การประเมินลักษณะดินและน้ำใต้ดิน ต่อการหาพื้นที่ฝังกลบขยะ โดยใช้ระบบสารสนเทศทางภูมิศาสตร์ และโปรแกรม วิชวลล์ เฮลพ์

นางสาวหฤทัย ไทยธรรม

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาการจัดการสิ่งแวดล้อม (สหสาขาวิชา)
บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2548

ISBN: 974-17-5332-2

EVALUATION OF SOIL CHARACTERISTICS AND GROUNDWATER CRITERIA ON LANDFILL SITING USING GEOGRAPHIC INFORMATION SYSTEM AND HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE COMPUTER PROGRAM

Miss Hareuthai Thaiyatham

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Environmental Management (Inter-department)

Graduate School
Chulalongkorn University

Academic Year 2005
ISBN: 974-17-5332-2

Thesis Title	EVALUATION OF SOIL CHARACTERISTICS AND GROUNDWATER CRITERIA ON LANDFILL SITING USING GEOGRAPHIC INFORMATION SYSTEM AND HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE COMPUTER PROGRAM
By	Miss Hareuthai Thaiyatham
Field of Study	Environmental Management
Thesis Advisor	Associate Professor Wanpen Wirojanagud, Ph.D.
Thesis Co-advisor	Assistant Professor Alissara Reungsang, 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 Alissara Reungsang, Ph.D.)

....Member
(Associate Professor Punya Charusiri, Ph.D.)

....Member
(Somsak Pitaksanurat, Ph.D.)

หฤทัย ไทยธรรม : การประเมินลักษณะดินและน้ำใต้ดิน ต่อการหาพื้นที่ฝังกลบขยะ โดยใช้ระบบสารสนเทศทางภูมิศาสตร์ และโปรแกรม วิชวลล์ เฮลพ์ (EVALUATION OF SOIL CHARACTERISTICS AND GROUNDWATER CRITERIA ON LANDFILL SITING USING GEOGRAPHIC INFORMATION SYSTEM AND HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE COMPUTER PROGRAM) อ.ที่ปรึกษา: รศ.ดร. วันเพ็ญ วิโรจนกูฏ, อ.ที่ปรึกษาร่วม: ผศ.ดร. อลิศรา เรืองแสง 198 หน้า. ISBN: 974-17-5332-2

