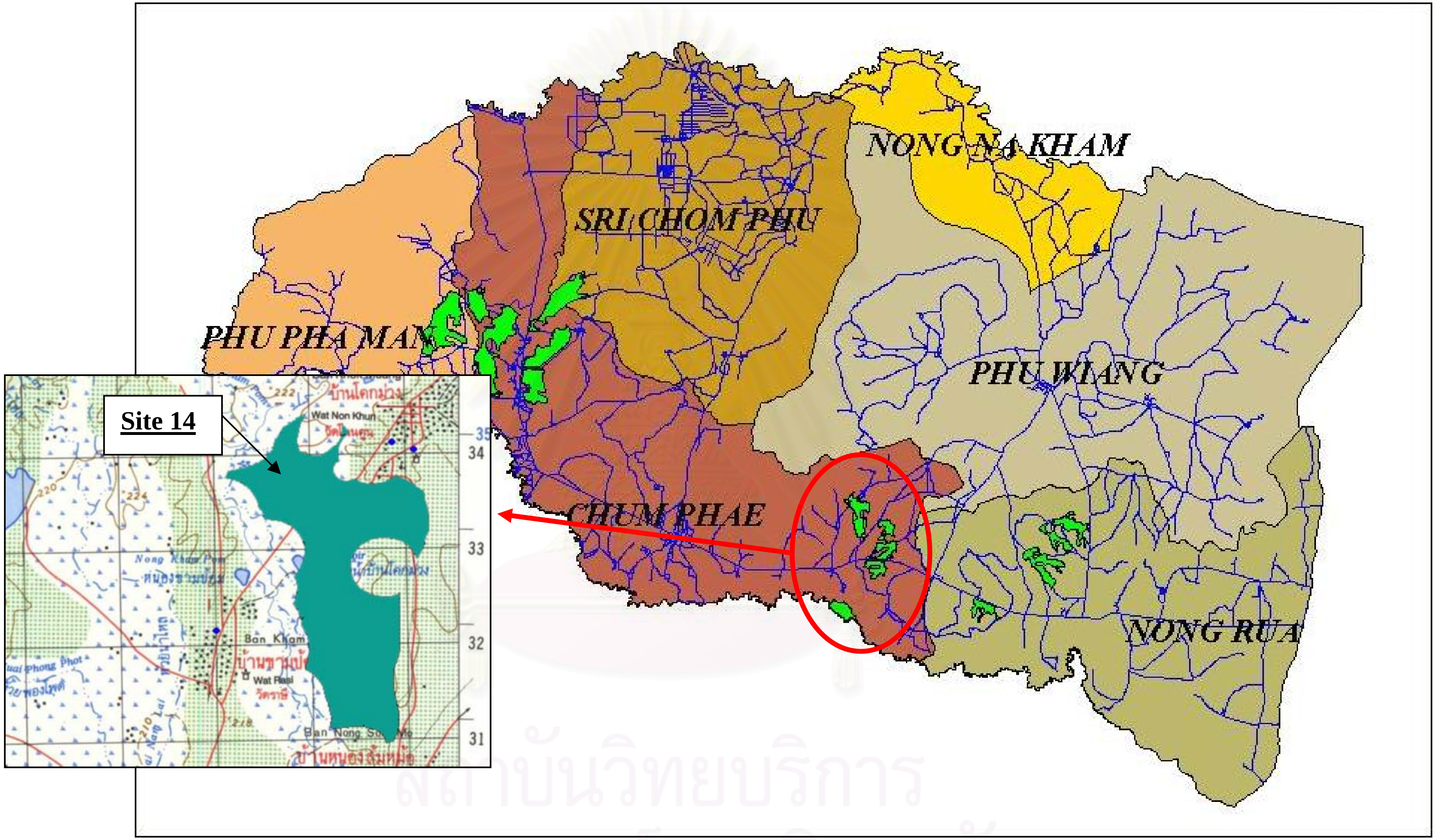


Figure 4.11 Location of Site 14

4.4 Site investigation and data analysis

After site 14 was selected as the first ranked potential disposal site, field survey and site investigation are employed to investigate the field data of soil and groundwater in the area. By field survey, this site has been also selected by the Local Administrative Organizations of Khua Reang in Chum Phae district for a landfill site. In the area, landfill has been already built up for solid waste disposal in the future as shown in Figures 4.12 and 4.13.

Figure 4.12 Landfill Pit Preparing Area in Study Area

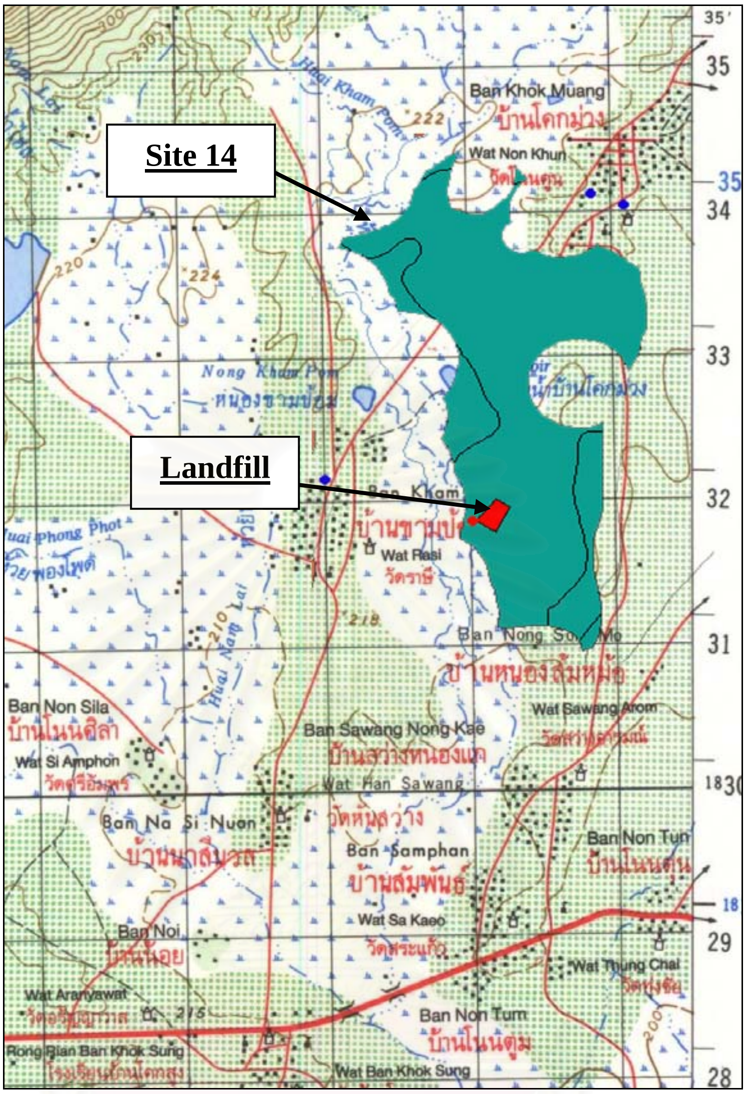


Figure 4.13 Location Map of Landfill Pit and Site 14

In this step, there are three processes of investigation consisting of preliminary investigation of soil layer, soil and groundwater sampling and data analysis. This analysis was conducted for evaluation of the existing quality of soil and groundwater in the area. The results from this step could be used as a basic data for designing the preventive measures and groundwater monitoring after the disposal site is operated.

4.4.1 Preliminary investigation of soil layer

After field survey, field investigation process was begun with resistivity imaging and sounding method for preliminary investigating on the soil layer. The line of resistivity surveying and result of the resistivity method are shown in Figures 4.14

and 4.16. The results show that in the west side of the selected disposal site, the earth materials in this area are existed with the characteristic of rock. On the east side of the site, the characteristic of the earth material is soil profile with the depth to 27 meters.

The result of this method were then compared with Table 4.4 (Satarugsa P., et. al., 2004) to alter the resistivity of the rock to the type of rock and soil.

Table 4.4 Material and their Specific Resistivity

Material types	Specific resistivity (Ω.m)
Igneous and Metamorphic Rocks	
Granite	$5 \times 10^{3} - 10^{6}$
Basalt	$10^{3} - 10^{6}$
Slate	$6 \times 10^{2} - 4 \times 10^{7}$
Marble	$10^{2} - 2.5 \times 10^{8}$
Quartzite	$10^{2} - 2 \times 10^{8}$
Sedimentary Rocks	
Sandstone	$1 - 7.4 \times 10^{8}$
Shale	$20 - 2 \times 10^{3}$
Limestone	$50 - 4 \times 10^{2}$
Soil and waters	
Clay	1 - 100
Alluvium	10 - 800
Groundwater (fresh)	10 - 100
Sea water	0.2
Iron	9.074×10^{-8}
0.01 M Potassium chloride	0.708
0.01 M Sodium chloride	0.843
0.01 M Acetic acid	6.13
Xylene	6.998×10^{16}
Rock salt	$30 - 10^{13}$

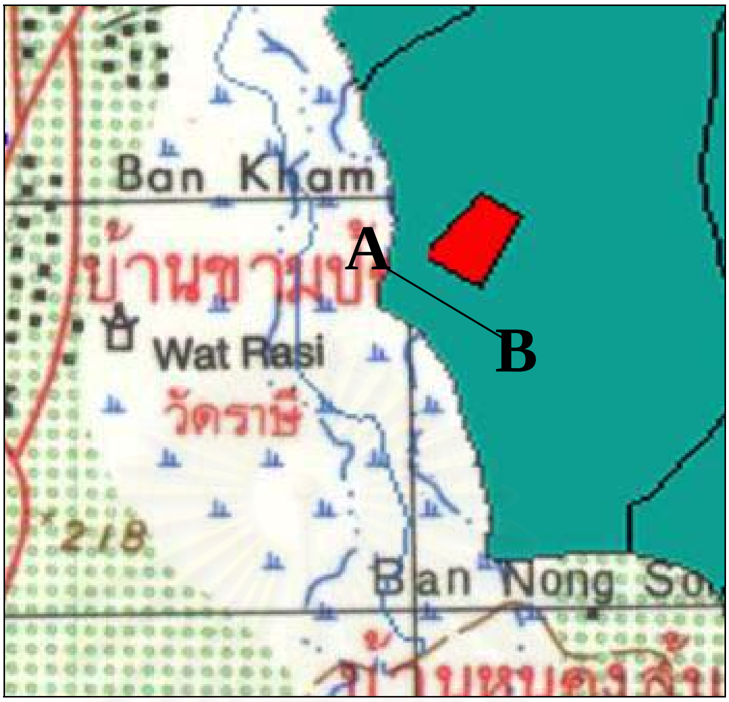


Figure 4.14 Line of Resistivity Survey (A-B)

From the resistivity imaging result and Table 4.4, the result of the resistivity method could be described as that in the cross section AB. The electrical conductivity of soil and rock vary from about 5 to less than 100 ohm-meter on the east side of the site, which indicates the characteristics of clay and groundwater. On the west side the electro conductivity varies from 100-90,000 ohm-meter, which indicated the properties of sandstone. From the geology map of the study area, this result showing that the type of soil and rock in this area could be a sedimentary rock which is sandstone and weathered sandstone or aquifer (water bearing rock).

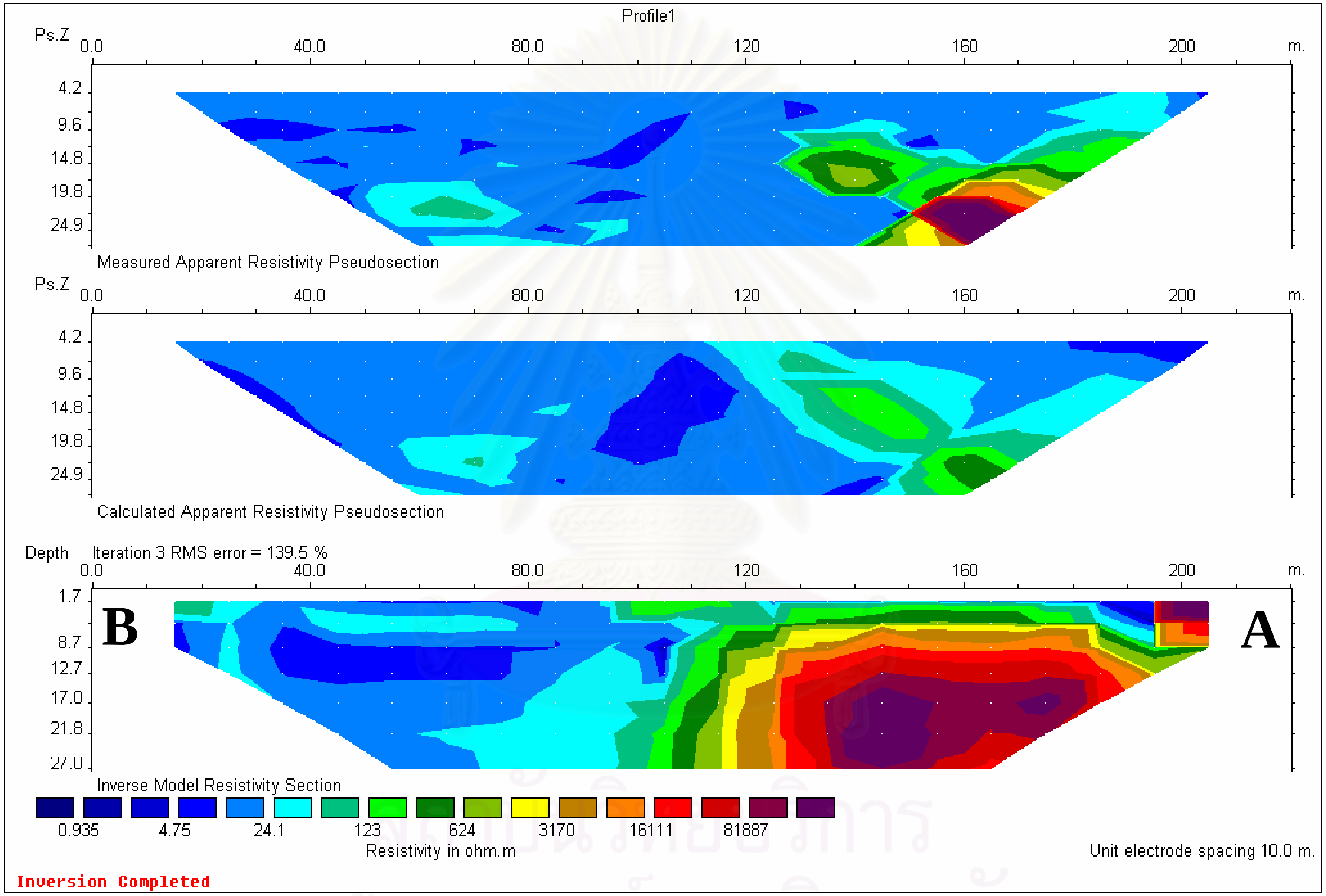


Figure 4.15 2D Profile of Resistivity Imaging

4.4.2 Soil and groundwater sampling

Soil and groundwater sampling were conducted by built up a monitoring well. In this step, the location of the well is located near the Local Administrative Organization’s landfill as shown in Figure 4.17. The exact location of the well is lain on the UTM grid 205110E and 1831629N.

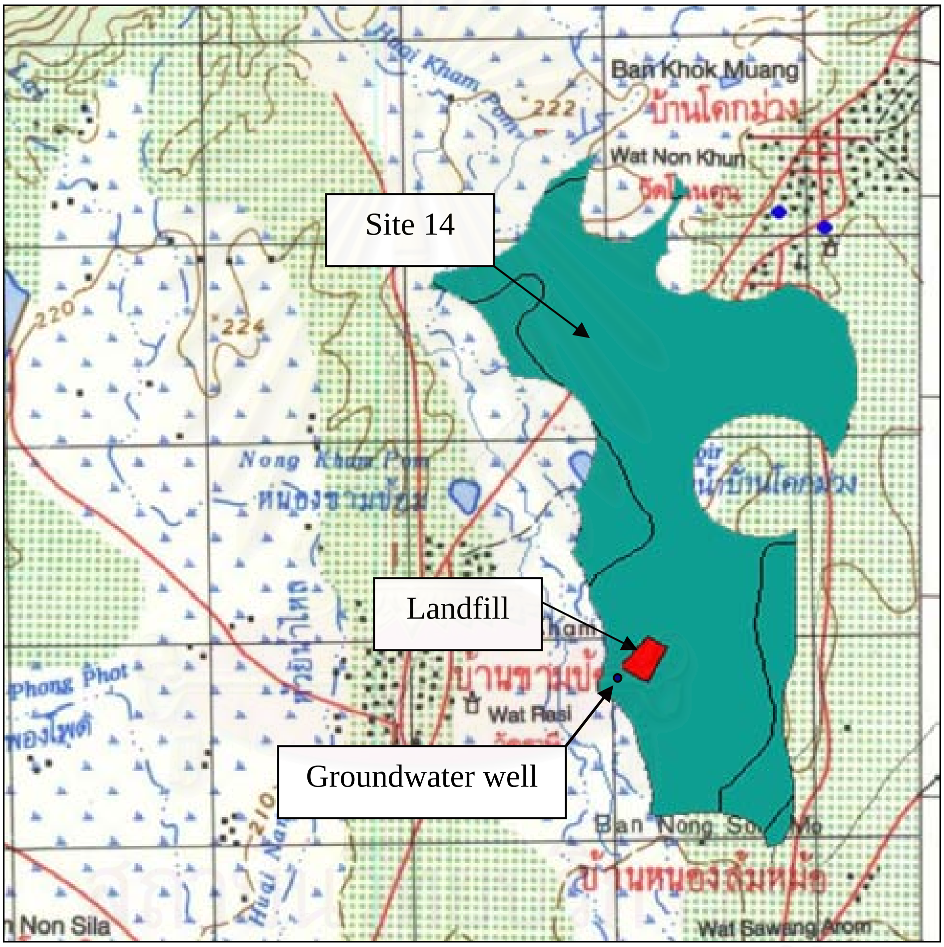


Figure 4.16 Location of Groundwater Monitoring Well (GMW)

After setting up the groundwater monitoring well, the soil sampling was conducted and the samples of soil and rock in the groundwater well is shown that soil and rock in the area are clay, sandstone and weathered sandstone. The well lithology and construction is shown in Figure E-1 Appendix E. In the step of setting up the groundwater well, the hydraulic conductivity (K) of aquifer in the area was also tested by pumping test method and slug test. The permeability of soil was tested by using the infiltration method. The pumped test data was analyzed by using recovery method and obtaining the K value of 3.55×10^{-7} m/s (see detail in Appendix E). The permeability of the top soil and the soil layer between top soil and aquifer was tested by slug test. The result from the sampling and slug test presented that top soil is clay and has permeability at 3×10^{-8} m/s and for the second soil layer is weathered sandstone and has permeability at 1.33×10^{-5} m/s (also sees details in Appendix E).

Four (4) groundwater samples were collected from well number F0194, F0621 in Ban Khok Muang, F0196 in Ban Non Tun, and GMW in the selected area (the location of the wells shown in Figure 4.17). Groundwater well numbers F0194, F0196 and F0621 were sampled from the water distribution pipe in the community. Beside, GMW was sampled by pumping out directly from the well.

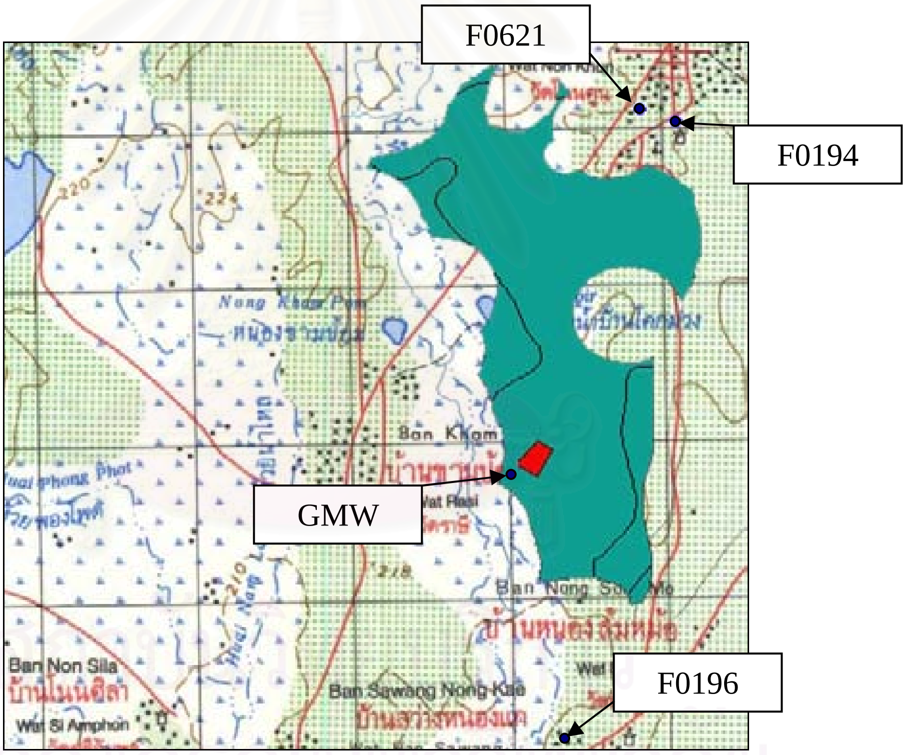


Figure 4.17 Locations of Groundwater Sampling Wells

The samples from these wells were brought to laboratory and were analyzed for the basic characteristics (Chuangcham U., 2001), such as hardness, pH, TDS, EC, major ions and some trace elements. The results were compared with drinking water standards, and plotted in Piper Trilinear Diagram to classify the water type. These basic data could be the background for monitoring of the disposal site in case of establishment of the disposal site.