งานวิจัยชิ้นนี้มีจุดประสงค์เพื่อทำการประเมินหาพื้นที่ที่มีศักยภาพสำหรับหลุมฝังกลบขยะ โดยใช้ระบบสารสนเทศทางภูมิศาสตร์และโปรแกรมวิชวล เฮลพ์ (Visual HELP)โดยใช้จังหวัดขอนแก่นเป็นพื้นที่ศึกษา ในเบื้องต้นได้มีการศึกษาหาพื้นที่อ่อนไหวต่อสิ่งแวดล้อมในการก่อสร้างหลุมฝังกลบขยะในรูปแบบของแผนที่โดยใช้เกณฑ์ต่างๆตามหลักการของกรมควบคุมมลพิษกอปรกับหลักเกณฑ์ของโครงการปฏิบัติการเพื่อการจัดการคุณภาพสิ่งแวดล้อมระดับจังหวัด โดยจัดประเภทพื้นที่สำหรับก่อสร้างหลุมฝังกลบขยะ เป็นพื้นที่อ่อนไหวสูงมาก พื้นที่อ่อนไหวสูง พื้นที่อ่อนไหวกลางถึงต่ำ การศึกษานี้ได้เพิ่มเกณฑ์ระดับน้ำใต้ดินเข้าไป ทำให้ได้แผนที่แสดงพื้นที่อ่อนไหวใหม่ มีขนาดของพื้นที่อ่อนไหวสูงมากเพิ่มขึ้น พื้นที่ที่สามารถก่อสร้างหลุมฝังกลบขยะได้ลดลงจาก 2,689.78 เหลือ 572 ตารางกิโลเมตร (ร้อยละ 79) หลังจากนั้นได้ทำการสำรวจภาคสนามประเมินผลกระทบที่อาจเกิดขึ้นจากน้ำชะขยะใน พื้นที่ที่อยู่ในพื้นที่อ่อนไหวปานกลางถึงต่ำจำนวน 7 แห่ง และใช้โปรแกรม วิชวล เฮลพ์ ทำการทำนายปริมาณน้ำที่จะซึมผ่านชั้นดินธรรมชาติ ลงสู่แหล่งน้ำใต้ดิน ภายใต้ปัจจัยแวดล้อมและข้อมูลนำเข้าเดียวกันได้แก่ สภาพอากาศ โครงสร้างของหลุมฝังกลบขยะ ผลของการจำลองพบว่าปริมาณน้ำที่เกิดขึ้นจากพื้นที่ทั้ง 7 แห่ง มีปริมาณไม่แตกต่างกันอย่างมีนัยสำคัญคือ อยู่ในช่วงระหว่าง 9.84 ล้าน ลบ.ม. ถึง 10.3 ล้าน ลบ.ม. และเมื่อมีมาตรการลดผลกระทบโดยการเพิ่มวัสดุปูพื้นสังเคราะห์ ผลการจำลองปริมาณน้ำที่ซึมผ่านชั้นดินธรรมชาติชั้นสุดท้ายพบว่า ปริมาณน้ำที่เกิดขึ้นลดลงประมาณ ร้อยละ 19-38 โดยที่ พื้นที่ที่5และ3 เป็นพื้นที่ที่เหมาะสมในการจัดทำพื้นที่ฝังกลบขยะ ในกรณีที่ ไม่มีและมี วัสดุปูพื้นสังเคราะห์ตามลำดับ งานวิจัยนี้สรุปได้ว่า การพิจารณาปัจจัยทางดินและน้ำใต้ดิน มีผลต่อ การหาพื้นที่ ฝังกลบขยะ ซึ่งเกี่ยวเนื่องกับน้ำชะขยะ และ ระบบสารสนเทศทางภูมิศาสตร์ และ โปรแกรมวิชวลล์ เฮลพ์ เป็นเครื่องมือที่มีประสิทธิภาพที่สามารถนำมาใช้ประโยชน์ ในการหาพื้นที่ที่เหมาะสมสำหรับการฝังกลบขยะได้

สาขาวิชา การจัดการสิ่งแวดล้อม (สหสาขาวิชา) ลายมือชื่อนิสิต..............................
ปีการศึกษา 2548 ลายมือชื่ออาจารย์ที่ปรึกษา..............................
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม..............................

4689508020 : MAJOR ENVIRONMENTAL MANAGEMENT
KEY WORD: LANDFILL / SITING / GIS / VISUAL HELP

HAREUTHAI THAIYATHAM: EVALUATION OF SOIL CHARACTERISTICS AND GROUNDWATER CRITERIA ON LANDFILL SITING USING GEOGRAPHIC INFORMATION SYSTEM AND HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE COMPUTER PROGRAM, THESIS ADVISOR: ASSOC. PROF. WANPEN WIROJANAGUD, THESIS CO-ADVISOR: ASSIS. PROF. ALISSARA REUNGSANG, 198 pp. ISBN: 974-17-5332-2

This research aimed at an evaluation of the potential sites for sanitary landfills in Khon Kaen province using Geographic Information System (GIS) and Visual Hydrologic Evaluation of Landfill Performance (HELP) computer program. Initially, the environmental sensitive areas for landfill sites were mapped based on the criteria of Pollution Control Department (PCD) together with some additional criteria from Changwat (province) Action Plan for Environmental Quality Management (CAPEQM) project. With the GIS approach, 3 levels of sensitive areas were categorized as the highest, high, and medium to low environmental sensitive area. In order to focus more specific criteria on groundwater level, the new environmental sensitive areas could be then created. With the groundwater level overlain onto the initial map, the medium to low sensitive area was significantly decreased approximately 79% (from 2689.78 km^2 to 572 km^2). Afterward, the impacts of the sensitive areas were assessed in terms of volume of leachate percolation using Visual HELP computer program. Soil profile of the 7 selected sites were carried out, they indicate the different soil types of individual sites. Under the same conditions of inputs (weather, leachate characteristics, structure of landfill) and a little different in soil types, the results simulated by Visual HELP that the percolation volume of all 7 sites were not much different in the range of 9.84 million cubic meters (MCM) to 10.3 MCM. With the mitigation measures by adding the liner of geo-membrane, the simulating water generated was decreased in the range of 19 to 38%. Site 5 and site 3 are the most potential sites in order to less water percolation. They are the most suitable with minimal impact to environment in both of without and with mitigation measures (geomembrane lining), respectively. It could be concluded that ground water level and soil characteristics are the important criteria for landfill siting. GIS and Visual HELP program are the meaningful tool to facilitate landfill siting. The study also guided the new useful siting process technology for disposal facilities.

Field of study Environmental Management (Inter-Department)
Academic year 2005

Student's signature.............................
Advisor's signature.............................
Co-advisor's signature..........................

ACKNOWLEDGEMENTS

First of all, I would like to acknowledge the National Research Center for Environmental and Hazardous Waste Management, Master of Science International Postgraduate Programs in Environmental Management (Hazardous Waste Management), Graduate School of Chulalongkorn University, for enabling me to develop my knowledge, skills, and attitudes inside the field of Environmental Management.

This thesis would never have been completed without the assistance of the following contributors. My deepest gratitude is given to my advisor, Associate professor Dr. Wanpen Wirojanagud, and my co-advisor, Assistant Professor Alissara Reungsang for generous suggestions, encouragement, and guidances through the completion of this thesis. Thanks are also given to the Chairman of the thesis committee, Manaskorn Rachakornkij, Ph.D. and the thesis committee member, Associate Professor Dr. Punya Charusiri, and Dr. Somsak Pitaksanurat.

For the valueable databases and information, my many thanks are dedicated to the staff members of Groundwater Resource Department of Thailand, Groundwater Research Center, Khon Kaen University, and Environmental Management Center, Khon Kaen University. I would also like to thank my friends in M.S. in environmental management program for being positive and providing me with friendship and support throughout the period.

Finally, I would like to express my deepest gratitude to my beloved family for their loves, understanding, and encouragement at all times.

Any error in this study deems my own.

CONTENTS

Page

ABSTRACT IN THAI..iv
ABSTRACT IN ENGLISH... v
ACKNOWLEDGEMENTS...vi
CONTENTS..vii
LIST OF TABLES..ix
LIST OF FIGURES... x
NOMENCLATURES……………………………………………………....xiv

CHAPTER I INTRODUCTION..1
1.1 State of the Problem...1
1.2 The Study Area.. 2
1.3 Objectives.. 3
1.4 Hypotheses...3
1.5 Scope of Study... 3
1.6 Expected Results..5

CHAPTER II THEORY AND LITERATURE REVIEW...............................8
2.1 Theoretical Background...8
2.1.1 Municipal Landfill and Siting Criteria…………....8
2.1.2 Leachate and Groundwater Contamination............ 15
2.1.3 Geographic Information System............................17
2.1.4 Model Application and Visual HELP Computer Program..18
2.2 Relevant Studies...19
2.2.1 GIS Application on Environmental Aspect............ 19
2.2.2 Siting Discipline with GIS..……………………..... 19
2.2.3 Changwat Action Plans of Environmental Management Project (CAPEQM-Project).............. 20

CHAPTER III MATERIALS AND METHODOLOGY.................................23
3.1 Materials..............……………………………………….... 23
3.1.1 Maps........……………………………………..........23
3.1.2 Computer Hardware and Software/Implemental Accessories... 23
3.2 Methodology.......................………………………………...24
3.2.1 Data Collection and Reviews……………………..24