4.4.3 The results of chemical analyses

- Hardness

Hardness is defined as water that is rich in calcium (Ca^{2+}) and/or magnesium (Mg^{2+}). Calcium and Magnesium are generally found in the groundwater due to the dissolving of limestone. The degree of hardness in water is commonly based on the classification listed in Table 4.5.

Table 4.5 Hardness classification of water (Sawyer and McCarty, 1967)

Hardness, mg/L as $CaCO_3$	Water Class
0-75	Soft
75-150	Moderately hard
150-300	Hard
Over 300	Very hard

The result of the hardness of groundwater in this present study is showing in the Table 4.6. All groundwater samples are showing as hard water.

Table 4.6 Total hardness of groundwater samples

Well ID	Total hardness (mg/L)
F0194	365
F0196	1050
F0621	410
GMW	305

- pH

Water is said to be acidic or alkaline depends on the relative of hydrogen ions concentration. The pH values range from 0 to 14, at pH value of 7 at 25°C indicated that water is neutral, because H^+ and OH^- concentration is equal. A pH less than 7 indicates an acid solution, while pH is greater than 7 indicates an alkaline solution. The result of pH of the groundwater samples in this study are shown in Table 4.7.

Table 4.7 pH of the groundwater sample

Well ID	pH
F0194	7.9
F0196	7.2
F0621	7.2
GMW	7.3

From the result of pH, every sample from each of the groundwater well indicates that the groundwater samples in this area have a little alkalinity.

- Total Dissolved Solids (TDS)

Total dissolved solids are defined as the concentration of all dissolved minerals in water. The high amount of TDS, which grater than 1,000 mg/L is commonly offensive to taste. TDS concentration value over 2,000 mg/L is generally considered undrinkable. A higher TDS than 10,000 mg/L is considered harm to human health. The standard classification base on the total dissolved solids of groundwater is shown in Table 4.8. The TDS values of wells in study area are also shown in Table 4.9.

Table 4.8 Simple groundwater classification based on TDS (Freeze and Cherry, 1979)

Categories	Total dissolved solids (mg/L)
Fresh water	0 - 1,000
Brackish water	1,000 - 10,000
Saline water	10,000 - 100,000
Brine water	More than 100,000

Table 4.9 Total dissolved solid of the groundwater sample

Well ID	TDS (mg/L)
F0194	826
F0196	2,636
F0621	698
GMW	1,080

The result from Table 4.9, the bores number F0194 and F0621 can be considered as fresh water and can be drinkable. The sample from selected site can be considered as brackish water and is offensive to taste. While, bore number F0196 is considered undrinkable because TDS is higher than 2,000 mg/L.

- Electrical Conductivity (EC)

Electrical conductivity is defined as the conductance of a cubic centimeter of any substance compared with the conductance of the same volume of water. The common types of natural water, calcium bicarbonate and calcium sulfate water generally have the lowest conductance and sodium chloride water the highest conductance for a given total dissolved solids. The results of the electrical conductivity of the groundwater samples are shown in the Table 4.10.

Table 4.10 Electrical conductivities of groundwater samples

Well ID	Specific conductance (μS/cm)
F0194	1,014
F0196	2,210
F0621	916
GMW	1,314

- Drinking water standards

The purpose of a water analysis is to determine the suitability of water for proposed use. Most drinking water supply in Thailand conform to the GROUNDWATER ACTS B.E. 2520 which established by the Department of Mineral Resources. A summary of the principal provisions relating to quantitative limits is given in Table 4.12.The result of the standard test of groundwater sample is also showing in the Table 4.11.

Table 4.11 Results of the trace elements in groundwater samples

Well ID	Cu (mg/L)	Cr (mg/L)	Cd (mg/L)	Pb (mg/L)	Zn (mg/L)	Total hardness (mg/L)
F0194	*ND*	*ND*	*ND*	0.0455	0.0295	365
F0196	*ND*	*ND*	*ND*	0.0930	0.0376	1050
F0621	*ND*	*ND*	*ND*	0.0230	0.0352	410
GMW	*ND*	*ND*	*ND*	0.0000	0.1159	305

Note: ND = not detected

From the results, lead found in the samples from the groundwater wells around the selected site may come from the galvanized pipeline. Because the sample was taken from the pipeline which is corroded by water salinity, then lead was released to the water, resulting in the sample from the well number F0196 has the amount of lead exceeds the standard.

Table 4.12 Standard of groundwater quality, GROUNDWATER ACTS B.E. 2520

Physical Characteristics		
Criterion	**Maximum Acceptable Limit**	**Maximum Allowable Limit**
Color	5 (Platinum-cobolt)	50 (Platinum-cobolt)
Turbidity	5 (Units)	20 (Units)
pH	7.0 - 8.5	6.5 - 9.2
Chemical Characteristics		
Criterion	**Maximum Acceptable Limit (ppm.)**	**Maximum Allowable Limit (ppm.)**
Iron (Fe)	0.5	1.0
Manganese (Mn)	0.3	0.5
Copper (cu)	1.0	1.5
Zinc (Zn)	5.0	15.0
Sulphate (SO_4)	200	250
Chloride (Cl)	200	600
Fluoride (F)	1.0	1.5
Nitrate (NO_3)	45	45
Total Hardness as $CaCO_3$	300	500
Non-carbonate hardness as $CaCO_3$	200	250
Total solids	750	1,500
Toxic Characteristics		
Criterion	**Maximum Acceptable Limit (ppm.)**	**Maximum Allowable Limit (ppm.)**
Arsenic (As)	-	0.05
Cyanide (CN)	-	0.2
Lead (Pb)	-	0.05
Mercury (Hg)	-	0.001
Cadmium (Cd)	-	0.01
Selenium (Se)	-	0.01

Table 4.12 ***(cont.)*** Standard of groundwater quality, GROUNDWATER ACTS B.E. 2520

Biological Characteristics	
Criterion	**Maximum Acceptable Limit**
Standard plate count	Not more than 500 colonies per cubic centimeters
Most probable number of coliform organism (MPN)	Less than 2.2 per 100 cubic centimeters
E.coli	-

- Piper trilinear diagram

Chuangcham U., 2001 stated that the trilinear diagram which developed by Piper in 1944, considers the cation and anions as two separated groups. The major group of cations is consisting of Calcium, Magnesium, Sodium, and Potassium. The major group of anions is consisting of Sulfate, Chloride, Bicarbonate (Carbonate) and Nitrate. The concentrations of the cations and anions are considered in equivalents per million (epm), which the relative concentrations of the chemical species are used to determine the dominant ions.

These two groups of ions in each water sample are plotted in separated triangular fields as two points and these two points are projected into the central diamond shaped field parallel to the sides of the triangles and the meeting point is marked. This point represents the water type and the zone in which this point falls in the diamond shaped field as well as in the two triangular fields determine the water type (Figure 4.18). The interpretation of water quality are explained from Palmer's classification (Palmer, 1911) as follows

Type I: carbonate hardness exceeds 50 percent-that is, chemical properties of the groundwater are dominated by alkaline earth and weak acids. This area is called "Carbonate Hardness Facies" or "Hydrochemical Facies type I" (Ca + Mg, HCO_3 + CO_3 > 50%). Its properties are temporary hardness and fresh water.

Type II: carbonate alkali exceeds 50 percent-that is, chemical properties of the groundwater are dominated by alkali and weak acids. The groundwater plotted in this area is inordinately soft in proportion to their content of dissolved solids. This area is called "Carbonate Alkali Facies" or "Hydrochemical Facies type II" (Na + K, HCO_3 + CO_3 > 50%). Its properties are soft and fresh water.

Type III: noncarbonate hardness exceeds 50 percent-that is, chemical properties of the groundwater are dominated by alkali-earth and strong acid. This area is called "Noncarbonate Hardness Facies" or "Hydrochemical Facies type III" (Ca + Mg, Cl + SO_4 > 50%). Its property is hard water.

Type IV: noncarbonate alkali exceeds 50 percent-that is, chemical properties of the groundwater are dominated by alkali and strong acids; ocean water and many brines plot in this area. This area is called "Noncarbonate Alkali Facies" or "Hydrochemical Facies type IV" (Na + K, Cl + SO_4 > 50%). Its property is brackish to salty water.

Type V: mixing water-that is, chemical properties of the groundwater are neither cation nor anion dominated. They are mixing together and their property is not soft or hard water cannot be specified.

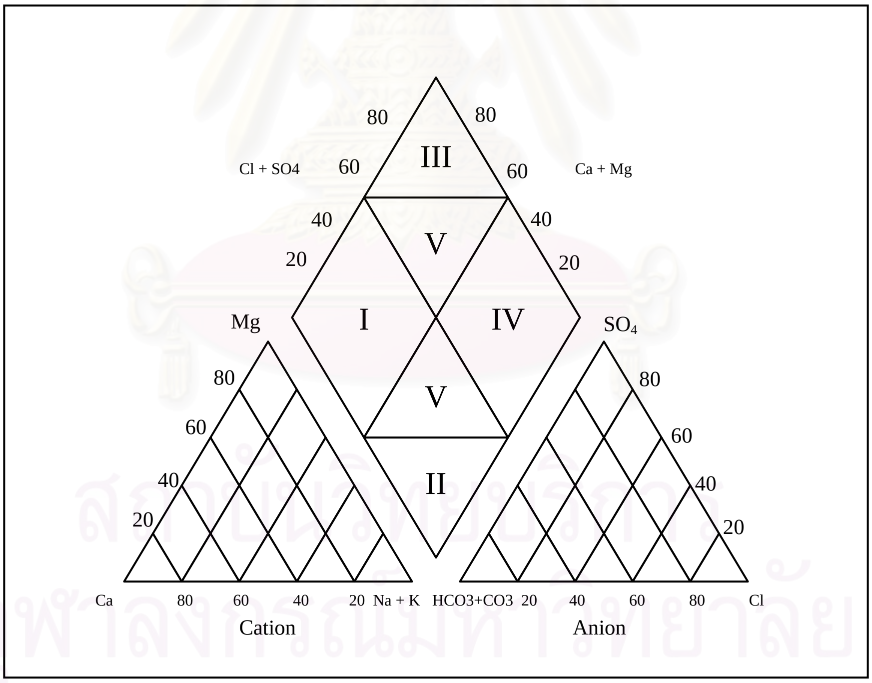


Figure 4.18 Classifications of Water Types Using Trilinear Diagram

The result of the water type from Piper Trilinear Diagram is showing in the Figure 4.19.

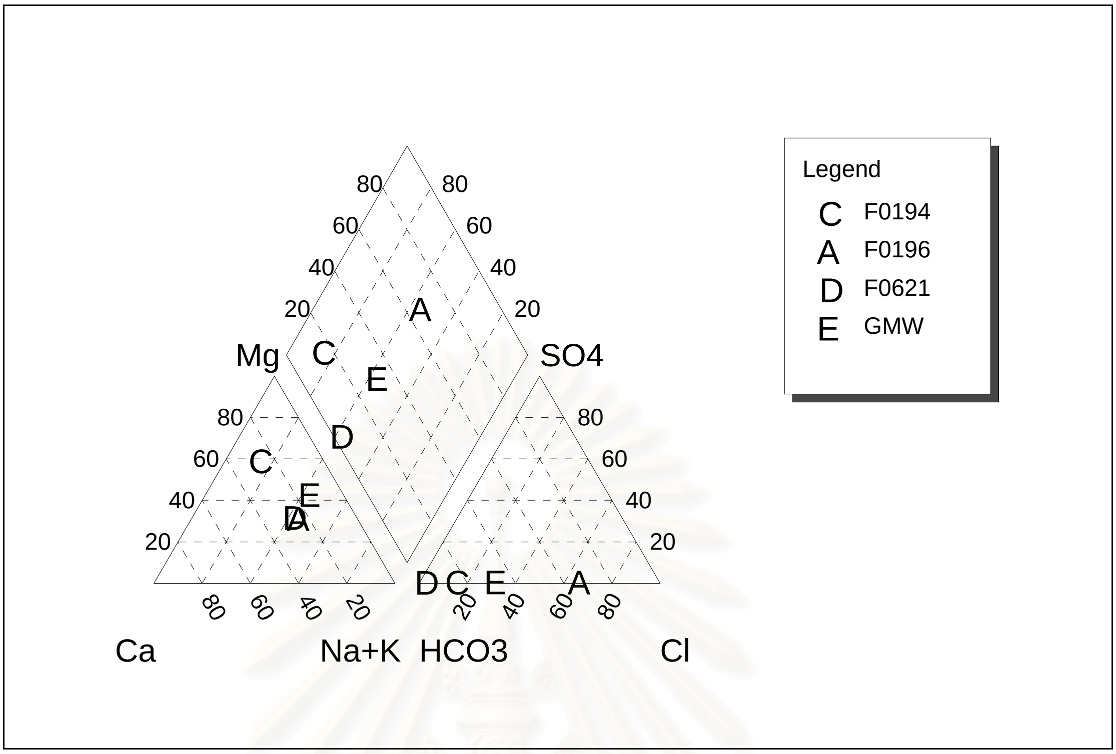


Figure 4.19 Groundwater Types in Study Area

The result from Piper Trilinear Diagram shows that three samples from F0194, F0621 and GMW well are groundwater Type I, and its properties are temporary hardness and fresh water. For the groundwater sample from F0196 well, it indicated that the groundwater in this area is Type V, which is mixed water.

From all of the laboratory results for basic characteristics of the groundwater, it is indicated that the groundwater in the upstream area of disposal site is likely good quality suitable for consumption. While the groundwater quality at the disposal site monitoring well and wells located downstream are not good quality and are unsuitable for consumption. Therefore, this disposal site is suitable potential site for disposal facilities because groundwater is not used for consumption. Consequently, this result of basic characteristics of the groundwater should be used as a background database for monitoring the groundwater in the future after the disposal site is operated. For the result of the permeability test of the soil in the selected site, it can be used as a criterion in designing the liner for protecting the leachate from the solid waste in the disposal site to contaminate with the groundwater resources.

Chapter V

Conclusion and Recommendations

5.1 Conclusion

Generally, one of many problems which can be found in operating the disposal site is groundwater contamination. The cause of contamination potentially comes from the mixed waste of solid waste and household hazardous waste. The leachate from the household hazardous waste such as battery, light bulb and empty pesticide can, is harmful to human health and environment if it leaked to the groundwater resources.

In this study, the criteria for site selection of landfill, incinerator and composting facilities of Pollution Control Department integrated with the criteria for selecting the site for disposing the hazardous waste were established to find the potential site for disposal in the area of Phu Wiang District Cluster which consists of 6 districts, Si Chomphu, Phu Wiang, Nong Rua, Chum Phae, Nong Na Kham and Phu Pa Man Districts in Khon Kaen Province. The Phu Wiang District Cluster have planned to develop for tourism, science technology as well as the economic zones in the future. By using GIS application, the results indicated that 14 sites meeting the general criteria for disposal site. Then, 14 sites were screened by the field surveying with Autodesk 2004 (AutoCAD application) implementation. Only 4 sites were selected for further ranking step. While other 10 sites did not pass the screening because they are adjacent to schools, temples or factories, and villages. The four selected sites were ranked by weight rating method to select the most appropriate site. These 4 sites, ie. sites 5, 6, 8 and 14 have the score as 280, 250, 256 and 285, respectively, which are not significantly different. However, with the highest score of 285 points compared to other sites, site 14 is considered as the most appropriate for establishing the disposal site. This area is located near Ban Khok Muang, Chum Phae District. In addition, this area has also been selected by Local Administrative Organization of Khua Reang for waste disposal landfill site. Soil resistivity and groundwater determination of the available water wells and monitoring well installed by this study for site 14 were performed for the basic characteristics. The geological profile of site 14 is consisted of clay layer on the top, weathered sandstone and sandstone. These layers were detected by resistivity survey with resistivity values ranging from 5-90,000 ohm-meter. From soil characteristics and geological conditions, it can be confirmed that the selected site 14 is suitable for disposal site of mixed wastes. The results from laboratory analyses are indicated that the groundwater quality upstream of this selected site meets the standard and can be used for consumption. While groundwater quality of monitoring well located in the site and wells downstream of the site 14 were hard and saline water which could not be used for consumption. Therefore, site 14 is again suitable in terms of no adverse impact to groundwater as it is not the source for consumption. In addition, soil and groundwater quality could be served as the background data for designing the disposal facility and mitigation measures as well as monitoring in the future.

5.2 Recommendations

1) Due to some limitation, only one of the groundwater monitoring wells could be installed, more groundwater monitoring wells should be added in the area which is downstream of groundwater flow direction of the disposal site where groundwater moves through the disposal area.
2) Despite the fact that site number 14 is the most suitable area for disposal site, other sites can be selected for establishing disposal facilities according to villager needs, if more preventive measures are provided.
3) Geo-membrane can reduce the risk of contamination in the groundwater resources by the leachate of hazardous substance from disposal site.
4) In case of the action plan for disposal site is made, the design of disposal should be considered based on the basic characteristics of groundwater and soil.
5) Monitoring of groundwater quality should be performed in the future for the disposal site, if it is established.
6) The findings of this study can be implemented to the action plan by proposing to the relevant Local Administration Organization as well as the Provincial office of Natural Resources and Environment of Khon Kaen Province.

7) The modified criteria using GIS application could be applied to any areas with some modifications according to the area, such as scoring, preventive measures according to soil and water characteristics.

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APPENDICES

APPENDIX A

Population prediction

Table A-1 Growth rate and population

Collected	Day/Month/Year	Population (persons)	Growth ratio
1	1/4/1911	8,266,408	-
2	1/4/1919	9,207,355	1.36
3	5/7/1929	11,506,207	2.69
4	23/5/1937	14,464,105	2.95
5	23/5/1947	17,442,689	1.89
6	25/4/1960	26,257,916	3.20
7	1/4/1970	34,397,374	2.76
8	1/4/1980	44,824,540	2.68
9	1/4/1990	54,532,000	1.98
10	1/4/2000	60,606,947	1.05

Source: National Statistical Office 2000

Table A-1 ***(cont.)*** Growth rate and population

Age group	Population (persons)					
	Nong Rua	Chum Phae	Si Chomphu	Phu Wiang	Phu Pha Man	Nong Na Kham
0-4	5,754	7,392	5,084	5,848	1,397	1,494
5-9	7,272	8,999	6,345	7,139	1,788	1,838
10-14	7,096	9,348	6,365	7,352	1,663	1,959
15-19	7,002	9,423	6,051	7,257	1,802	1,931
20-24	7,417	10,348	7,233	7,774	1,992	2,137
25-29	8,602	10,707	7,440	8,593	2,167	2,160
30-34	9,023	11,291	7,538	8,853	2,195	2,248
35-39	8,807	11,272	7,134	8,703	1,964	2,177
40-44	6,868	9,514	5,662	6,801	1,683	1,749
45-49	5,914	8,092	4,725	5,771	1,306	1,517
50-54	4,808	6,530	3,936	4,520	1,100	1,148
55-59	4,195	5,482	3,127	3,754	829	911
60-64	2,979	4,013	2,246	2,712	557	618
65-69	2,325	3,231	1,775	2,104	495	479
70-74	1,513	2,293	1,215	1,452	373	336
75-79	941	1,396	794	790	230	215
80-84	475	801	392	435	129	112
85-89	166	382	182	178	52	56
90-94	64	132	89	67	25	29
95-99	17	61	50	31	8	8
>100	5	85	29	21	9	3
Unknow	1,518	5,784	1,022	1,610	381	379
Not Thai nationality	24	194	17	22	5	2
Total	92,785	126,770	78,451	91,787	22,150	23,506

Source : Department of Local Administration, Ministry of Interior

Table A-2 Population prediction

Year	Growth rate (5%)	Population (persons)					
		Chum Phae	Phu Pa Man	Nong Na Kham	Phu Wiang	Nong Rua	Si Chomphu
2004	1.05	126,770	22,150	23,506	91,787	92,785	78,451
2005	1.05	133,109	23,258	24,681	96,376	97,424	82,374
2006	1.05	139,764	24,420	25,915	101,195	102,295	86,492
2007	1.05	146,752	25,641	27,211	106,255	107,410	90,817
2008	1.05	154,090	26,923	28,572	111,568	112,781	95,358
2009	1.05	161,794	28,270	30,000	117,146	118,420	100,126
2010	1.05	169,884	29,683	31,500	123,003	124,341	105,132
2011	1.05	178,378	31,167	33,075	129,154	130,558	110,388
2012	1.05	187,297	32,726	34,729	135,611	137,086	115,908
2013	1.05	196,662	34,362	36,466	142,392	143,940	121,703
2014	1.05	206,495	36,080	38,289	149,511	151,137	127,788
2015	1.05	216,820	37,884	40,203	156,987	158,694	134,178
2016	1.05	227,661	39,778	42,213	164,836	166,629	140,887
2017	1.05	239,044	41,767	44,324	173,078	174,960	147,931
2018	1.05	250,996	43,855	46,540	181,732	183,708	155,328
2019	1.05	263,546	46,048	48,867	190,819	192,893	163,094
2020	1.05	276,723	48,351	51,311	200,360	202,538	171,249
2021	1.05	290,559	50,768	53,876	210,377	212,665	179,811
2022	1.05	305,087	53,307	56,570	220,896	223,298	188,802
2023	1.05	320,341	55,972	59,398	231,941	234,463	198,242
2024	1.05	336,359	58,771	62,368	243,538	246,186	208,154

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Table A-2 *(cont.)* Population prediction