Page

3.2.2 Establishing GIS and Mapping………………….…... 25
3.2.3 Investigate Soil Profile and Field Survey....……... 25
3.2.4 Assess the Area Using Visual HELP Computer Program...25
3.2.5 Mitigation Measures Development.........................27
3.2.6 Re-Evaluation Using the HELP Computer Program...27

CHAPTER IV RESULTS AND DISCUSSIONS... 35
4.1 GIS Database for MSW Landfill Siting...................................35
4.2 Groundwater Level Contour.. 41
4.3 The New Environmental Sensitive Areas Map……………......44
4.4 Sites Characteristics……………………………………….. 48
4.5 Results from Visual HELP Simulation…………………….... 78
4.6 Mitigation Measures Development..81

CHAPTER V CONCLUSIONS AND RECOMMENDATIONS....................85
5.1 Conclusions.................………...85
5.2 Recommendations..86
REFERENCES……………………………..……………………….........87
APPENDICES..90
APPENDIX A..92
APPENDIX B.. 126
APPENDIX C..163
APPENDIX D..166
BIOGRAPHY... 198

LIST OF TABLES

Table Page

1.1 Groundwater monitoring data of Nakorn Khon Kaen Municipality.............6
2.1 Comparison of three different waste disposal methods.................................9
2.2 The criteria of CAPEQM-project for sensitive area for sanitary Landfill..... 22
3.1 Landfill facility siting criteria...32
4.1 Criteria for area classification...36
4.2 The alternate groundwater levels represented groundwater fluctuation.........43
4.3 The environmental sensitive areas for landfill with groundwater level in range of 0-4 m. >4-9 m, and >9 m...43
4.4 The environmental sensitive areas for landfill with groundwater level in range of 0-6 m. >6-11 m, and >11 m...44
4.5 Comparison the Area Between Without and With Groundwater Contour Maps...45
4.6 The Landfill Structure..79
4.7 Layer 10 of each site..79
4.8 The Properties of soil barrier...80
4.9 Total simulated percolation or leakance through layer 10 (m^3) of 7 sites in 23 years...81
4.10 Properties of geomembrane layer...82
4.11 Comparison volume of water between with and without liner adding.1.4 Hypotheses...82
C-1 Default soil, waste, and geosynthetic characteristics...................................164

LIST OF FIGURES

Figure Page

1.1 Map of study area covering the whole Khon Kaen province.........................7
2.1 Landfill gas contamination mechanism...17
2.2 Major components of GIS...18
2.3 Environmental sensitive area for landfill map of CAPEQM-project............ 21
3.1 Research methodology applied in this study..29
3.2 GIS technique on screening the environmental sensitive areas for landfill
site...30
4.1 Map of environmental sensitive areas without groundwater contour factor..46
4.2 Map of environmental sensitive areas with groundwater contour factor.......47
4.3 Location of proposed sites..49
4.4 Map showing location and land use of site 1 and surrounding area..............50
4.5 Map showing the contour lines of site 1 and surrounding area
(meters above Mean Sea Level)..50
4.6 Index map of site 1 showing lines of sections...51
4.7 Cross section of line AA' in area 1 showing the profile of sediments and
sedimentary rock...52
4.8 Cross section of line BB' in area 1 showing the profile of sediments and
sedimentary rock...53
4.9 Map showing location and land use of site 2 and surrounding area..............55
4.10 Map showing the contour lines of site 2 and surrounding area
(meters above Mean Sea Level)..55
4.11 Index map of site 2 showing lines of sections...54
4.12 Cross section of line AA' in area 2 showing the profile of sediments and
sedimentary rock...56
4.13 Cross section of line BB' in area 2 showing the profile of sediments and
sedimentary rock...57
4.14 Cross section of line CC' in area 2 showing the profile of sediments and
sedimentary rock...57
4.15 Map showing location and land use of site 3 and surrounding area............59