Year	Population + Tourist (30%)	Population (persons)					
		Chum Phae	Phu Pa Man	Nong Na Kham	Phu Wiang	Nong Rua	Si Chomphu
2004	1.35	168,604	29,460	31,263	122,077	123,404	104,340
2005	1.35	177,034	30,932	32,826	128,181	129,574	109,557
2006	1.35	185,886	32,479	34,467	134,590	136,053	115,035
2007	1.35	195,180	34,103	36,191	141,319	142,856	120,786
2008	1.35	204,939	35,808	38,000	148,385	149,998	126,826
2009	1.35	215,186	37,599	39,900	155,804	157,498	133,167
2010	1.35	225,946	39,479	41,895	163,594	165,373	139,825
2011	1.35	237,243	41,452	43,990	171,774	173,642	146,817
2012	1.35	249,105	43,525	46,190	180,363	182,324	154,157
2013	1.35	261,560	45,701	48,499	189,381	191,440	161,865
2014	1.35	274,638	47,986	50,924	198,850	201,012	169,959
2015	1.35	288,370	50,386	53,470	208,793	211,063	178,457
2016	1.35	302,789	52,905	56,144	219,232	221,616	187,379
2017	1.35	317,928	55,550	58,951	230,194	232,697	196,748
2018	1.35	333,825	58,328	61,899	241,704	244,332	206,586
2019	1.35	350,516	61,244	64,993	253,789	256,548	216,915
2020	1.35	368,042	64,306	68,243	266,478	269,376	227,761
2021	1.35	386,444	67,522	71,655	279,802	282,844	239,149
2022	1.35	405,766	70,898	75,238	293,792	296,987	251,106
2023	1.35	426,054	74,443	79,000	308,482	311,836	263,662
2024	1.35	447,357	78,165	82,950	323,906	327,428	276,845

Table A-3 Waste volume prediction

Year	Waste generation rate (kg/capita/day)	Waste volume (kg)					
		Chum Phae	Phu Pa Man	Nong Na Kham	Phu Wiang	Nong Rua	Si Chomphu
2004	1.00	46,271,050	8,084,750	8,579,690	33,502,255	33,866,525	28,634,615
2005	1.00	48,584,603	8,488,988	9,008,675	35,177,368	35,559,851	30,066,346
2006	1.00	51,013,833	8,913,437	9,459,108	36,936,236	37,337,844	31,569,663
2007	1.00	53,564,524	9,359,109	9,932,064	38,783,048	39,204,736	33,148,146
2008	1.00	56,242,750	9,827,064	10,428,667	40,722,200	41,164,973	34,805,553
2009	1.00	59,054,888	10,318,417	10,950,100	42,758,310	43,223,221	36,545,831
2010	1.00	62,007,632	10,834,338	11,497,605	44,896,226	45,384,383	38,373,123
2011	1.00	65,108,014	11,376,055	12,072,485	47,141,037	47,653,602	40,291,779
2012	1.00	68,363,415	11,944,858	12,676,110	49,498,089	50,036,282	42,306,368
2013	1.00	71,781,585	12,542,101	13,309,915	51,972,993	52,538,096	44,421,686
2014	1.00	75,370,665	13,169,206	13,975,411	54,571,643	55,165,001	46,642,771
2015	1.00	79,139,198	13,827,666	14,674,181	57,300,225	57,923,251	48,974,909
2016	1.00	83,096,158	14,519,049	15,407,891	60,165,237	60,819,413	51,423,654
2017	1.00	87,250,966	15,245,002	16,178,285	63,173,498	63,860,384	53,994,837
2018	1.00	91,613,514	16,007,252	16,987,199	66,332,173	67,053,403	56,694,579
2019	1.00	96,194,190	16,807,615	17,836,559	69,648,782	70,406,073	59,529,308
2020	1.00	101,003,899	17,647,995	18,728,387	73,131,221	73,926,377	62,505,773
2021	1.00	106,054,094	18,530,395	19,664,807	76,787,782	77,622,696	65,631,062
2022	1.00	111,356,799	19,456,915	20,648,047	80,627,171	81,503,830	68,912,615
2023	1.00	116,924,639	20,429,761	21,680,449	84,658,530	85,579,022	72,358,246
2024	1.00	122,770,871	21,451,249	22,764,472	88,891,456	89,857,973	75,976,158

Table A-3 ***(cont.)*** Waste volume prediction (plus the tourist)

Year	Waste generation rate (kg/capita/day)	Waste volume (kg)					
		Chum Phae	Phu Pa Man	Nong Na Kham	Phu Wiang	Nong Rua	Si Chomphu
2004	1.00	61,540,497	10,752,718	11,410,988	44,557,999	45,042,478	38,084,038
2005	1.00	64,617,521	11,290,353	11,981,537	46,785,899	47,294,602	39,988,240
2006	1.00	67,848,397	11,854,871	12,580,614	49,125,194	49,659,332	41,987,652
2007	1.00	71,240,817	12,447,615	13,209,645	51,581,454	52,142,299	44,087,034
2008	1.00	74,802,858	13,069,995	13,870,127	54,160,526	54,749,414	46,291,386
2009	1.00	78,543,001	13,723,495	14,563,633	56,868,553	57,486,885	48,605,955
2010	1.00	82,470,151	14,409,670	15,291,815	59,711,980	60,361,229	51,036,253
2011	1.00	86,593,659	15,130,153	16,056,406	62,697,579	63,379,290	53,588,066
2012	1.00	90,923,342	15,886,661	16,859,226	65,832,458	66,548,255	56,267,469
2013	1.00	95,469,509	16,680,994	17,702,187	69,124,081	69,875,667	59,080,843
2014	1.00	100,242,984	17,515,044	18,587,297	72,580,285	73,369,451	62,034,885
2015	1.00	105,255,133	18,390,796	19,516,661	76,209,300	77,037,923	65,136,629
2016	1.00	110,517,890	19,310,336	20,492,494	80,019,765	80,889,820	68,393,460
2017	1.00	116,043,784	20,275,853	21,517,119	84,020,753	84,934,310	71,813,133
2018	1.00	121,845,974	21,289,645	22,592,975	88,221,791	89,181,026	75,403,790
2019	1.00	127,938,272	22,354,127	23,722,624	92,632,880	93,640,077	79,173,980
2020	1.00	134,335,186	23,471,834	24,908,755	97,264,524	98,322,081	83,132,679
2021	1.00	141,051,945	24,645,425	26,154,193	102,127,750	103,238,185	87,289,313
2022	1.00	148,104,543	25,877,697	27,461,902	107,234,138	108,400,094	91,653,778
2023	1.00	155,509,770	27,171,582	28,834,998	112,595,845	113,820,099	96,236,467
2024	1.00	163,285,258	28,530,161	30,276,747	118,225,637	119,511,104	101,048,290

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APPENDIX B

Waste Characteristics

Table B-1 Waste characteristics and sources (Piyaprasit C., 1996)

Waste characteristics for composting

C/N	30-35/1
C/P	75-100/1
Size of waste	0.5-1.5 inches
Moisture content	50-60%
Air quantity	10-30 ft3/day/lb
Temperature	55 ^{o}C

Waste characteristics for incineration

Calorific	≥800 kcal/kg
Incinerable compound	<15% of ash
Moisture content	15-35%

Table B-1 ***(cont.)*** Waste characteristics and sources (Piyaprasit C., 1996)

Main sources	Weight	Generated sources	Percentage of waste											
			Garbage	Paper	Plastic	Rubber	Leather	Wood	Textile	Glass	Metal	Stone	Miscellaneous	*total*
Residential	30.81%	-	42.89	12.91	18.69	0.09	0.02	8.60	3.06	8.40	3.16	0.66	1.52	100.00
Institutional	12.59%	School	27.07	27.82	25.33	0.44	0.34	7.25	2.07	4.12	2.74	1.05	1.77	100.00
		Hospital	33.22	17.12	27.47	2.75	0.00	2.23	4.20	8.72	4.17	0.00	0.14	100.00
		Government office	14.50	59.68	13.21	0.54	0.00	2.25	1.30	5.66	1.36	0.23	1.29	100.00
		Average	24.93	34.87	22.00	1.24	0.11	3.91	2.52	6.16	2.76	0.43	1.06	100.00
Municipal service	0.78%	Street	5.42	13.29	16.24	0.81	0.00	12.11	1.87	7.23	3.12	35.66	4.27	100.00
		Park	10.86	6.72	26.58	2.89	0.00	1.81	0.36	45.17	4.16	1.47	0.00	100.00
		Average	8.14	10.01	21.41	1.85	0.00	6.96	1.12	26.20	3.64	18.56	2.14	100.00
Commercial	55.82%	*Factory*	10.44	9.94	13.96	0.30	0.04	36.45	2.41	6.17	17.31	0.03	2.97	100.00
		Store	6.19	44.34	31.91	0.92	0.00	1.66	2.25	3.41	6.32	0.25	2.77	100.00
		Private office	17.13	64.64	8.99	0.18	0.00	1.80	0.35	4.68	1.74	0.00	0.51	100.00
		Hotel	38.41	22.41	12.22	0.71	0.15	1.87	3.24	15.13	2.55	1.93	1.41	100.00
		Restaurant	53.75	4.88	10.85	0.00	0.00	2.86	0.32	16.21	3.46	7.70	0.00	100.00
		Theater	6.69	11.40	56.58	0.00	0.00	0.68	0.88	7.82	10.54	0.20	5.22	100.00
		Market	37.24	15.78	25.52	1.84	0.08	8.16	0.81	5.26	5.10	0.24	0.00	100.00
		Large store	30.36	20.80	23.14	0.37	0.00	3.15	2.03	11.25	2.19	3.70	3.05	100.00
		Average	25.02	24.27	22.89	0.54	0.03	7.08	1.53	8.74	6.15	1.75	1.99	100.00

Table B-1 ***(cont.)*** Waste characteristics and sources (Piyaprasit C., 1996)

MainSources	Weight	Percentage of waste											
		Garbage	**Paper**	**Plastic**	**Rubber**	**Leather**	**Wood**	**Textile**	**Glass**	**Metal**	**Stone**	**Miscellaneous**	***total***
Residential	30.81%	13.21	3.98	5.76	0.03	0.01	2.65	0.94	2.59	0.97	0.20	0.47	30.81
Institutional	12.59%	3.14	4.39	2.77	0.16	0.01	0.49	0.32	0.78	0.35	0.05	0.13	12.59
Municipal service	0.78%	0.06	0.08	0.17	0.01	0.00	0.05	0.01	0.20	0.03	0.14	0.02	0.78
Commercial	55.82%	13.97	13.55	12.78	0.30	0.02	3.95	0.86	4.88	3.43	0.98	1.11	55.82

Type of waste	**Description**	**Characteristics**	**Disposal facility**
Garbage	including all wastes from selling, preparation, cooking and serving food	Combustibles	*Composting*
Paper	all kind of waste paper, newspaper and cardboard		*Incineration*
Plastic	all kind of plastic materials		
Rubber	all kind of rubber materials		
Leather	all kind of leather materials		
Wood	all kind of wood materials, branches, and leaves		
Textile	cloth, fibers and thread		
Glass	all kind of glass materials, bottle and broken glass	Non-combustible	*Landfill*
Metal	ferrous and non-ferrous metal		
Stone	including brick, concrete, gypsum, sand, etc.		
Miscellaneous	all materials are not obviously sorted into above categories such as dirt, ashes, synthetic, etc.	-	

APPENDIX C

Score table

Table C-1 Haul distance from each of Tessaban area to selected area

Amphoe	site 5	site 6	site 8	site 14
Si Chomphu	45.27	45.89	48.39	45.43
Phu Pa Man	40.16	40.78	7.84	40.32
Nong Rua	19.55	21.87	56.72	22.44
Nong Kae	4.28	6.60	41.45	7.18
Non Han	28.71	29.33	8.47	28.87
Khoksung Samphan	1.37	1.99	32.76	1.53
Don Mong	31.00	33.32	68.18	33.9
Chum Phae	17.03	17.65	20.15	17.17
Ban Ruea	35.47	37.79	72.65	38.37

Table C-2 Haul distance score table

Criteria	Distance	weight	Site							
			5		6		8		14	
			score	total	score	total	score	total	score	total
Si Chomphu	0-5 km	5	NA	NA	NA	NA	NA	NA	NA	NA
	5-10 km	4	NA	NA	NA	NA	NA	NA	NA	NA
	10-15 km	3	NA	NA	NA	NA	NA	NA	NA	NA
	15-20 km	2	NA	NA	NA	NA	NA	NA	NA	NA
	>20 km	1	5	5	5	5	5	5	5	5
Phu Pa Man	0-5 km	5	NA	NA	NA	NA	NA	NA	NA	NA
	5-10 km	4	NA	NA	NA	NA	5	20	NA	NA
	10-15 km	3	NA	NA	NA	NA	NA	NA	NA	NA
	15-20 km	2	NA	NA	NA	NA	NA	NA	NA	NA
	>20 km	1	5	5	5	5	NA	NA	5	5
Nong Rua	0-5 km	5	NA	NA	NA	NA	NA	NA	NA	NA
	5-10 km	4	NA	NA	NA	NA	NA	NA	NA	NA
	10-15 km	3	NA	NA	NA	NA	NA	NA	NA	NA
	15-20 km	2	5	10	NA	NA	NA	NA	NA	NA
	>20 km	1	NA	NA	5	5	5	5	5	5
Nong Kae	0-5 km	5	5	25	NA	NA	NA	NA	NA	NA
	5-10 km	4	NA	NA	5	20	NA	NA	5	20
	10-15 km	3	NA	NA	NA	NA	NA	NA	NA	NA
	15-20 km	2	NA	NA	NA	NA	NA	NA	NA	NA
	>20 km	1	NA	NA	NA	NA	5	5	NA	NA
Non Han	0-5 km	5	NA	NA	NA	NA	NA	NA	NA	NA
	5-10 km	4	NA	NA	NA	NA	5	20	NA	NA
	10-15 km	3	NA	NA	NA	NA	NA	NA	NA	NA
	15-20 km	2	NA	NA	NA	NA	NA	NA	NA	NA
	>20 km	1	5	5	5	5	NA	NA	5	5
Khoksung Samphan	0-5 km	5	5	25	5	25	NA	NA	5	25
	5-10 km	4	NA	NA	NA	NA	NA	NA	NA	NA
	10-15 km	3	NA	NA	NA	NA	NA	NA	NA	NA
	15-20 km	2	NA	NA	NA	NA	NA	NA	NA	NA
	>20 km	1	NA	NA	NA	NA	5	5	NA	NA

Note: NA = not applicable

Table C-2 (***cont.)*** Haul distance score table

Criteria	Distance	weight	Site							
			5		6		8		14	
			score	total	score	total	score	total	score	total
Don Mong	0-5 km	5	NA	NA	NA	NA	NA	NA	NA	NA
	5-10 km	4	NA	NA	NA	NA	NA	NA	NA	NA
	10-15 km	3	NA	NA	NA	NA	NA	NA	NA	NA
	15-20 km	2	NA	NA	NA	NA	NA	NA	NA	NA
	>20 km	1	5	5	5	5	5	5	5	5
Chum Phae	0-5 km	5	NA	NA	NA	NA	NA	NA	NA	NA
	5-10 km	4	NA	NA	NA	NA	NA	NA	NA	NA
	10-15 km	3	NA	NA	NA	NA	NA	NA	NA	NA
	15-20 km	2	5	10	5	10	NA	NA	5	10
	>20 km	1	NA	NA	NA	NA	5	5	NA	NA
Ban Ruea	0-5 km	5	NA	NA	NA	NA	NA	NA	NA	NA
	5-10 km	4	NA	NA	NA	NA	NA	NA	NA	NA
	10-15 km	3	NA	NA	NA	NA	NA	NA	NA	NA
	15-20 km	2	NA	NA	NA	NA	NA	NA	NA	NA
	>20 km	1	5	5	5	5	5	5	5	5
Total			95		85		75		85	

Note: NA = not applicable

Table C-3 Score table

Criteria			weight	Site 5		Site 6		Site 8		Site 14		Remark
				score	total	score	total	score	total	score	total	
Permeability of soil	high		0	NA	NA	NA	NA	1	0	NA	NA	*fast = 1*
	medium		3	3	9	3	9	3	9	3	9	*medium = 3*
	low		5	5	25	5	25	5	25	NA	NA	*low = 5*
Available land area	1.17-2.34 km^2		1	1	1	1	1	1	1	1	1	
	2.34-3.51 km^2		3	3	9	3	9	3	9	3	9	
	>3.51 km^2		5	NA	NA	NA	NA	5	25	NA	NA	
Site access	Concrete		5	NA	NA	NA	NA	NA	NA	5	25	*Concrete = 5*
	Asphalt		4	4	16	4	16	4	16	4	16	*Asphalt = 4*
	Gravel		3	NA	NA	3	9	3	9	3	9	*Gravel = 3*
	Dirt		2	2	4	NA	NA	NA	NA	2	4	*DIrt = 2*
	No road		1	NA	NA	NA	NA	NA	NA	NA	NA	*No road = 1*
Topography (percent slope)	0-2	%	5	5	25	5	25	5	25	5	25	*0-8% = 5*
	2-6	%	3	5	15	5	15	NA	NA	5	15	*8-20% = 3*
	>6	%	1	NA	NA	NA	NA	NA	NA	NA	NA	*>20% = 1*
Hydrological condition	GW level from the top soil (m.)	1-2	1	NA	NA	NA	NA	NA	NA	NA	NA	*1-2 = 1*
		2-3	2	NA	NA	NA	NA	NA	NA	NA	NA	*2-3 = 2*
		3-4	3	NA	NA	NA	NA	NA	NA	NA	NA	*3-4 = 3*
		4-5	4	NA	NA	NA	NA	NA	NA	NA	NA	*4-5 = 4*
		>5	5	5	25	5	25	5	25	5	25	*>5 = 5*

Note: NA = not applicable

Table C-3 ***(cont.)*** Score table

Criteria		weight	Site 5		Site 6		Site 8		Site 14		*Remark*
			score	total	score	total	score	total	score	total	
Land use	Forest	0	NA	NA	NA	NA	1	NA	NA	NA	*Forest = 1*
	Paddy field	2	3	6	3	6	3	6	3	6	*Field crop,Paddy field = 3*
	Field crop	2	NA	NA	NA	NA	3	6	3	6	*Grassland, Uncommercial forest = 5*
	Uncommercial forest	5	5	25	NA	NA	NA	NA	5	25	
	Grassland	5	5	25	5	25	5	25	5	25	
Total			185		165		181		200		
Total Score			280		250		256		285		

Note: NA = not applicable

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APPENDIX D

Layout and Data of 14 sites

Table D-1 Data of 14 sites

site 1

1	Soil type	49B (slope 2-5%)
2	Area description	Paddy field, Grassland
3	Size of the area	2.53 km^2
4	Distance from the major highway	Road no. 2133 100 m.
5	Located in	Nong Rua district
6	Sea level	190-210 m. from sea level
7	Adjacent area	Village -Dong Noi -Noi
8	Groundwater level	2-4 m. from top soil
9	Etc.	Concrete and gravel road in the area

site 2

1	Soil type	49B (slope 2-5%)
2	Area description	Paddy field, Sugarcane, Uncommercial forest
3	Size of the area	1.55 km^2
4	Distance from the major highway	Road no. 2133 1306 m.
5	Located in	Nong Rua district
6	Sea level	190-210 m. from sea level
7	Adjacent area	Village -Huay Sai
8	Groundwater level	3-4 m. from top soil
9	Etc.	Gravel road in the area

site 3

1	Soil type	49
2	Area description	Paddy field, Grassland
3	Size of the area	3.36 km^2
4	Distance from the major highway	Road no. 2133 1889 m. Maliwan road 2161 m.
5	Located in	Nong Rua district
6	Sea level	190-200 m. from sea level
7	Adjacent area	Village -Phang
8	Groundwater level	3-5 m. from top soil
9	Etc.	Gravel road in the area

site 4

1	Soil type	49 6/7d3
2	Area description	Paddy field, Grassland
3	Size of the area	1.59 km^2
4	Distance from the major highway	Maliwan road 100 m.
5	Located in	Nong Rua district
6	Sea level	200 m. from sea level
7	Adjacent area	Village -Kilometer 53
8	Groundwater level	9-10 m. from top soil
9	Etc.	No road

Table D-1 ***(cont.)*** Data of 14 sites

site 5

1	Soil type	49B (slope 2-5%)
2	Area description	Paddy field, Grassland, Uncommercial forest
3	Size of the area	1.39 km^2
4	Distance from the major highway	Maliwan road 100 m.
5	Located in	Chum Phae district
6	Sea level	200-210 m. from sea level
7	Adjacent area	Village -Non Tun
8	Groundwater level	5-6 m. from top soil
9	Etc.	Located near Maliwan Rd., most of the area is agricultural area

site 6

1	Soil type	49B (slope 2-5%)
2	Area description	Paddy field, Grassland
3	Size of the area	2.71 km^2
4	Distance from the major highway	Maliwan road 100 m.
5	Located in	Chum Phae district
6	Sea level	210-220 m. from sea level
7	Adjacent area	Village -Non Tun
8	Groundwater level	5-8 m. from top soil
9	Etc.	Located near Maliwan Rd., most of the area is agricultural area

site 7

1	Soil type	4
2	Area description	Paddy field
3	Size of the area	1.84 km^2
4	Distance from the major highway	Maliwan road 2917 m.
5	Located in	Chum Phae district
6	Sea level	200 m. from sea level
7	Adjacent area	Village -Non Udom
8	Groundwater level	8-9 m. from top soil
9	Etc.	No road access to this area

site 8

1	Soil type	49B (slope 2-5%)
2	Area description	Paddy field, Grassland, Cassava, Teak
3	Size of the area	3.91 km^2
4	Distance from the major highway	Road no. 201 100 m.
5	Located in	Chum Phae district
6	Sea level	240 m. from sea level
7	Adjacent area	Village -Nong Wa
8	Groundwater level	5-6 m. from top soil
9	Etc.	Asphalt road in the area

Table D-1 ***(cont.)*** Data of 14 sites

site 9

1	Soil type	49B (slope 2-5%)
2	Area description	Paddy field, Grassland, Sugarcane, Uncommercial forest, teak
3	Size of the area	4.7 km^2
4	Distance from the major highway	Road no. 201 100 m.
5	Located in	Chum Phae district
6	Sea level	250-280 m. from sea level
7	Adjacent area	Village -Nong Nhamtang
8	Groundwater level	6-8 m. from top soil
9	Etc.	Asphalt road in the area

site 10

1	Soil type	49B (slope 2-5%)
2	Area description	Paddy field, Grassland, Sugarcane, Uncommercial forest, corn
3	Size of the area	5.83 km^2
4	Distance from the major highway	Road no. 201 100 m.
5	Located in	Chum Phae district Si Chomphu district
6	Sea level	260-280 m. from sea level
7	Adjacent area	Village -Non Sa-ad
8	Groundwater level	7-10 m. from top soil
9	Etc.	Asphalt and gravel road in the area

site 11

1	Soil type	49B (slope 2-5%) 49 3/4 31/52B (Slope 2-5%)
2	Area description	Paddy field, Grassland, Sugarcane, teak, forest
3	Size of the area	9.48 km^2
4	Distance from the major highway	Road no. 201 2205 m.
5	Located in	Chum Phae district
6	Sea level	240-260 m. from sea level
7	Adjacent area	Village -Houy Epor -Nong Gung
8	Groundwater level	5-10 m. from top soil
9	Etc.	Asphalt and gravel road in the area

Table D-1 ***(cont.)*** Data of 14 sites

site 12

1	Soil type	31/31B (Slope 2-5%) 31/52B (Slope 2-5%) 52b
2	Area description	Paddy field, Sugarcane, forest
3	Size of the area	2.95 km^2
4	Distance from the major highway	Road no. 201 4669 m.
5	Located in	Chum Phae district
6	Sea level	260-280 m. from sea level
7	Adjacent area	Village -Wang Yaw -Nong Gung
8	Groundwater level	3-10 m. from top soil
9	Etc.	Asphalt road in the area

site 13

1	Soil type	31/31B (Slope 2-5%) 7 49B (slope 2-5%)
2	Area description	Paddy field, Sugarcane, Grassland, Field crop
3	Size of the area	8.73 km^2
4	Distance from the major highway	Road no. 201 6875 m.
5	Located in	Phu Pa Man district
6	Sea level	250-260 m. from sea level
7	Adjacent area	Village -Wang Charoen
8	Groundwater level	3-6 m. from top soil
9	Etc.	Asphalt road in the area Factory located inside the area

site 14

1	Soil type	Ska-B (slope 2-5 %) St-A (slope 0-2 %)
2	Area description	Paddy field, Field crop, Grassland
3	Size of the area	3.12 km^2
4	Distance from the major highway	Maliwan road 1500 m.
5	Located in	Chum Phae district
6	Sea level	210-220 m. from sea level
7	Adjacent area	Village -Non Tun
8	Groundwater level	5-8 m. from top soil
9	Etc.	Concrete, asphalt and gravel roadin the area