Page

4.16 Map showing the contour lines of site 3 and surrounding area (meters above Mean Sea Level)....60
4.17 Index map of site 3 showing lines of sections....60
4.18 Cross section of line AA’ in area 3 showing the profile of sediments and sedimentary rock....61
4.19 Cross section of line BB’ in area 3 showing the profile of sediments and sedimentary rock....61
4.20 Map showing location and land use of site 4 and surrounding area....63
4.21 Map showing the contour lines of site 4 and surrounding area (meters above Mean Sea Level)....64
4.22 Index map of site 4 showing lines of sections....64
4.23 Cross section of line AA’ in area 4 showing the profile of sediments and sedimentary rock....65
4.24 Cross section of line BB’ in area 4 showing the profile of sediments and sedimentary rock....65
4.25 Map showing location and land use of site 5 and surrounding area....67
4.26 Map showing the contour lines of site 5 and surrounding area (meters above Mean Sea Level)....67
4.27 Index map of site 5 showing lines of sections....68
4.28 Cross section of line AA’ in area 5 showing the profile of sediments and sedimentary rock....68
4.29 Cross section of line BB’ in area 5 showing the profile of sediments and sedimentary rock....69
4.30 Map showing location and land use of site 6 and surrounding area....71
4.31 Map showing the contour lines of site 6 and surrounding area (meters above Mean Sea Level)....71
4.32 Index map of site 6 showing lines of sections....72
4.33 Cross section of line AA’ in area 6 showing the profile of sediments and sedimentary rock....73
4.34 Cross section of line BB’ in area 6 showing the profile of sediments and sedimentary rock....73

Page

4.35 Cross section of line CC’ in area 6 showing the profile of sediments and sedimentary rock..........74
4.36 Map showing location and land use of site 7 and surrounding area..........75
4.37 Map showing the contour lines of site 7 and surrounding area (meters above Mean Sea Level)..........76
4.38 Index map of site 7 showing lines of sections..........76
4.39 Cross section of line AA’ in area 7 showing the profile of sediments and sedimentary rock..........77
4.40 Cross section of line BB’ in area 7 showing the profile of sediments and sedimentary rock..........77
4.41 Chart of total simulated percolation or leakance through layer 10 (m^3) of sites in 23 years..........81
4.42 Chart of Total Simulated percolation or leakance Comparison volume of water between with and without liner adding..........83
A-1 The highest environmental sensitive areas for landfill..........93
A-2 Watershed Area..........94
A-3 Heritage Sites..........95
A-4 Airport + Buffer..........96
A-5 Buildup Area..........97
A-6 National Park..........98
A-7 Conservation Forest..........99
A-8 4 Municipalities Area..........100
A-9 High Environmental Sensitive Area..........101
A-10 Water Bodies..........102
A-11 Water Pumping Station..........103
A-12 Village water supply..........104
A-13 Flood Prone Area..........105
A-14 National reserve forest (Zone A and E)..........106
A-15 Existing Forest..........107
A-16 Irrigation Area..........108
A-17 Potential , protected, and critical; areas for groundwater..........109

Page

A-18 Buildup Area+ 300m. buffer........110
A-19 Sor Por Kor Area........111
A-20 Groundwater level at 0-5 m........112
A-21 Groundwater level at 5-10 m........113
A-22 Groundwater level at >10 m........114
A-23 Groundwater level at 0-4 m........115
A-24 Groundwater level at >4-9 m........116
A-25 Groundwater level at >9 m........117
A-26 Groundwater level at 0-6 m........118
A-27 Groundwater level at >6-11 m........119
A-28 Groundwater level at >11 m........120
A-29 Map of environmental sensitive areas without groundwater contour factor (0-4, >4-9, and > 9 m)........121
A-30 Map of environmental sensitive areas without groundwater contour factor (0-6, >6-11, and > 11 m)........122
A-31 New highest environmental sensitive areas for landfill proposed in this study........123
A-32 New highest environmental sensitive areas for landfill proposed in this study........124
A-33 New highest environmental sensitive areas for landfill proposed in this study........125

NOMENCLATURES

CAPEQM	=	Changwat Action Plan for Environment Quality Management
GIS	=	Geographic Information System
GW	=	Groundwater
HELP	=	Hydrologic Evaluation of Landfill Performance
MCM	=	Million Cubic Meter
MSL	=	Mean Sea Level
PCD	=	Pollution Control Department

CHAPTER I

INTRODUCTION AND BACKGROUND

1.1 State of the Problem

Presently, the amount of municipal solid waste (MSW) generated in the communities has tended to increase significantly due to the rapid growth of urban and rural development as well as expansion of tourism activity. Thailand produces approximately 22 million tons of waste annually (World Bank, 2002). While the amount of waste has been increasing, the collection service has not been accordingly performed and does not cover all area. Besides, the disposal of wastes is likely carried out improperly. In such that, they have created health hazards and environmental problems. It is hence necessary to find the way to handle such large amount of wastes. In addition to the solid wastes problem is the disposal of household hazardous wastes such as batteries, fluorescence light bulb, insecticides and pesticides, cleansing agent, dye and paint mixing with municipal solid waste. Pollution Control Department (PCD) reports in the Summary of Year 2004 Environmental State that the amount of household hazardous waste is about 380,000 tons and most of them had been still dumped with municipal solid waste. The chemicals contained in household hazardous waste can cause soil and groundwater contamination. Moreover, an inadequate provision of waste collection and disposal equipments and tools, and the inability of the responsible agencies to find appropriate disposal sites are also the causes of such above mentioned harmful impacts. As a result, the comprehensive disposal system should be established.

Landfill or land disposal is the most current conventional method for waste disposal. A sanitary landfill refers to an engineered facility for the disposal of municipal solid waste designed and operated to minimize public health and environmental impact (Tchobanoglous et.al., 1993:362). However, if the management of landfill was not properly, it would have a high possibility for causing environment problems from the leachate (Pollution Control Department, 2004). Groundwater contamination according to hazardous substances has been detected in many disposal sites. Appropriate landfill site is evidently required by considering the criteria for site selection. With the criteria, one of the most concerning parameters is groundwater which would be affected by leachate. It is important to evaluate leachate generation and movement from the landfill site to the groundwater receptor.

1.2 The Study Area

Disposal sites for this study were selected in the area of Khon Kaen province (Figure1.1) locating in the north-eastern region of Thailand with distance of 445 kilometers from Bangkok. The area is between longitude 101^{o} and 103^{o} and latitude between 15^{o} and17^{o}. Khon Kaen has a total area of about 10,886 square kilometers. The area is bounded by

the north:	Udorntani, Loei, and Nong Bua Lam Pu,
the south:	Nakorn ratchasima, and Burirum,
the east:	Kalasin, and Mahasarakam, and
the west:	Chaiyabhum, and Petchabun

The topography of the area is characterized by highland plain and plateau. The western region occupies with Phu Kradung and Petchabun mountains. While, to the east and west, the area is covered with the plain area of the Chi and the Phong river basin. The mean sea level is about 200 meters. The lowest and highest temperatures are 22.35 and 32.79 ^{o}C respectively. An average annual rainfall is about 1,467.4 millimeters.

Khon Kaen province is set to be the development center of Northeast region. This province is going to be accordingly expanded together with the population growth. As a result, the amount of municipal solid wastes (MSW) has continually increased. In accordance with the data of Khon Kaen province, the amount of solid wastes generated in and outside of the municipal area is 813 tons per day of which 276 tons per day are collected and disposed of at seven landfill sites (Khon Kaen Provincial Office of Natural Resources and Environment, 2003). The remaining solid wastes are left without proper management such as open dumping and open burning. As mentioned above, the impact of landfill leachate to groundwater is possible if the landfill site is not properly managed. It is obviously shown by groundwater monitoring data of Nakorn Khon Kaen municipality that the hazardous substances detected in groundwater (Table 1.1). Therefore, groundwater level and soil characteristics are crucial points to be focused for this study.