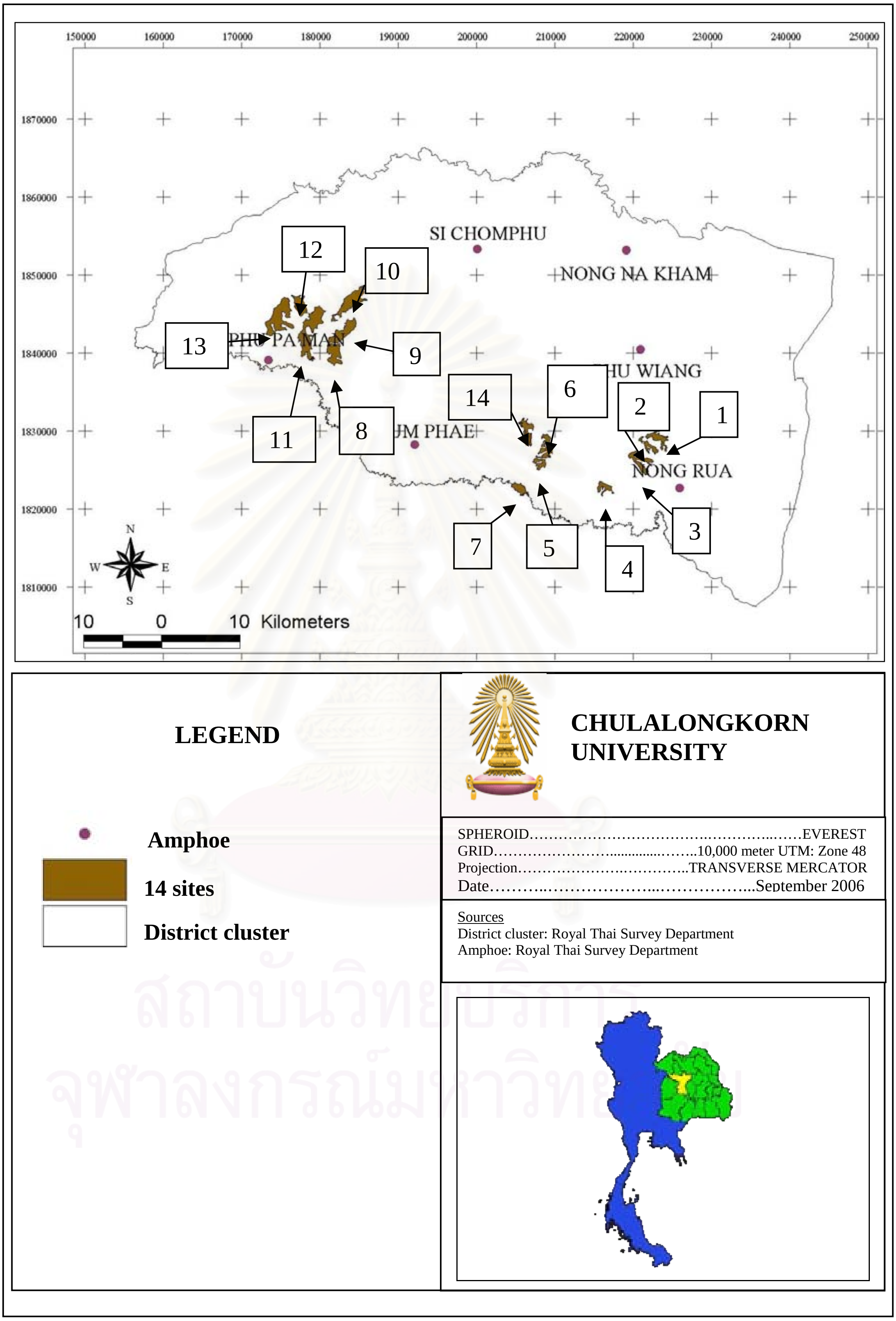


Figure D-1 Location of 14 Sites

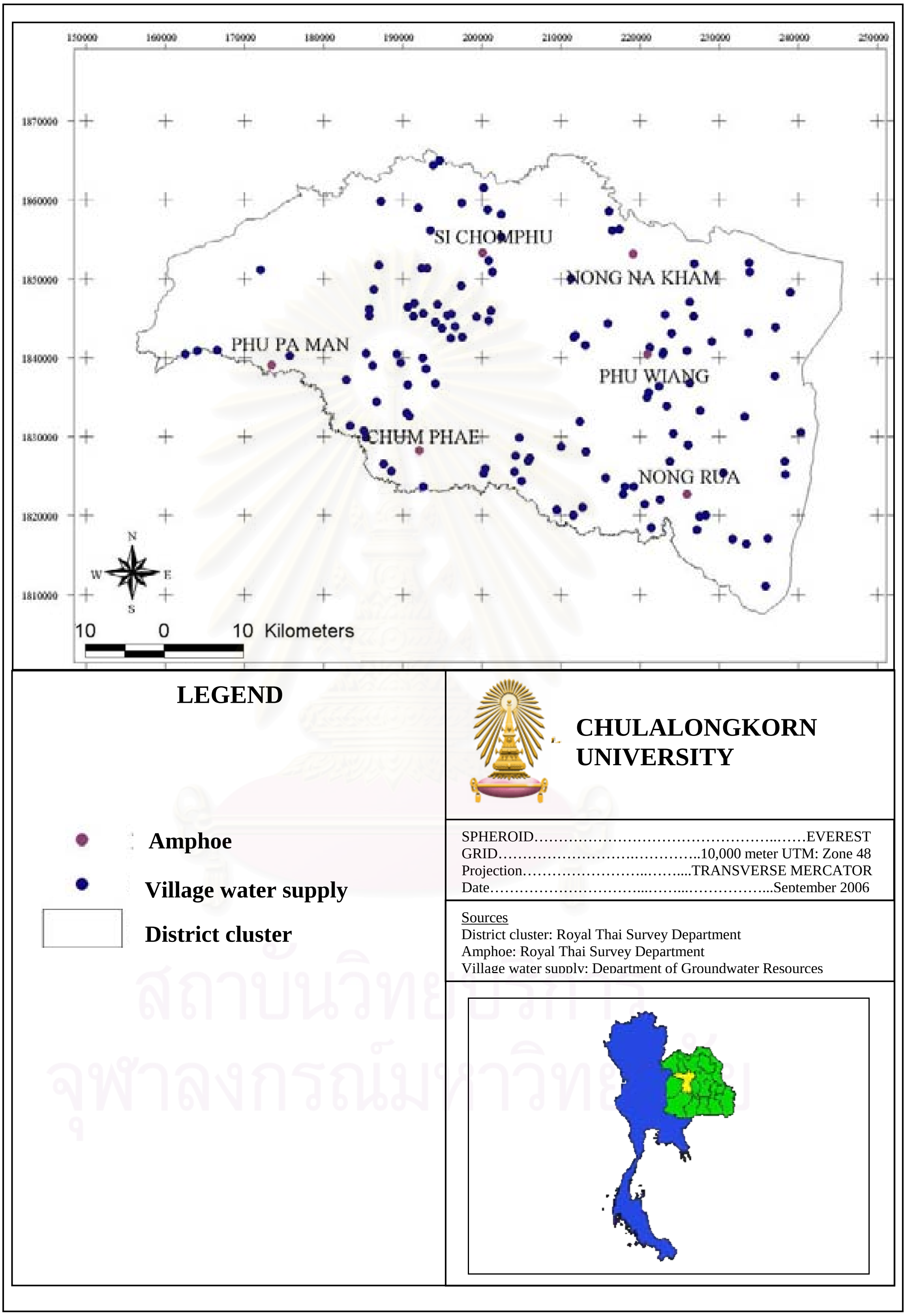


Figure D-2 Layout of Village Water Supply

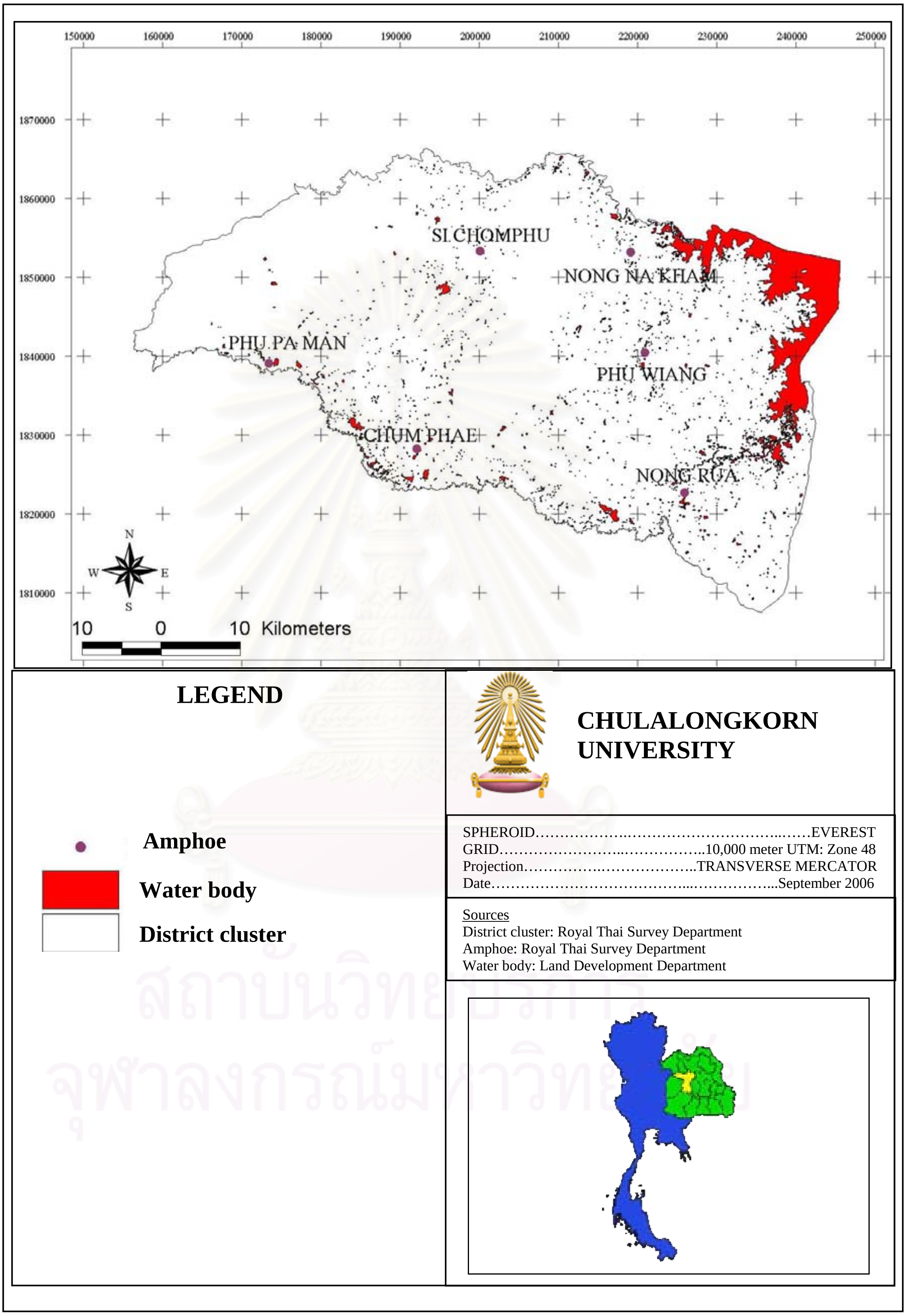


Figure D-3 Layout of Water Body

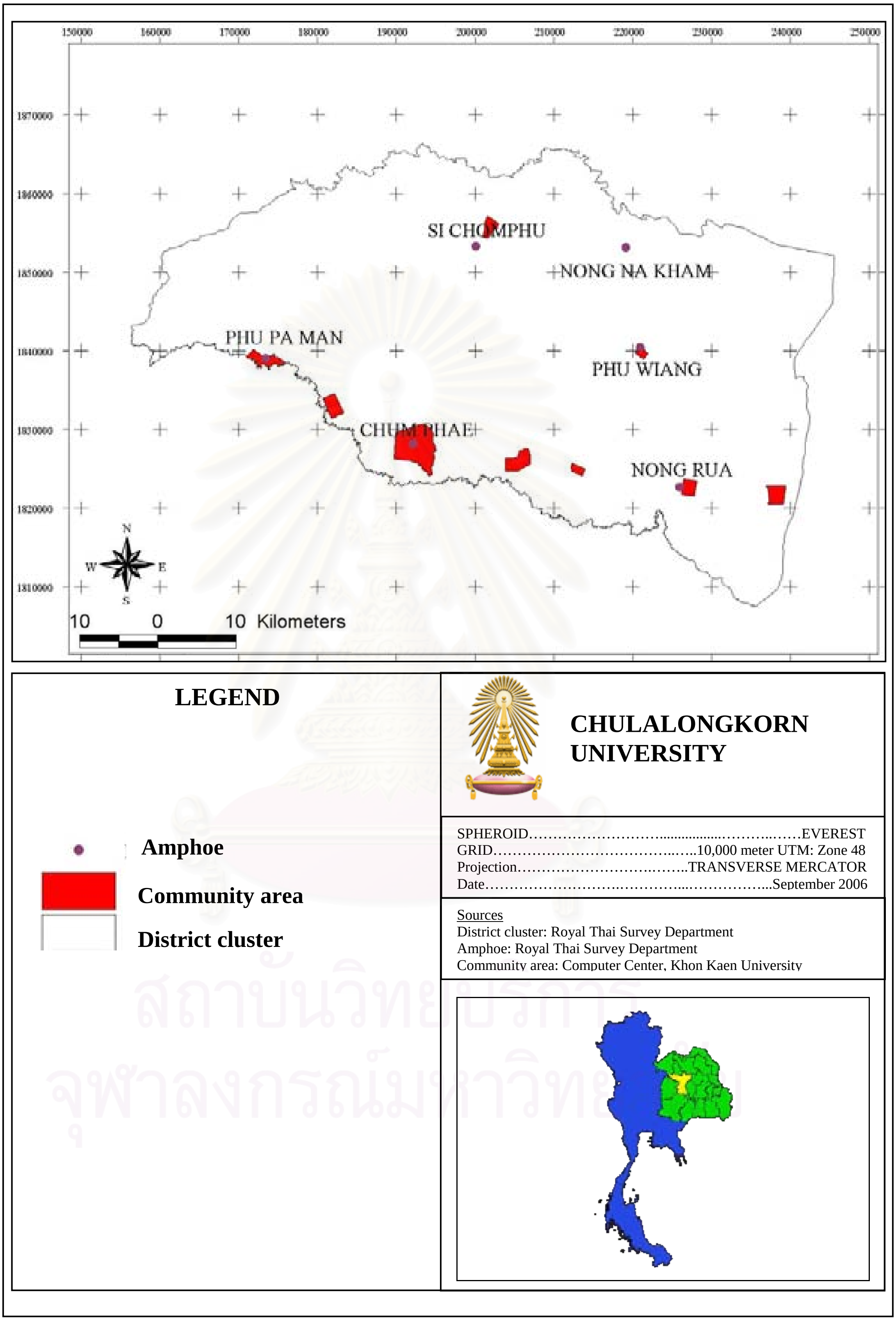


Figure D-4 Layout of Community Area

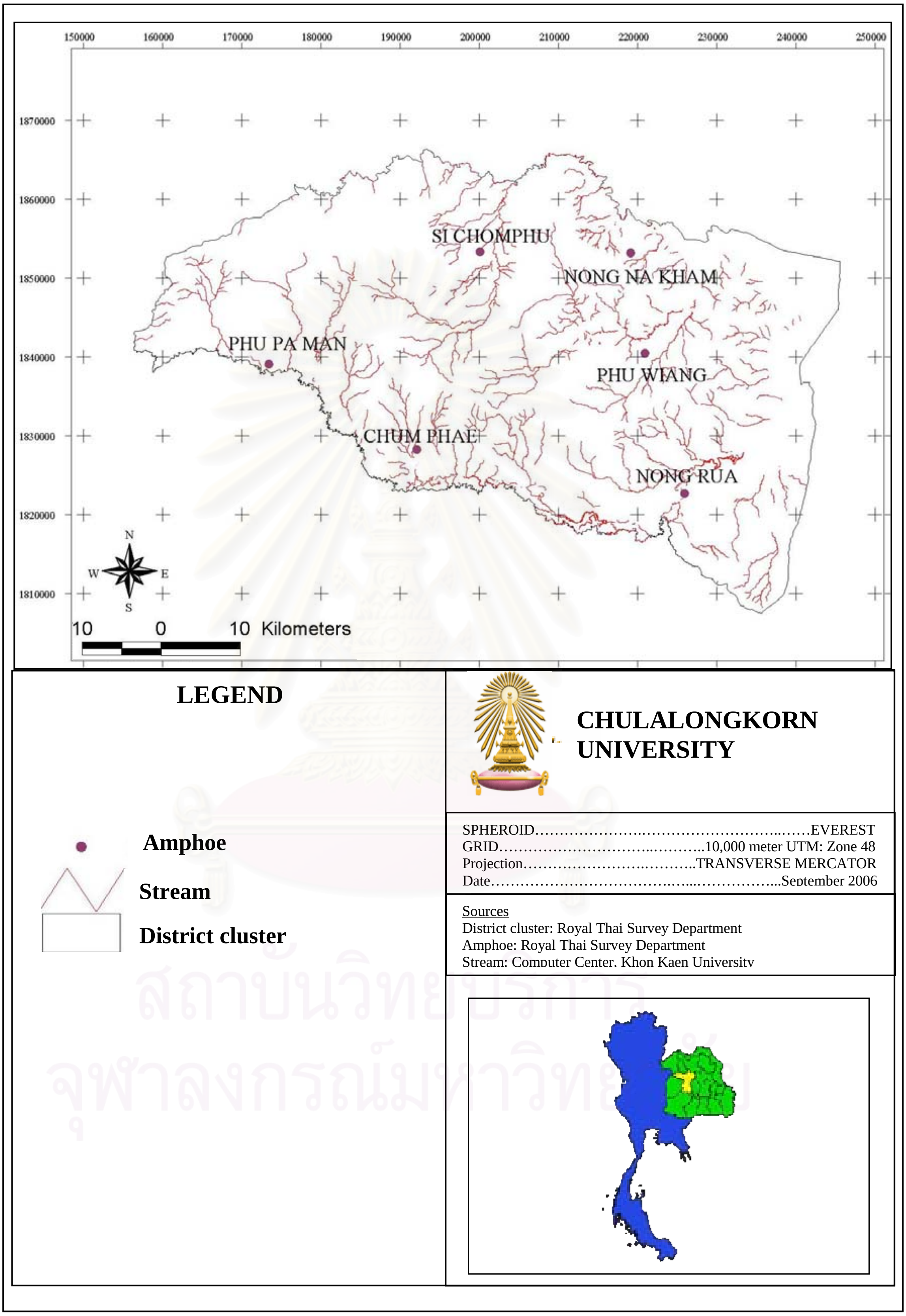


Figure D-5 Layout of Stream

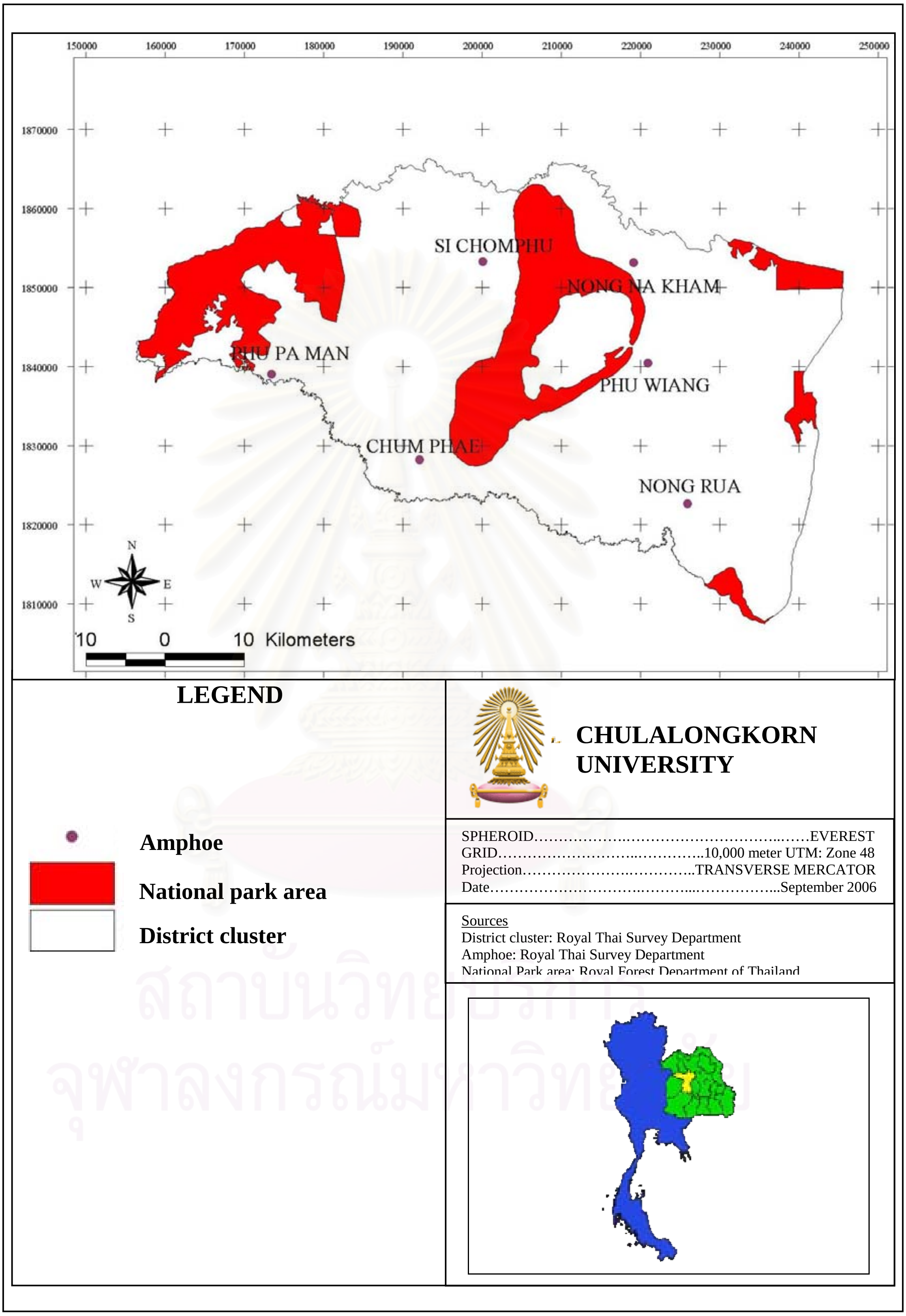


Figure D-6 Layout of National Park

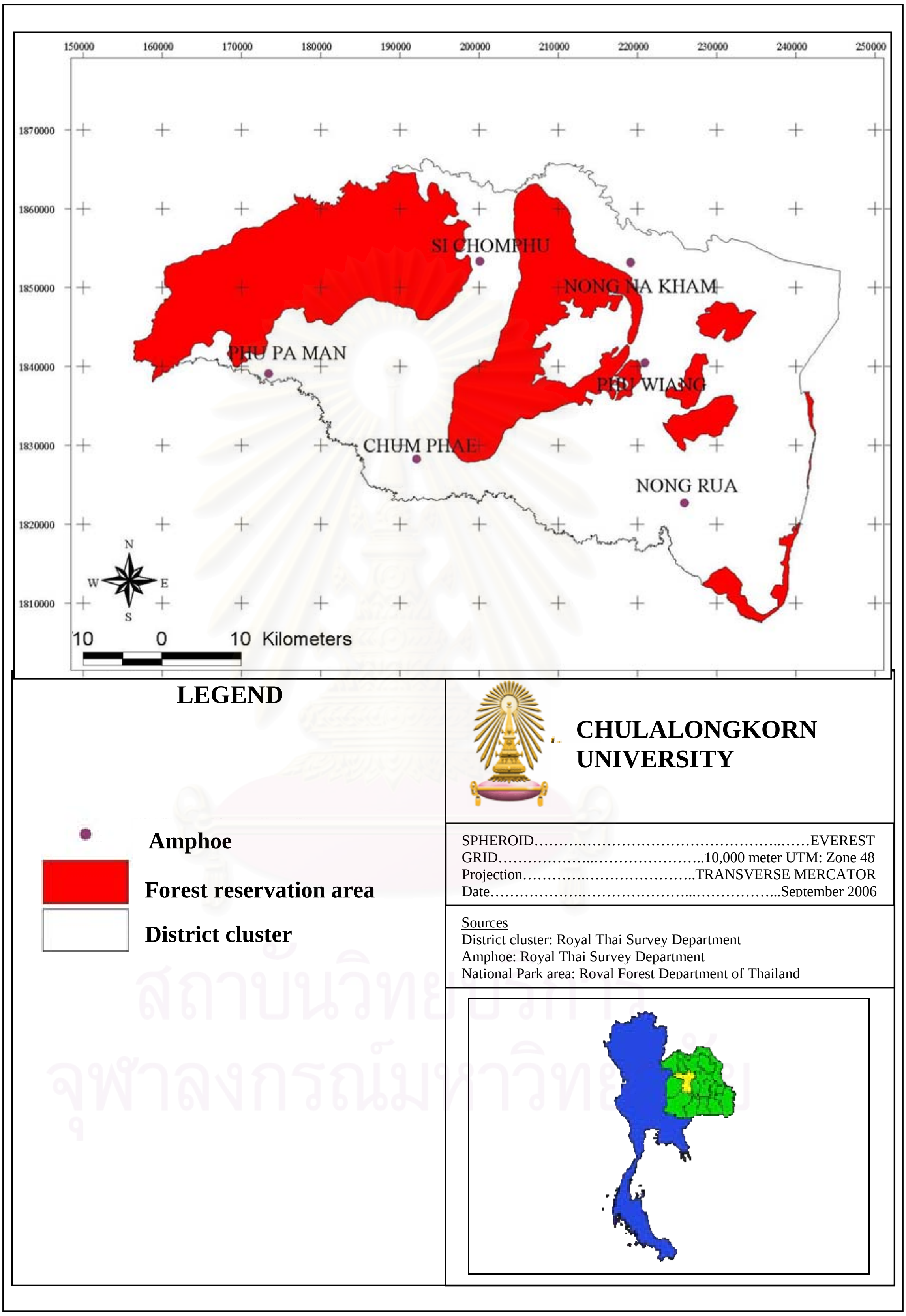


Figure D-7 Layout of Forest Reservation Area

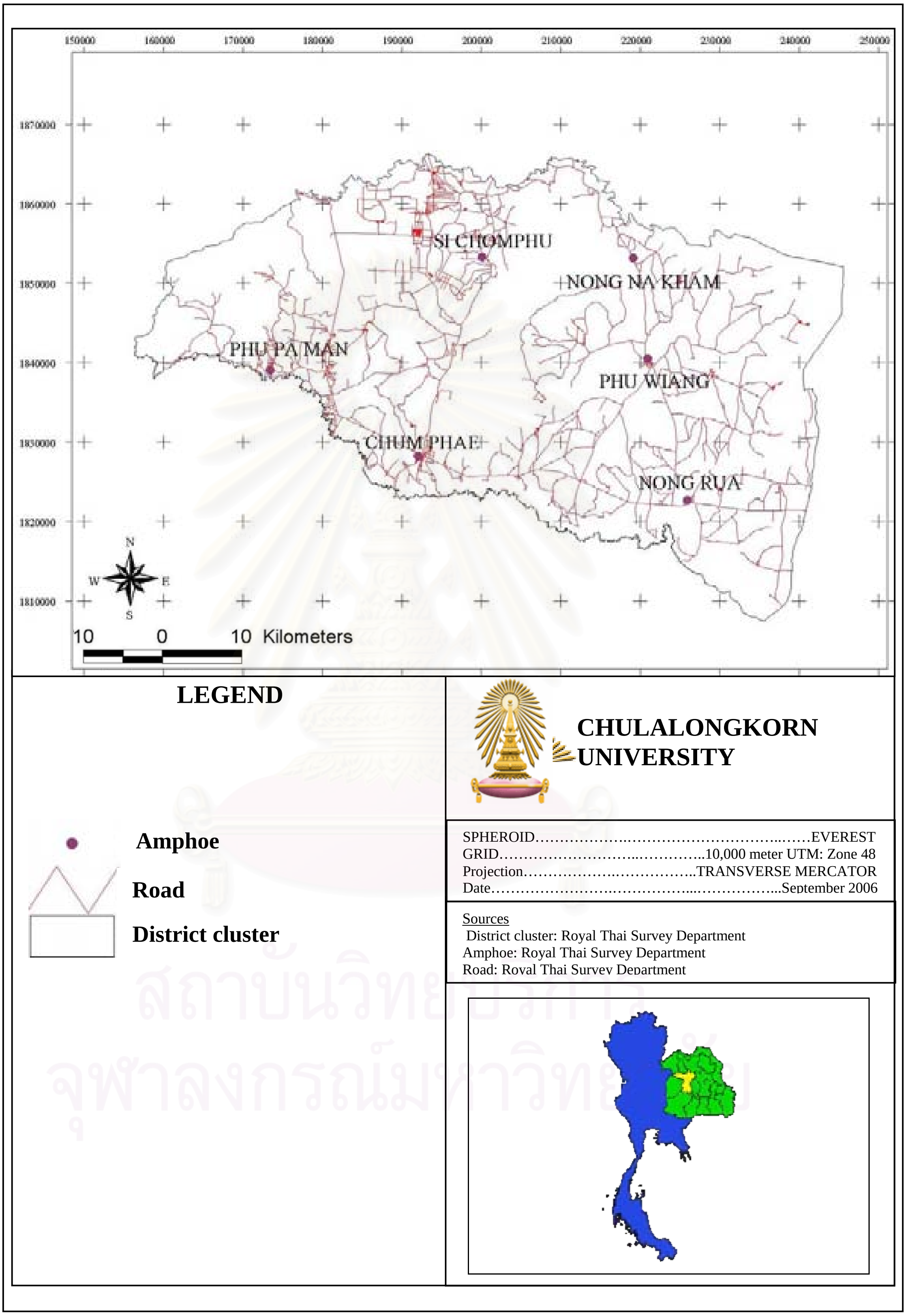


Figure D-8 Layout of Road

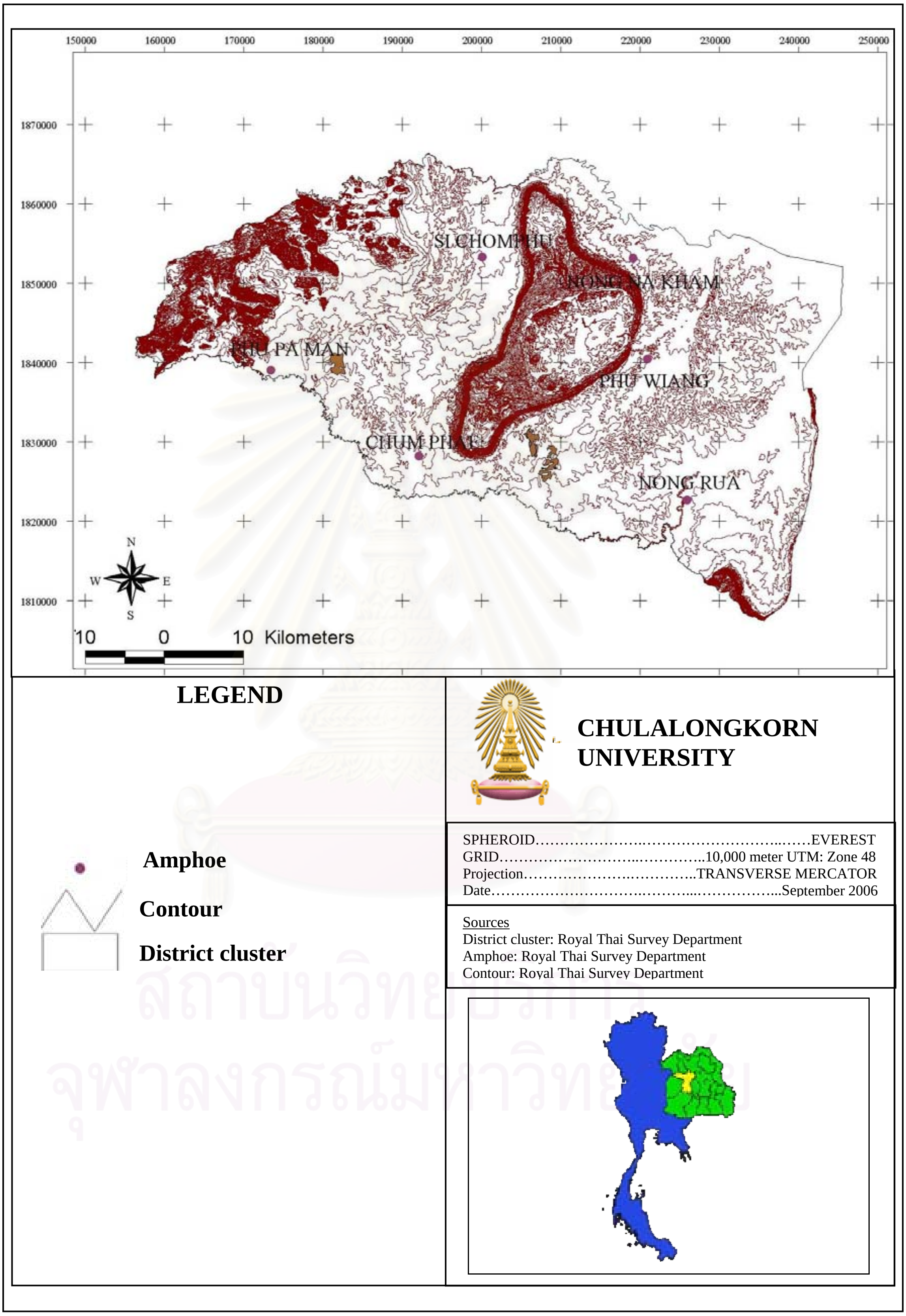


Figure D-9 Layout of Contour

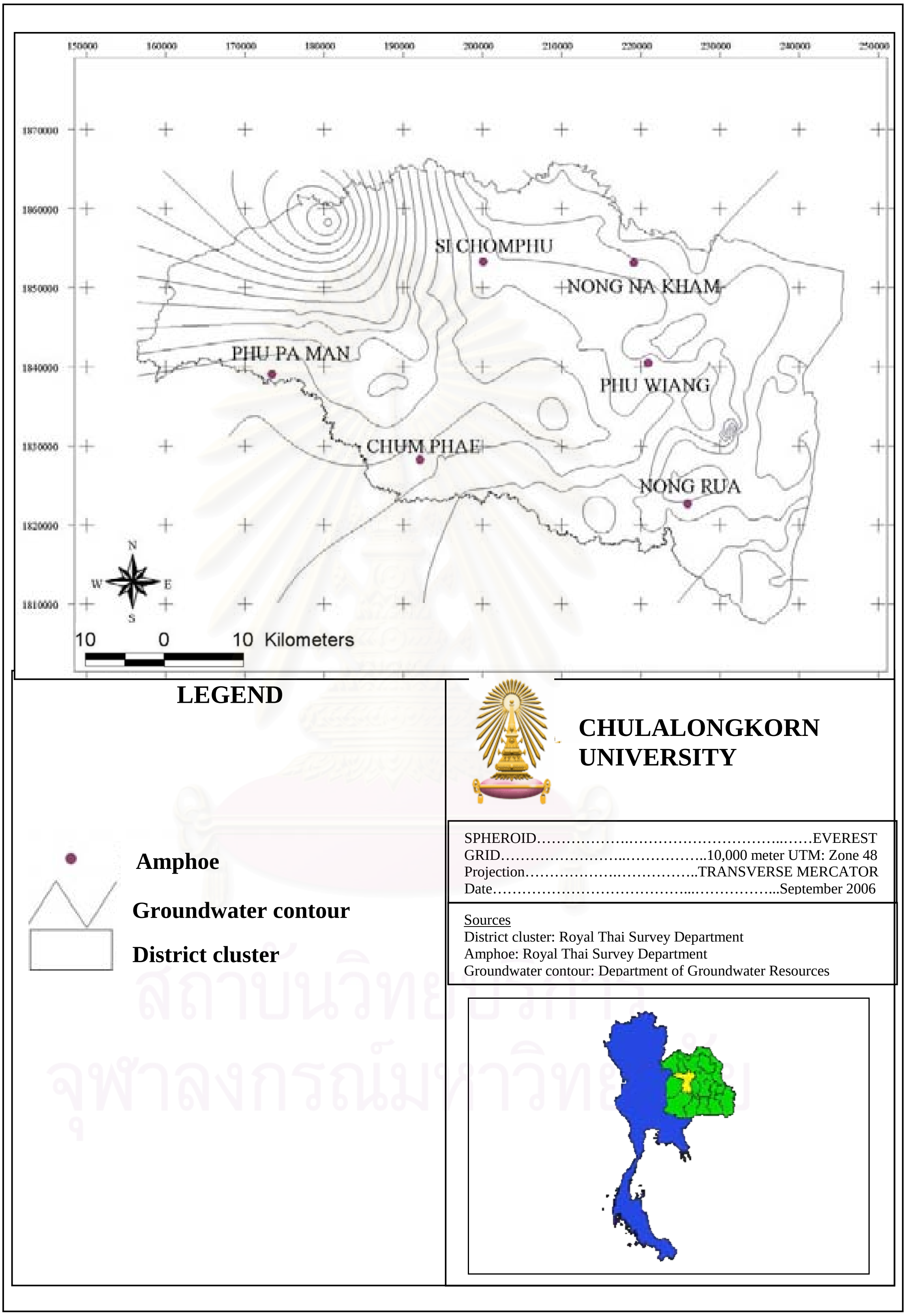
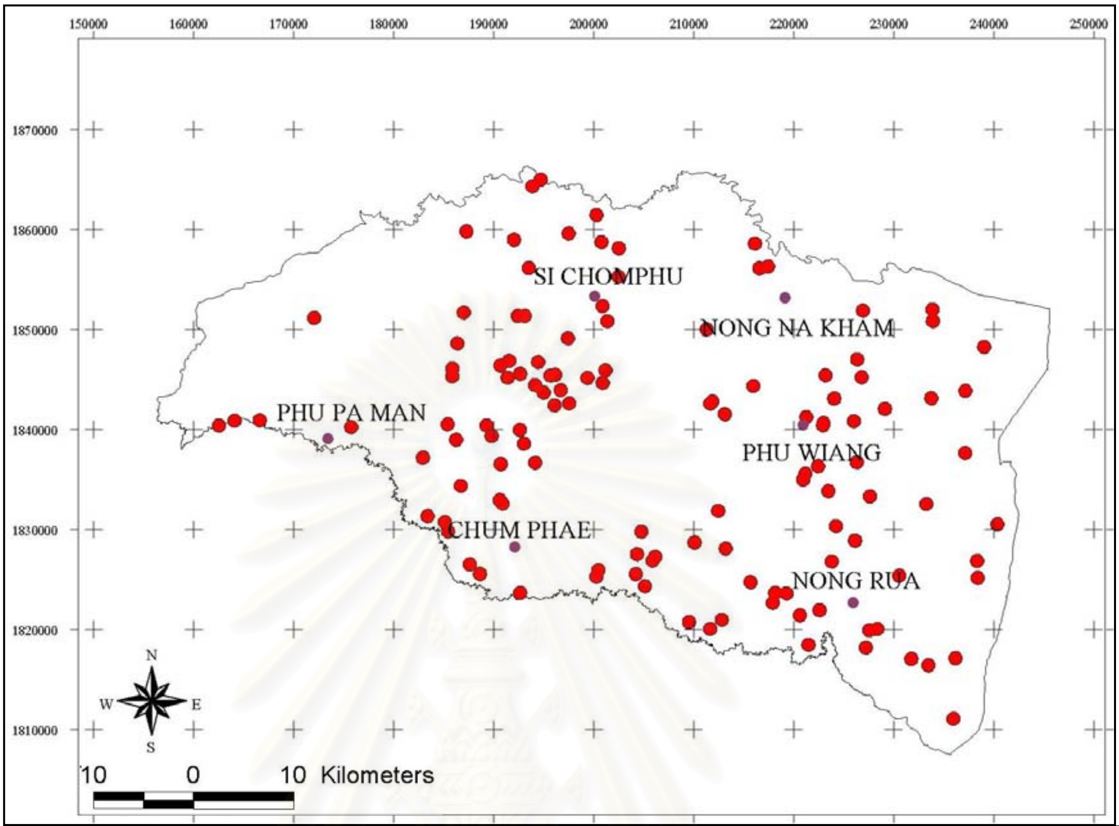


Figure D-10 Layout of Groundwater Contour



LEGEND

Amphoe

Water supply buffer area

District cluster

CHULALONGKORN UNIVERSITY

SPHEROID……………..……………………………..……EVEREST
GRID…………………..………………..10,000 meter UTM: Zone 48
Projection………………..……………..TRANSVERSE MERCATOR
Date………………………..………...……………...September 2006

Sources
District cluster: Royal Thai Survey Department
Amphoe: Royal Thai Survey Department
Village water supply: Department of Groundwater Resources

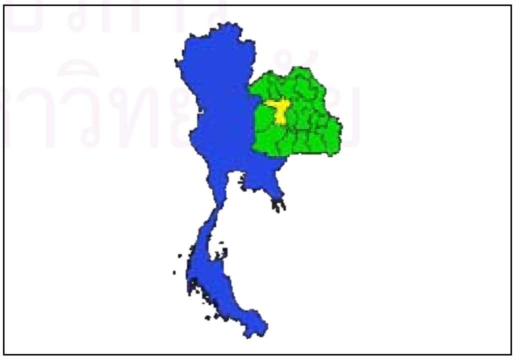


Figure D-11 Layout of Water Supply Buffer

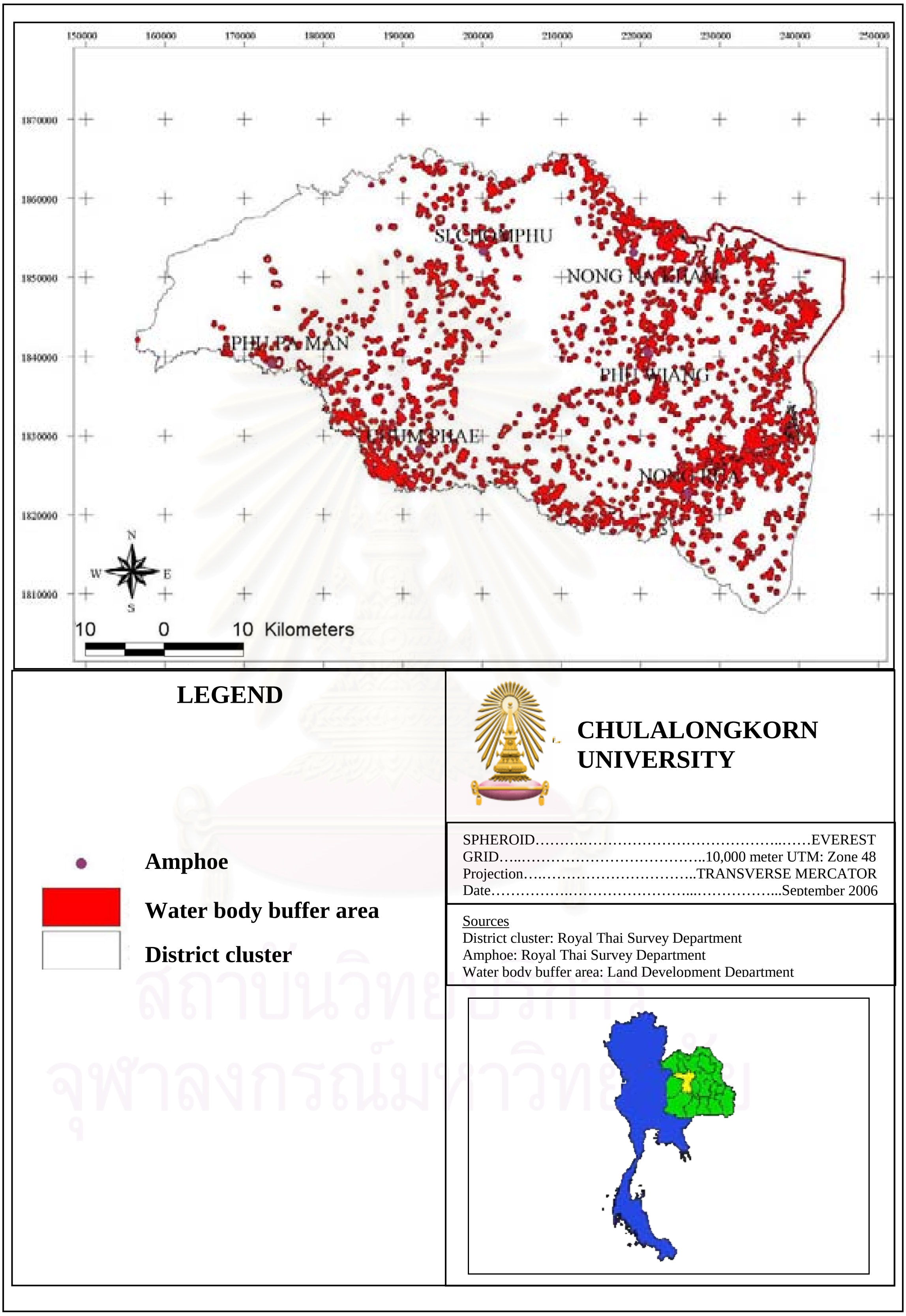
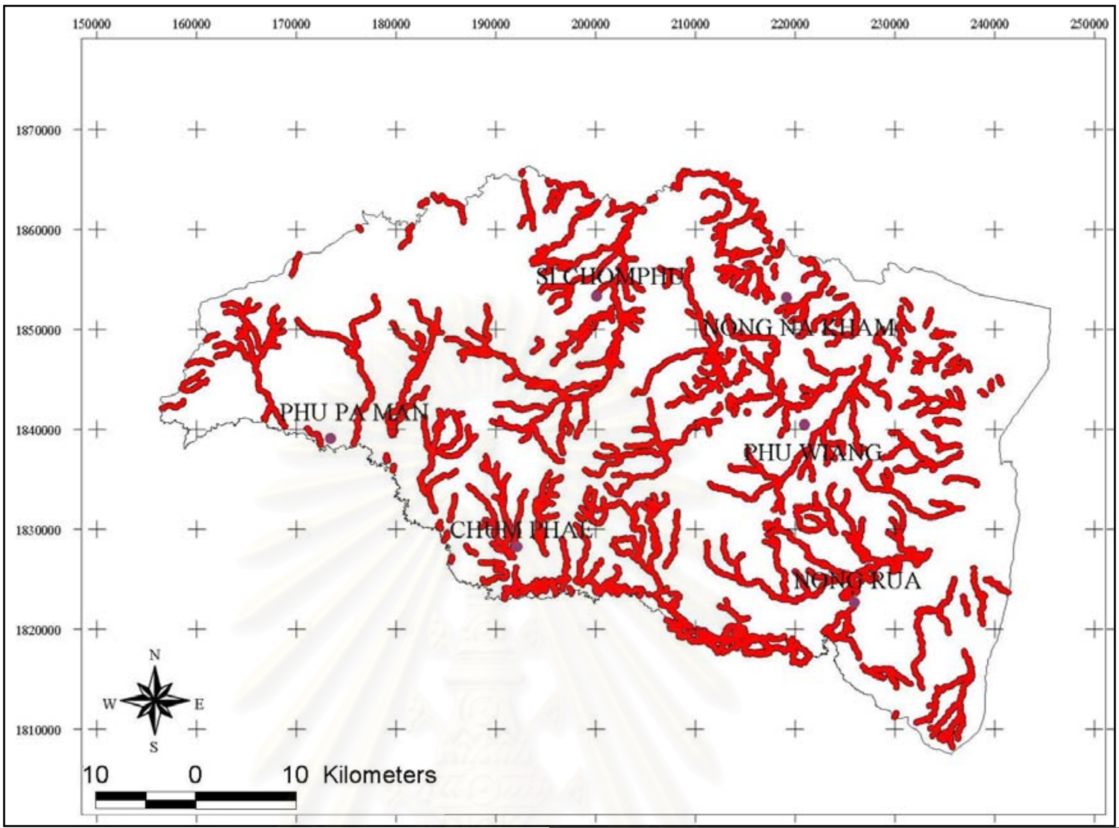


Figure D-12 Layout of Water Body Buffer



LEGEND

Amphoe

Stream buffer area

District cluster

CHULALONGKORN UNIVERSITY

SPHEROID………………..…………….…………..……EVEREST
GRID……………...……………………..10,000 meter UTM: Zone 48
Projection……..…………………………..TRANSVERSE MERCATOR
Date……………..…………………....……………...September 2006

Sources
District cluster: Royal Thai Survey Department
Amphoe: Royal Thai Survey Department
Stream buffer area: Computer Center, Khon Kaen University

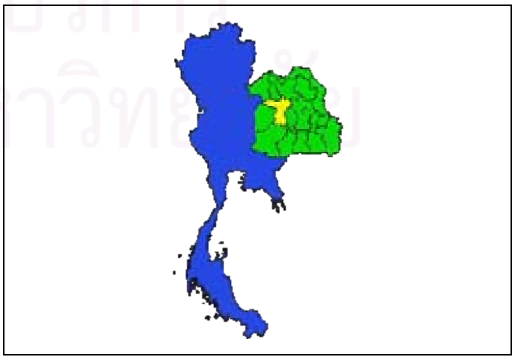


Figure D-13 Layout of Stream Buffer

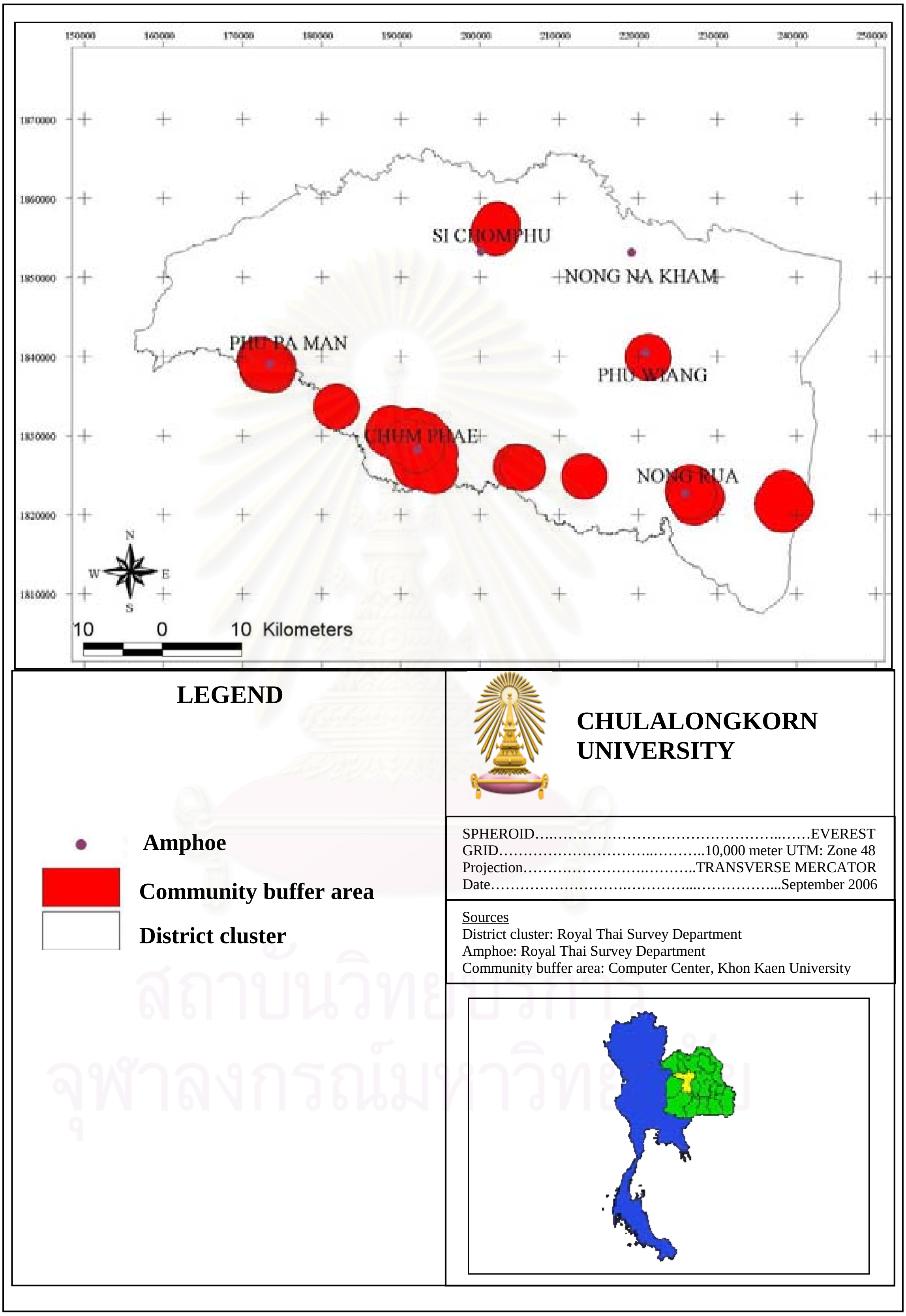


Figure D-14 Layout of Community Buffer

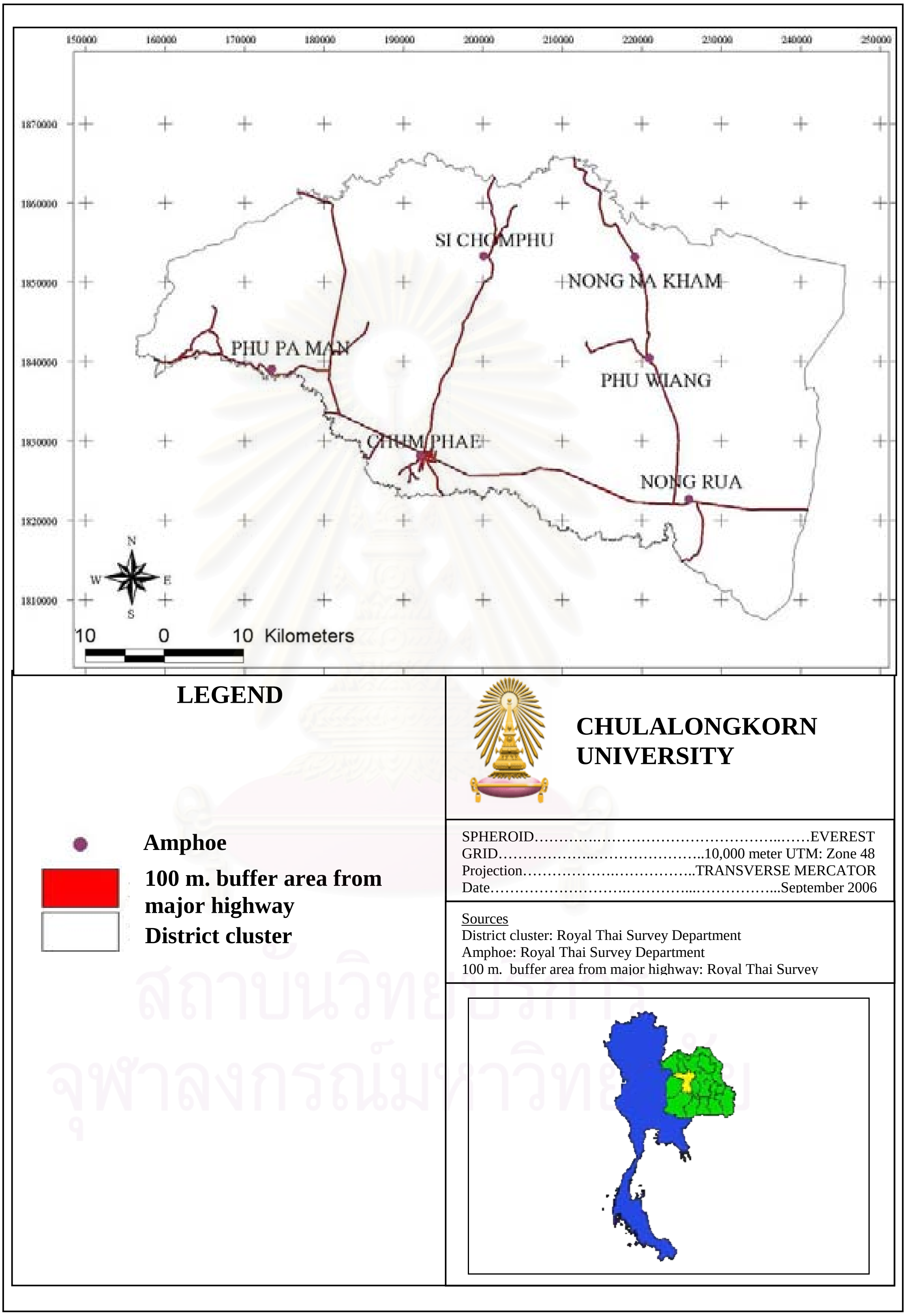


Figure D-15 Layout of Major Highway With 100 Metres Buffer

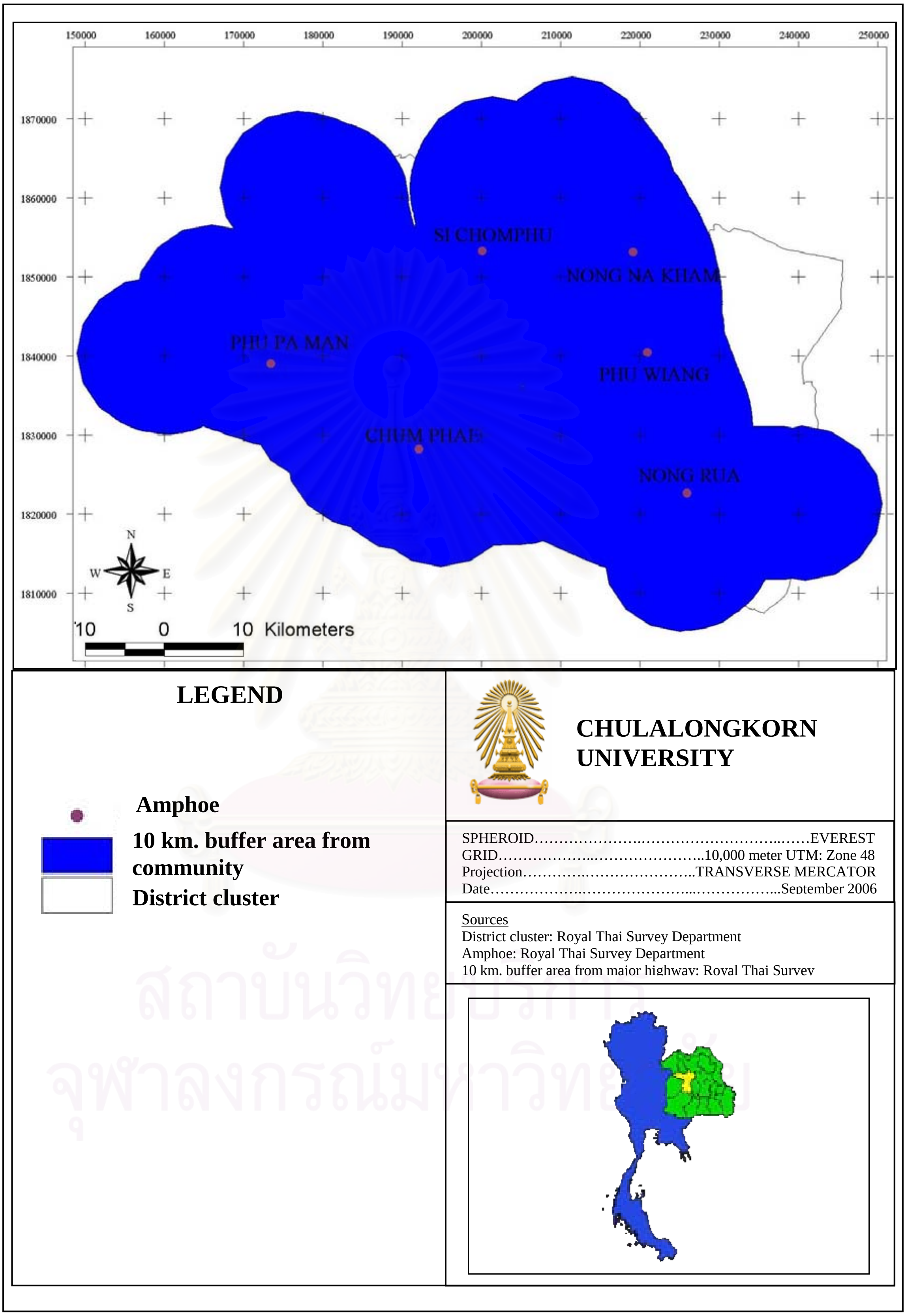


Figure D-16 Layout of Major Highway with 10 Kilometers Buffer

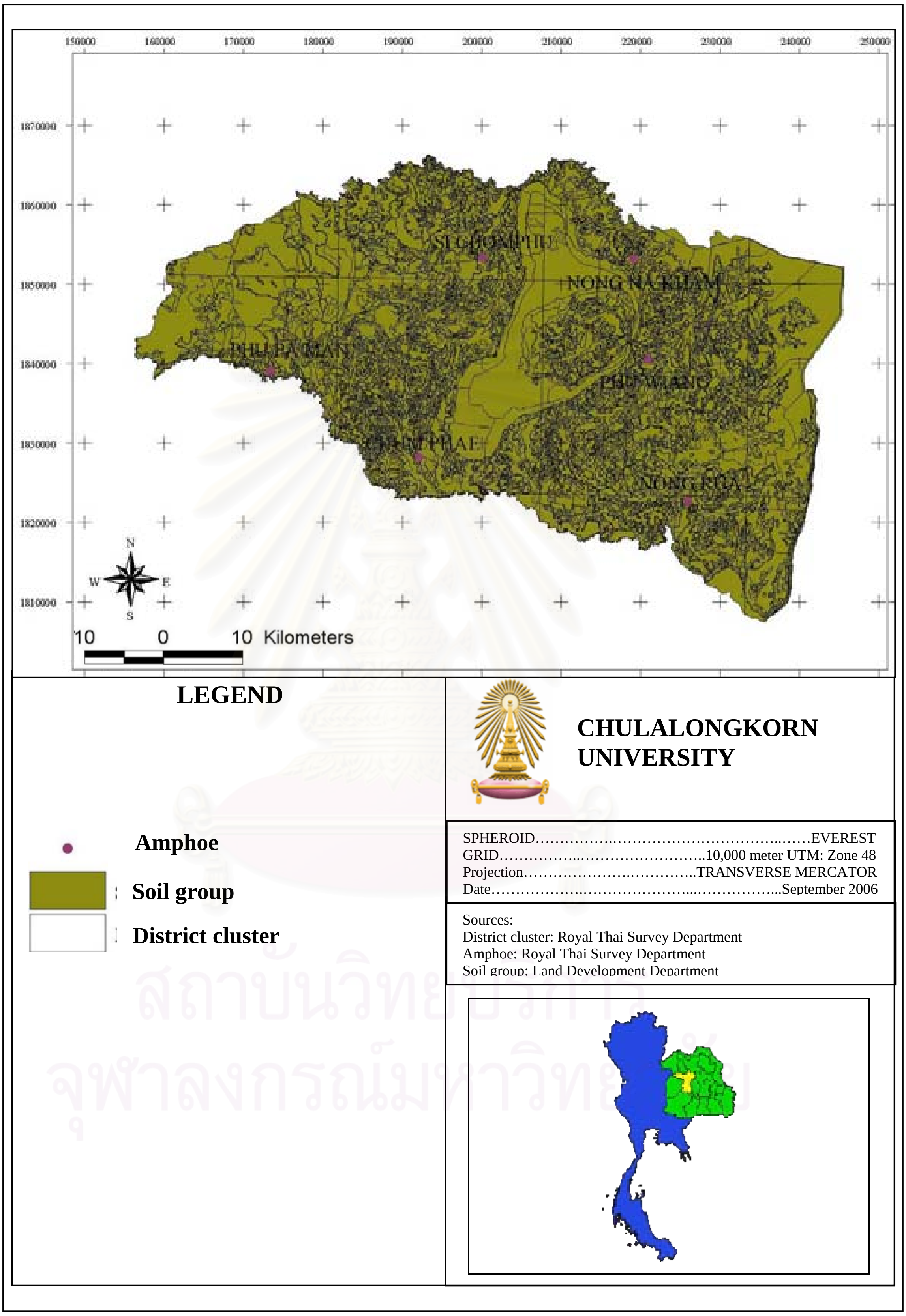


Figure D-17 Layout of Soil Group

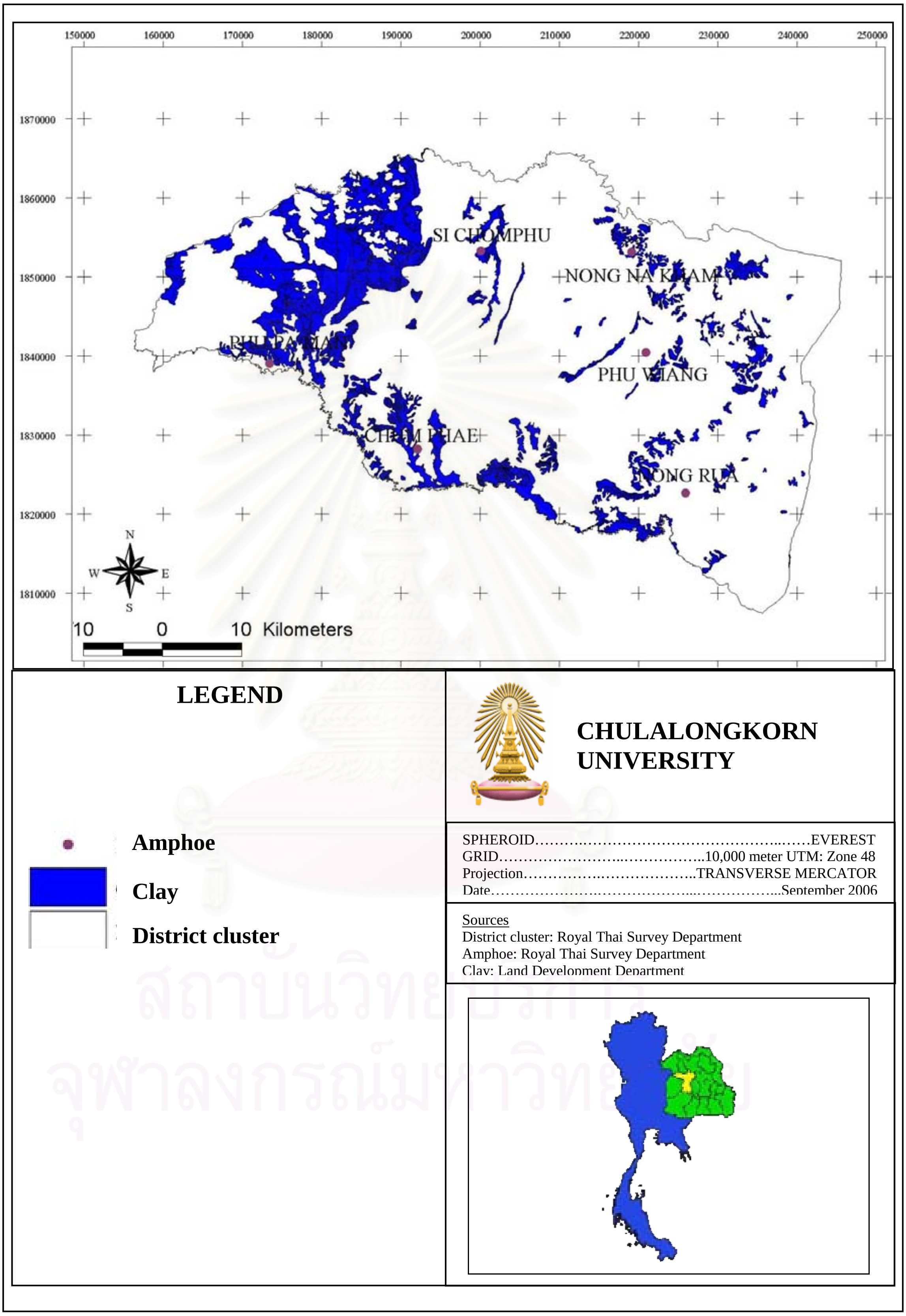


Figure D-18 Layout of Clay

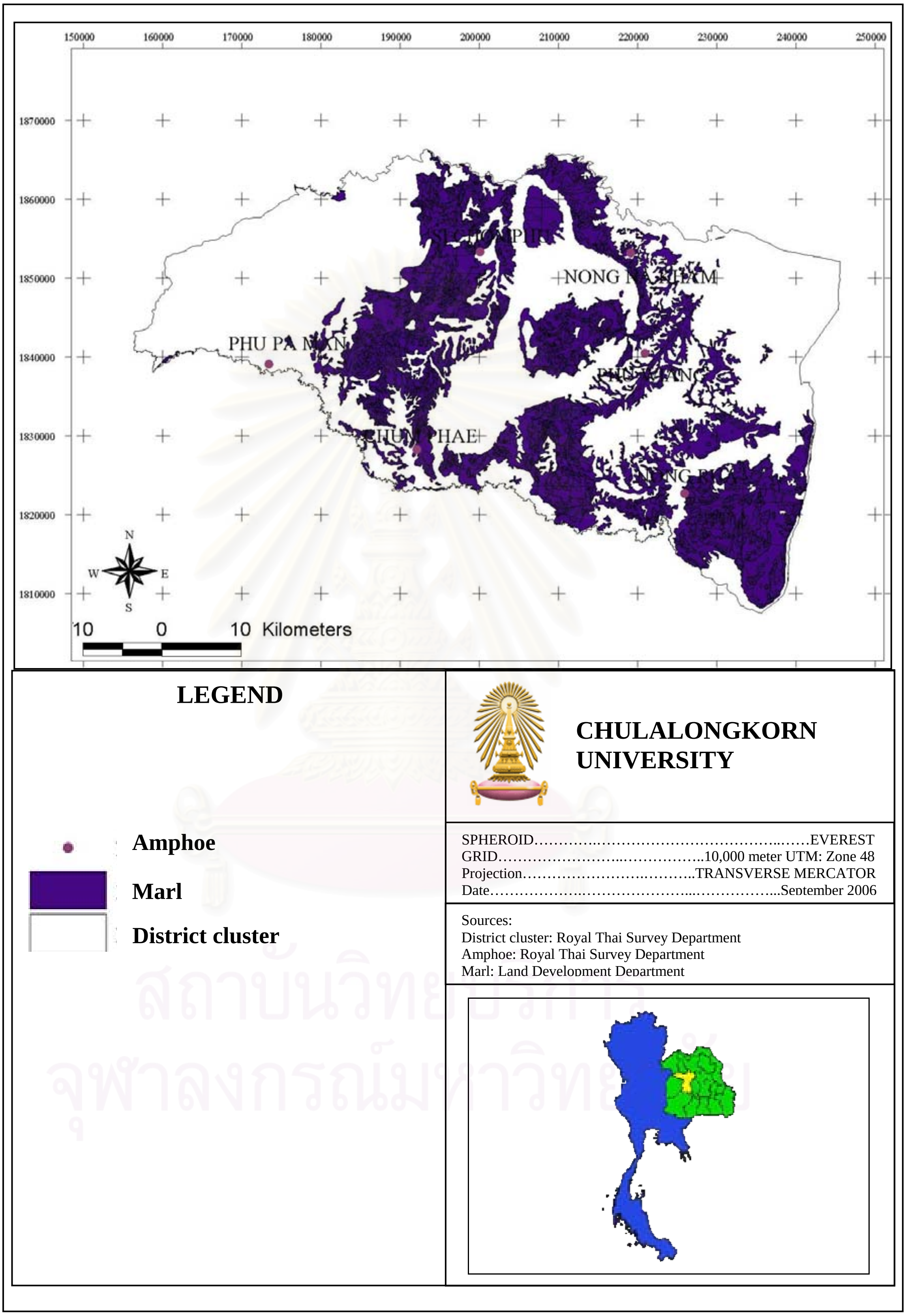


Figure D-19 Layout of Marl

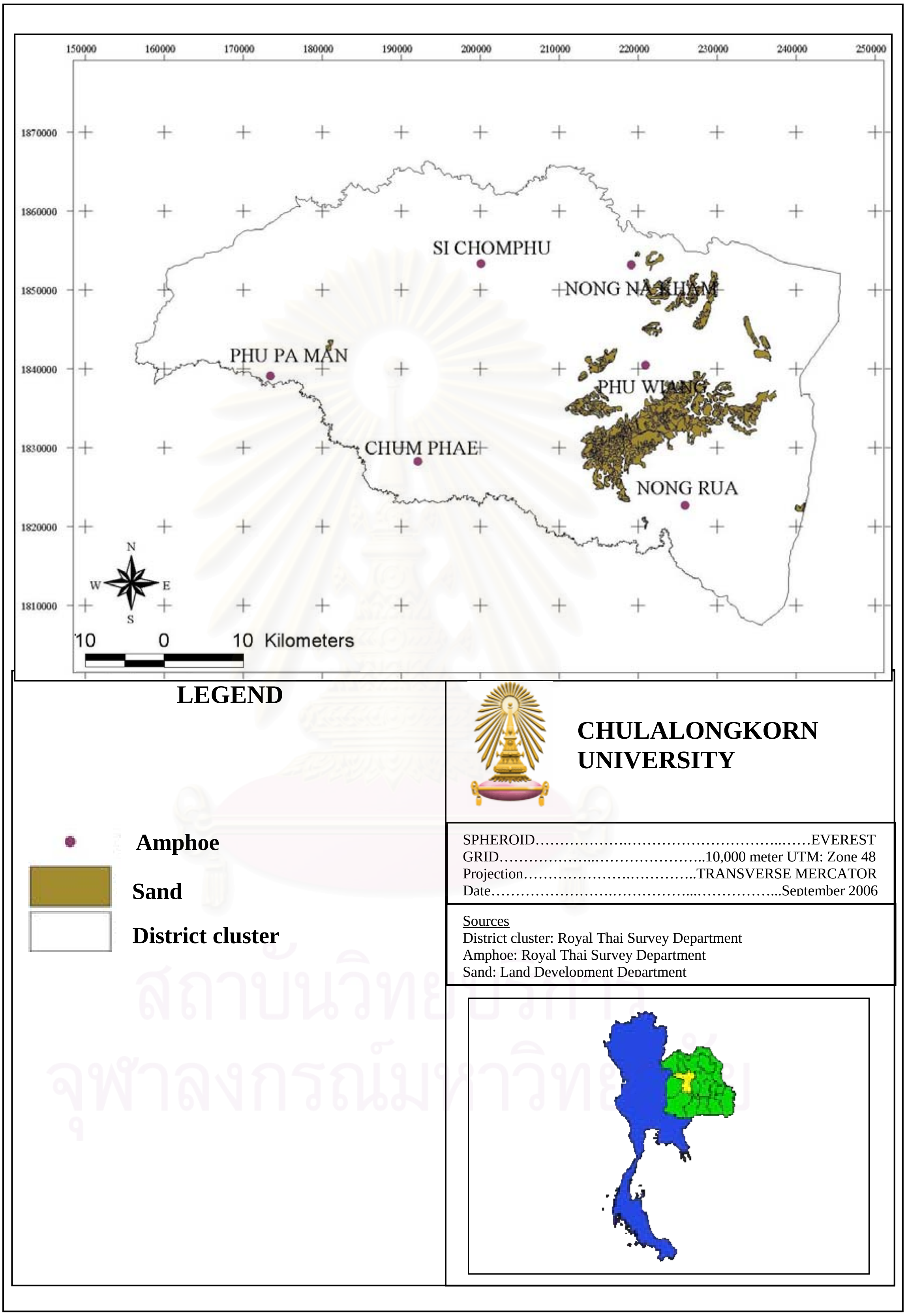


Figure D-20 Layout of Sand

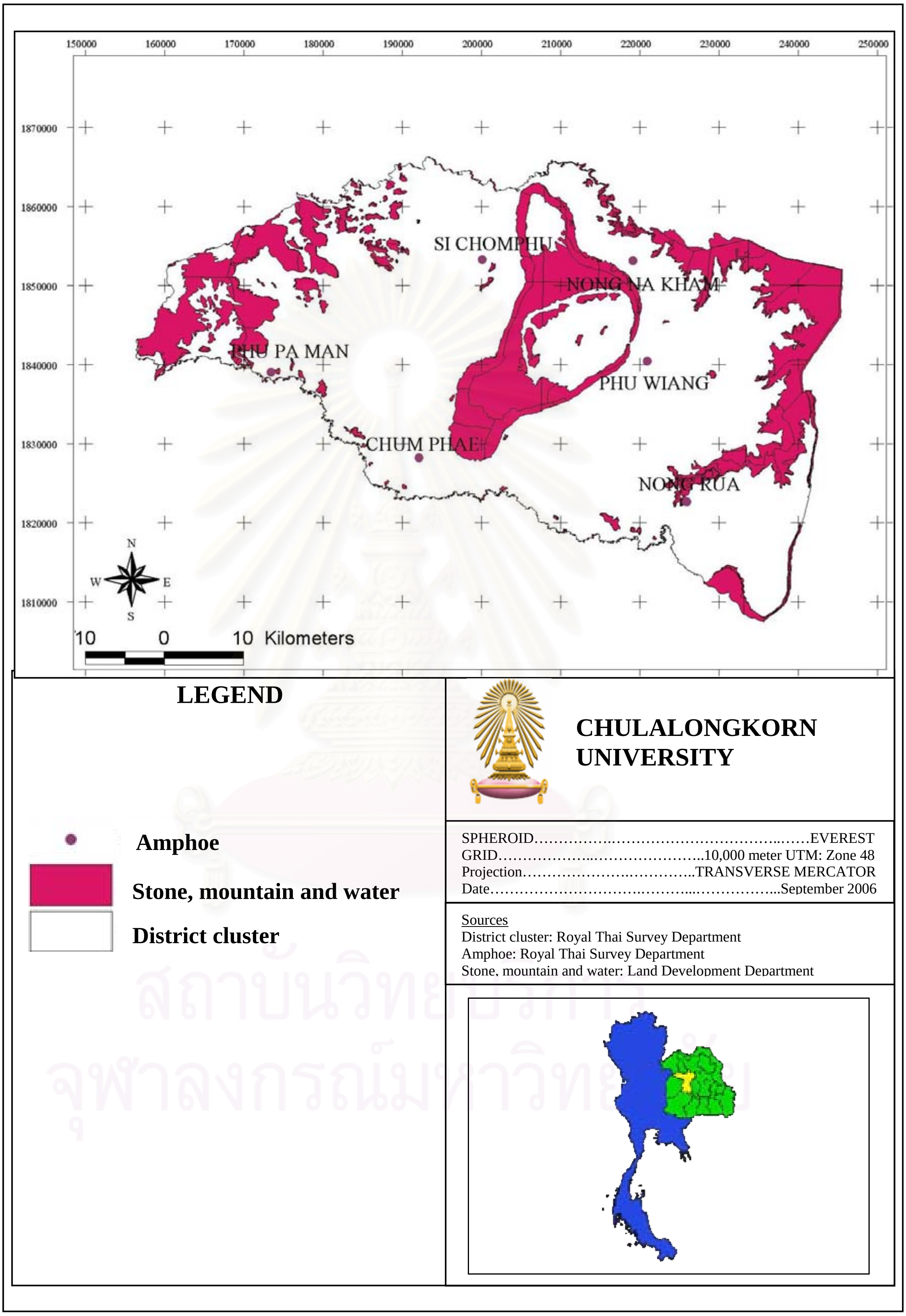


Figure D-21 Layout of Stone, Mountain and Water

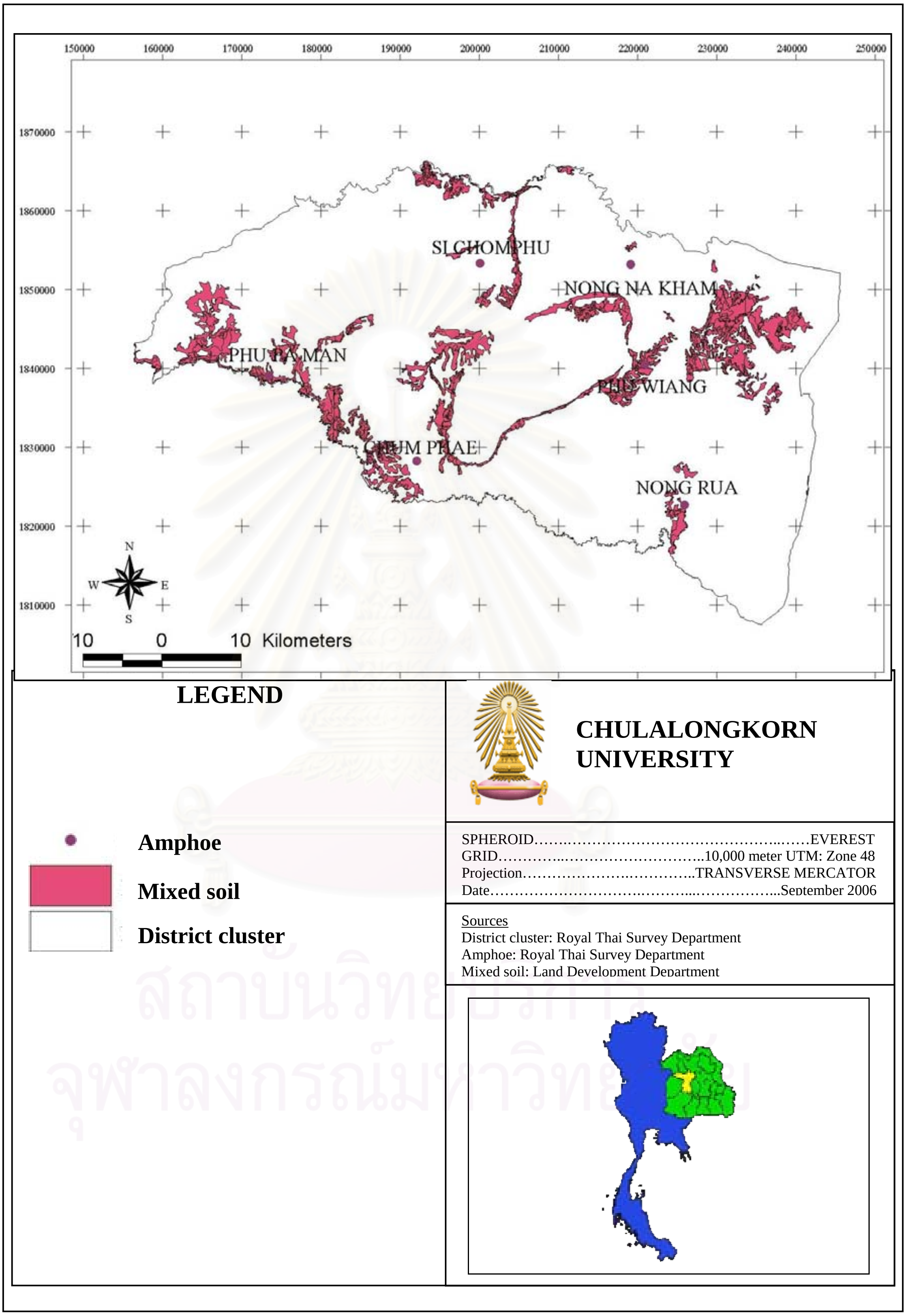


Figure D-22 Layout of Mixed Soil

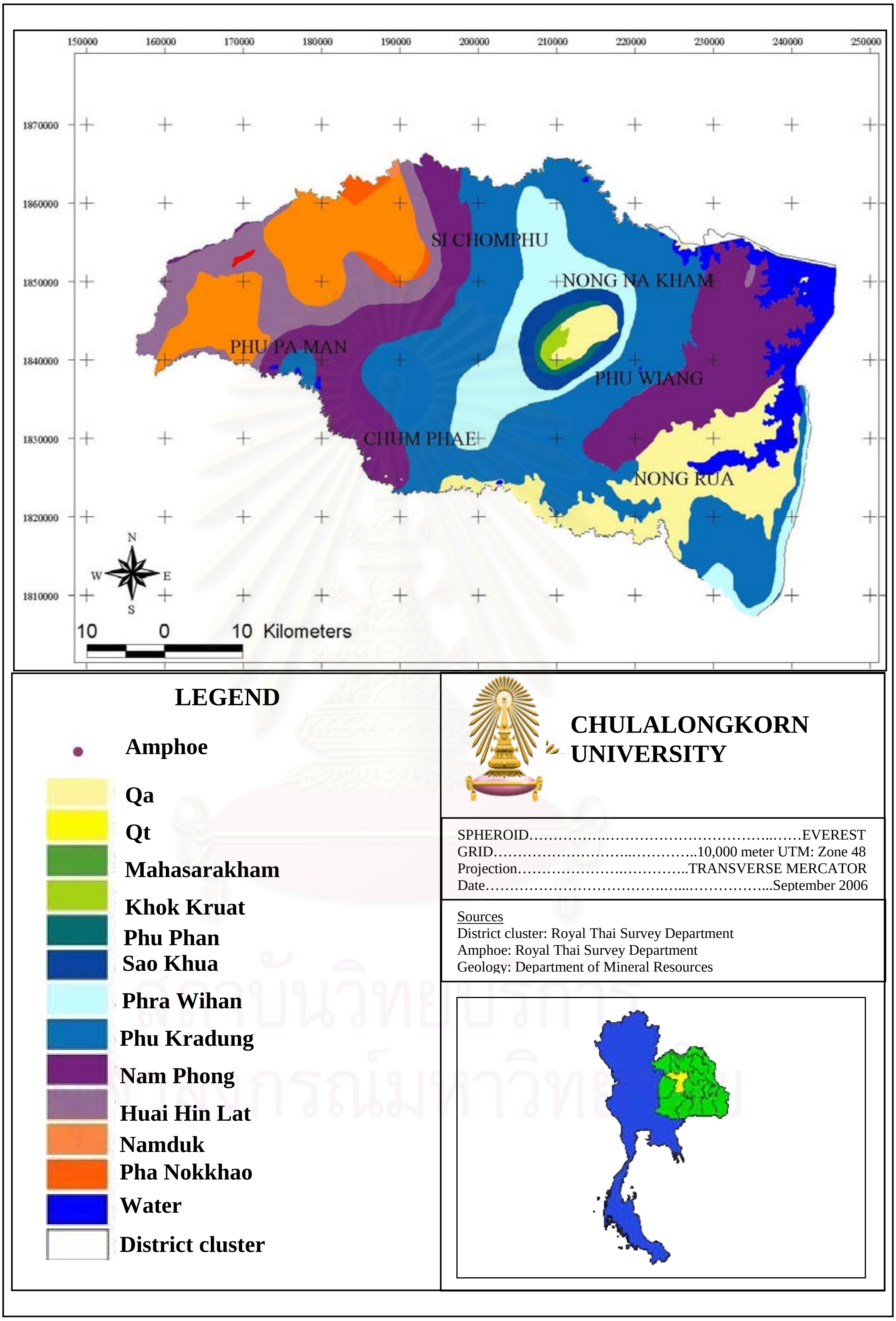


Figure D-23 Layout of Geology

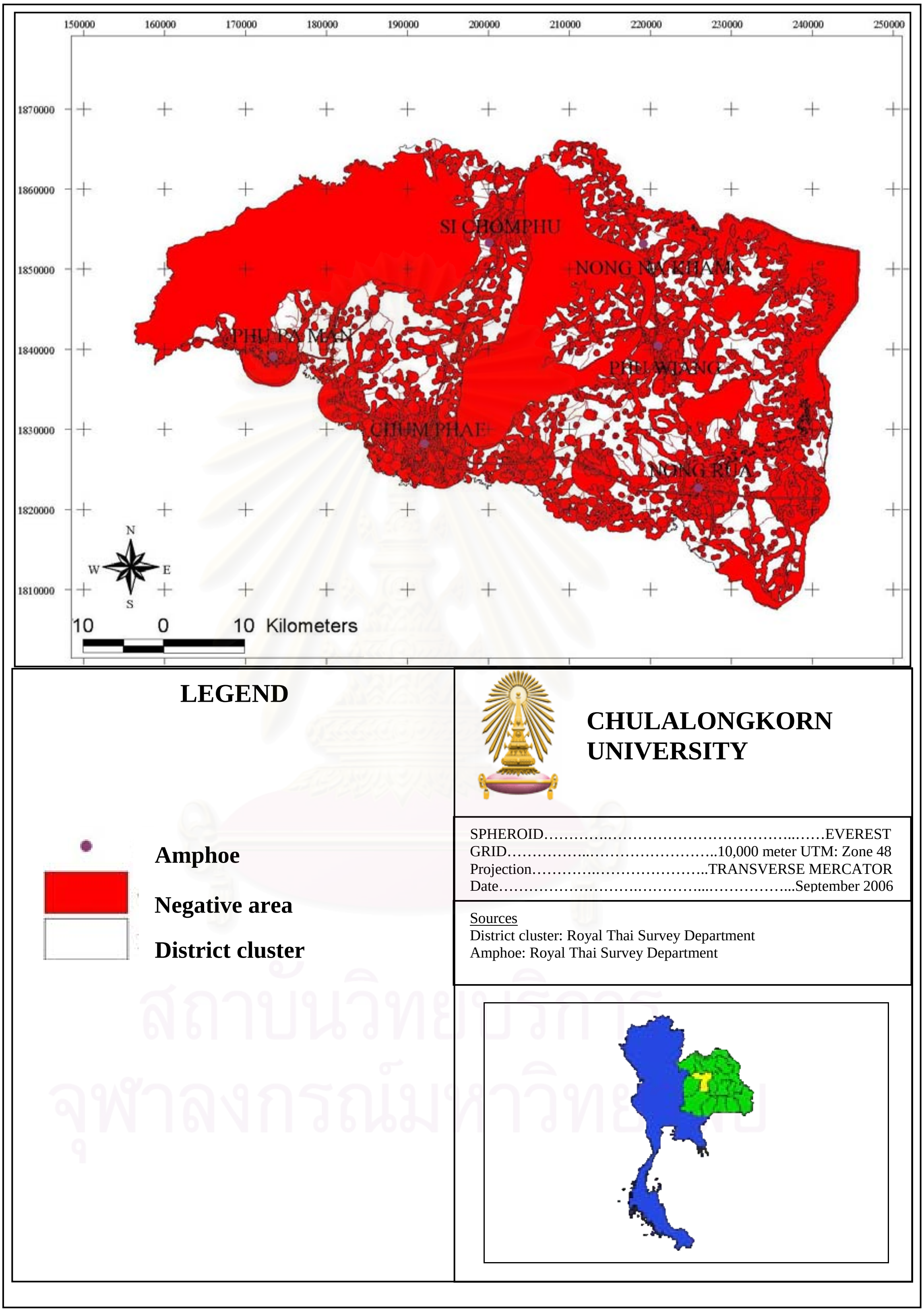


Figure D-24 Layout of Negative Area for Disposal Site

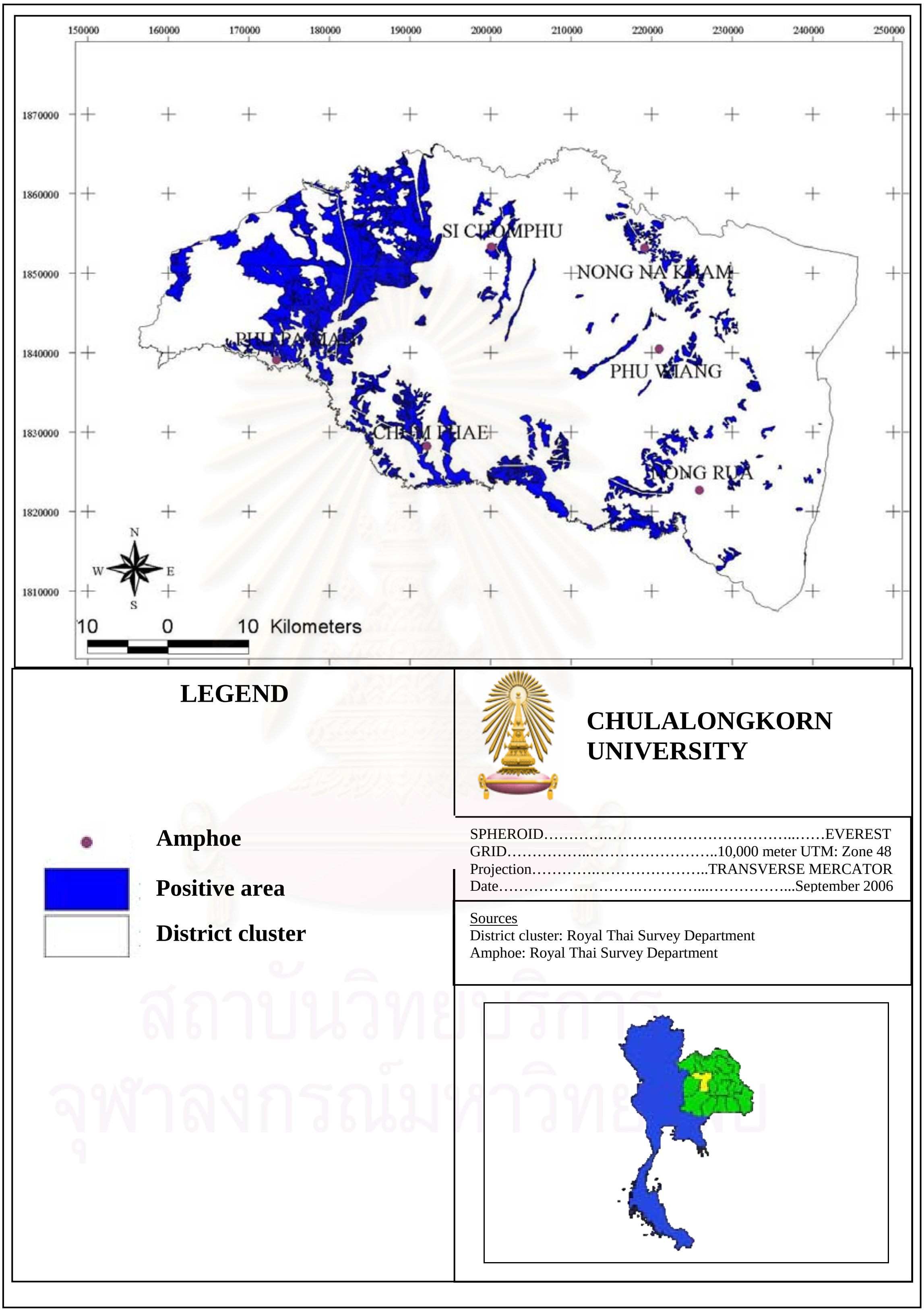


Figure D-25 Layout of Positive Area for Disposal Site

APPENDIX E

Permeability and Well Logging Data

WELL LOGGING

ภาควิชาเทคโนโลยีธรณี คณะเทคโนโลยี มหาวิทยาลัยขอนแก่น โทร. 0-4336-2125 Fax 0-4336-2126

PROJECT :

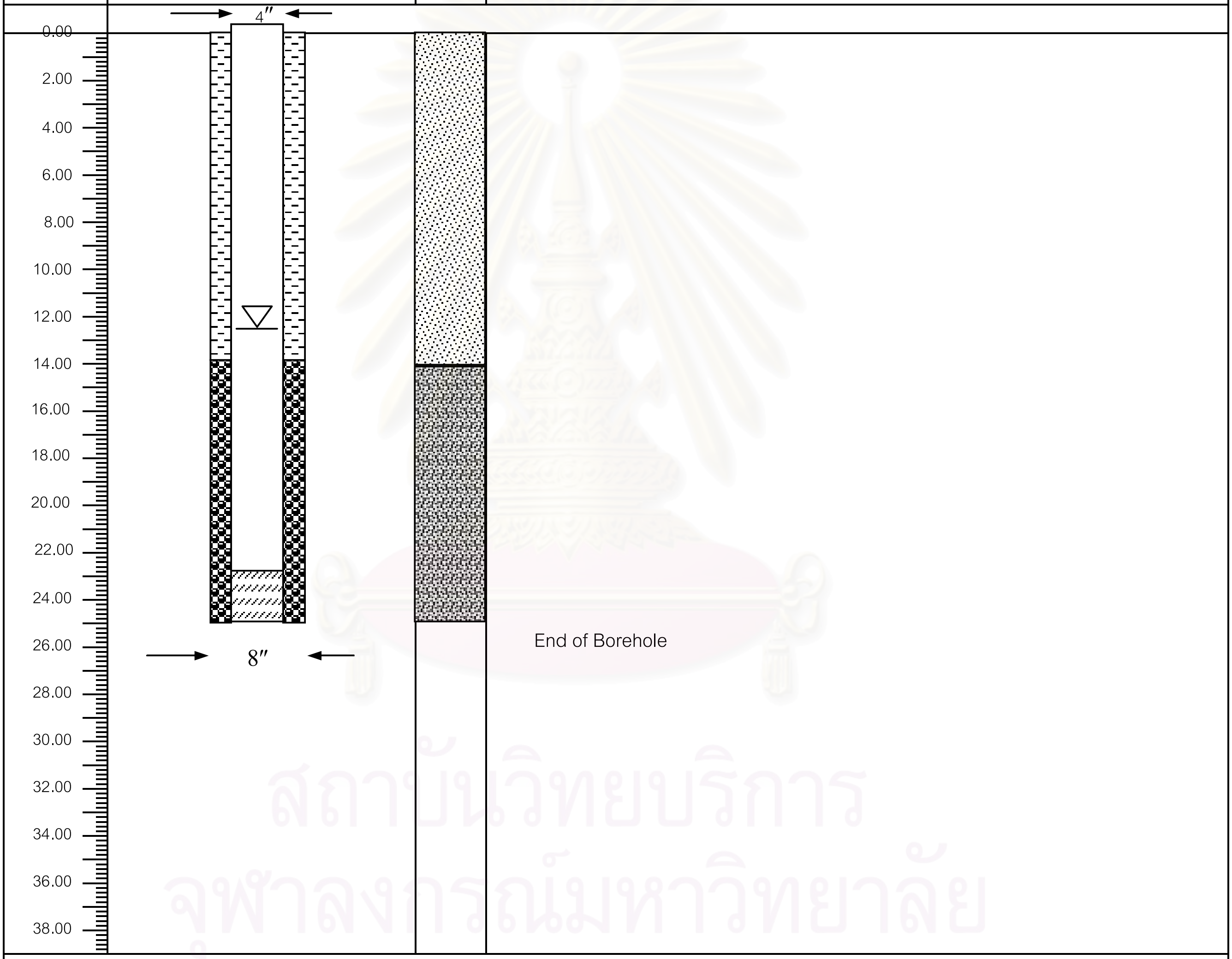
WELL NO: PT 01 LocationX : 2 051 10 LocationY : 18 316 29 MAP SHEET : 5442 III

LOCATION : B. Khokmaung A. Chumphae CH. Khonkaen

WATER LEVEL : DEPTH : 25 เมตร. DEAMETER : 4″ LOGGED BY :

DRILLING METHOD : Rotary DRILLED BY : S.Sakorn and Staff DATE : 31 / 08 / 2006

Depth	WELL DESIGN	SYM	DESCRIPTION



REMARK :

SYMBOL : Clay pack, Gravel Pack 3/8 in., Slots, Water teble

Figure D-1 Well logging of GWM

ภาควิชาเทคโนโลยีธรณี คณะเทคโนโลยี มหาวิทยาลัยขอนแก่น

GROUNDWATER FOR AGRICULTURE (GWAG)

ภาควิชาเทคโนโลยีธรณี คณะเทคโนโลยี มหาวิทยาลัยขอนแก่น

Department of Geotechnology Facalty of Technology Khon Kaen University

Pumping Test Data

Well no : PT 01 Area : Location : B. Khokmaung A. Chumphae CH. Khonkaen

Coordinate : 2 051 00 / 18 316 31 Elevation : Distance (r) : 0.05 m.

Well function : Pumping Well Depth : 25.00 m. Diameter : 4 inch.

Date : 31 - 08 - 2006 Start : 10:00 am Stop : 11.00 am

Discharge measurement : Bugget Initial water level : 12.61 m. Final water level : 15.67 m.

Depth of pump intake : Pumping test by : S. Sakorn

Remark :

Time	since pumping		Water level	S	S'	t / t'	EC	TDS	pH	Q		Remarks
	t (min)	t' (min)	(m)	(m)	(m)		µS/cm	mg/l		gpm	m³/d	
	0		12.61									
	60	0	15.67									
	61	1	15.48									
	62	2	15.36									
	63	3	15.16									
	65	5	14.87									
	67	7	14.6									
	70	10	14.26									
	82	22	13.35									
	90	30	13.01									
	105	45	12.79									
	120	60	12.68									
	135	75	12.65									
	150	90	12.64									
	165	105	12.63									
	180	120	12.62									
	195	135	12.62									
	210	150	12.62									

Figure D-2 Pumping test calculation table

ภาควิชาเทคโนโลยีธรณี คณะเทคโนโลยี มหาวิทยาลัยขอนแก่น

Department of Geotechnology Facalty of Technology Khon Kaen University

FIELD PERMEABILITY TEST

Project ;
Location ; B. Khokmaung A. Chumphae CH. Khonkaen

Boring No ; BH - 01
Coordinate ;
Elevation ;

Total depth ; 0.63 m
Method ; Variable Head
Hole Diameter ; 7.62 cm.

Tested by ; S Sakorn
Cheaked by ;
Date ; 31 - 08 - 2006

Depth (m.)	Ground Water Depth (cm.)	Test Condition	Uncased Length L (cm.)	Casing above Ground (cm.)	Hole Radius R (cm.)	Elapsed Time t (min.)	Water Depth d (cm.)	Water Head H (cm.)	Co-efficient of Permeability K (cm./sec.)	Soil Type
0.63	0.63	b	0	0.58	3.81	0	0.000	121.000	3×10^{-8}	
						1	0.003	120.997		
						2	0.042	120.958		
						3	0.050	120.950		
						4	0.056	120.944		
						5	0.056	120.944		
						7	0.060	120.940		
						10	0.060	120.940		
						20	0.060	120.940		
						30	0.060	120.940		

Remark.

Figure D-3 Permeability calculation table of top soil

ภาควิชาเทคโนโลยีธรณี คณะเทคโนโลยี มหาวิทยาลัยขอนแก่น

Department of Geotechnology Facalty of Technology Khon Kaen University

FIELD PERMEABILITY TEST

Project ;	Location ; B. Khokmaung A. Chumphae CH. Khonkaen	
Boring No ; BH - 02	Coordinate ;	Elevation ;
Total depth ; 0.89 m	Method ; Variable Head	Hole Diameter ; 7.62 cm.
Tested by ; S Sakorn	Cheaked by ;	Date ; 31 - 08 - 2006

Depth (m.)	Ground Water Depth (cm.)	Test Condition	Uncased Length **L** (cm.)	Casing above **Ground** (cm.)	Hole Radius **R** (cm.)	Elapsed Time **t** (min.)	Water Depth **d** (cm.)	Water Head **H** (cm.)	Co-efficient of Permeability **K** (cm./sec.)	Soil Type
0.89	0.89	b	0	0.85	3.81	0	0.00	174.00	1.33×10^{-5}	
						1	0.20	173.80		
						3	0.30	173.70		
						4	1.00	173.00		
						5	1.00	173.00		
						10	1.50	172.50		
						15	2.10	171.90		
						20	2.40	171.60		
						30	2.90	171.10		
						45	4.00	170.00		
						60	4.80	169.20		

Remark.

Figure D-4 Permeability calculation table of medium soil layer

BIOGRAPHY

Mr. Ayuwat Thanasate-angkool was born on July 9, 1981 at Khon Kaen and graduated from high school at Demonstration School, KKU in 1998. He received a bachelor degree in Civil Engineering from Khon Kaen University in 2002. After graduation, he worked at Zenith Graphic Company until 2004. He enrolled the Master of Science in Environmental Management Program at Chulalongkorn University in 2004.