1.3 Objectives

The main objective is to evaluate the potential site for sanitary landfill using Geographic Information System (GIS) and Visual Hydrologic Evaluation of Landfill Performance (HELP) computer program.

The specific objectives are:

1) To assess groundwater criteria on landfill siting using GIS to get candidate sites;
2) To assess the potential impact of the candidate sites on groundwater based on soil characteristics using the Visual HELP Computer program, which will get the potential sites ;
3) To rank the potential sites; and
4) To develop the mitigation measures for landfill sites based on soil characteristics on the Visual HELP computer program in order to minimize the impact to groundwater.

1.4 Hypotheses

1) Soil characteristics and groundwater level criteria can affect landfill siting.
2) Improvements of liners can minimize impact of landfill to groundwater.

1.5 Scope of Study

An important element of sanitary landfill siting is the technique of evaluation. In this research, the area in Khon Kaen province was evaluated to select the appropriate sanitary landfill sites by using the Geographic Information System and

Visual HELP computer program. The scope of this research could be divided into six major steps

1) Data Preparation and Reviewing

Raw data from various sources in form of maps and tables were collected and prepared to be the input in GIS process. Such raw data had been reviewed and evaluated for the areas. Particularly, the data was drawn from the Changwat Action Plan of the Environmental Quality Management Project (CAPEQM-project) of the areas in Khon Kaen province of which the potential sanitary landfill areas were categorized using GIS techniques. For this research study, the candidate areas for landfill sites were preliminary selected by using the criteria of the CAPEQM project. Then, the sensitive areas for landfill site construction in form of spatial planning map were consequently produced. In addition, data of soil properties and groundwater were reviewed in order to study the contamination of groundwater resource impacted by the leachate and percolation from the hazard substances. Landfill siting criteria were investigated to develop the suitable criteria for this study. Data of landfill design, weather data of Khon Kaen were collected to use in Visual HELP program.

2) Establishment of GIS and Mapping

The research developed geological criteria designed for protection of groundwater sources from the leachate. This step divided into two processes in relevant to GIS and mapping. Firstly, groundwater level criteria were added to the criteria data of the CAPEQM-project using GIS technique. The improved sanitary landfill sites were shown as the new map. Secondly, the most suitable areas (low groundwater level) were selected to build soil profiles of the areas. The output was demonstrated on the spatial planning map, which is easier to understand. The characteristic of soil such as saturated hydraulic conductivity had to be used in the next step for amount of water (leachate) evaluation.

3) Analysis of Data Using Visual HELP Computer Program

In order to assess the impact of landfill sites, the amount of contaminated water or leachate distributed from the landfill area was simulated using the Visual HELP computer program. The program automatically solicits input from the user based on the option selected. In general, the Visual HELP model requires the following data, whether data, soil data, landfill design information (details in Chapter 3). Some of them may be selected from the default values.

4) Mitigation Measures Development

The results of Step 3 would be the information used for developing the mitigation measures to minimize the impacts from the leachate. Addition of the synthetic liner is the approach for mitigation development.

5) Re-evaluation of the uses of Visual HELP Computer Program

From the Step 4, one of the mitigation measures is adding the synthetic liners to reduce the leaked water from landfill. Hence, the new data of the sites were entered in the Visual HELP computer program to find the amount of potential leachate of the new designed sites.

6) Discussions and Conclusions

The results of all steps were discussed and concluded that brought to the expected output of the research.

1.6 Expected Result

The sanitary landfill site which is critically considered on soil and groundwater criteria, is most suitable with minimal impact to environment

Table 1.1 Groundwater monitoring data of Nakorn Khon Kaen Municipality

Station	Colour Unit	Ni Mg./l	Cd Mg./l	T- Cr Mg./l
No.17	75	<0.02	<0.004	<0.02
No.18	750	<0.02	0.009	0.10
No.19	20	<0.02	0.005	<0.02
No.20	250	<0.02	0.20	1.56
No.21	250	<0.02	0.22	3.28

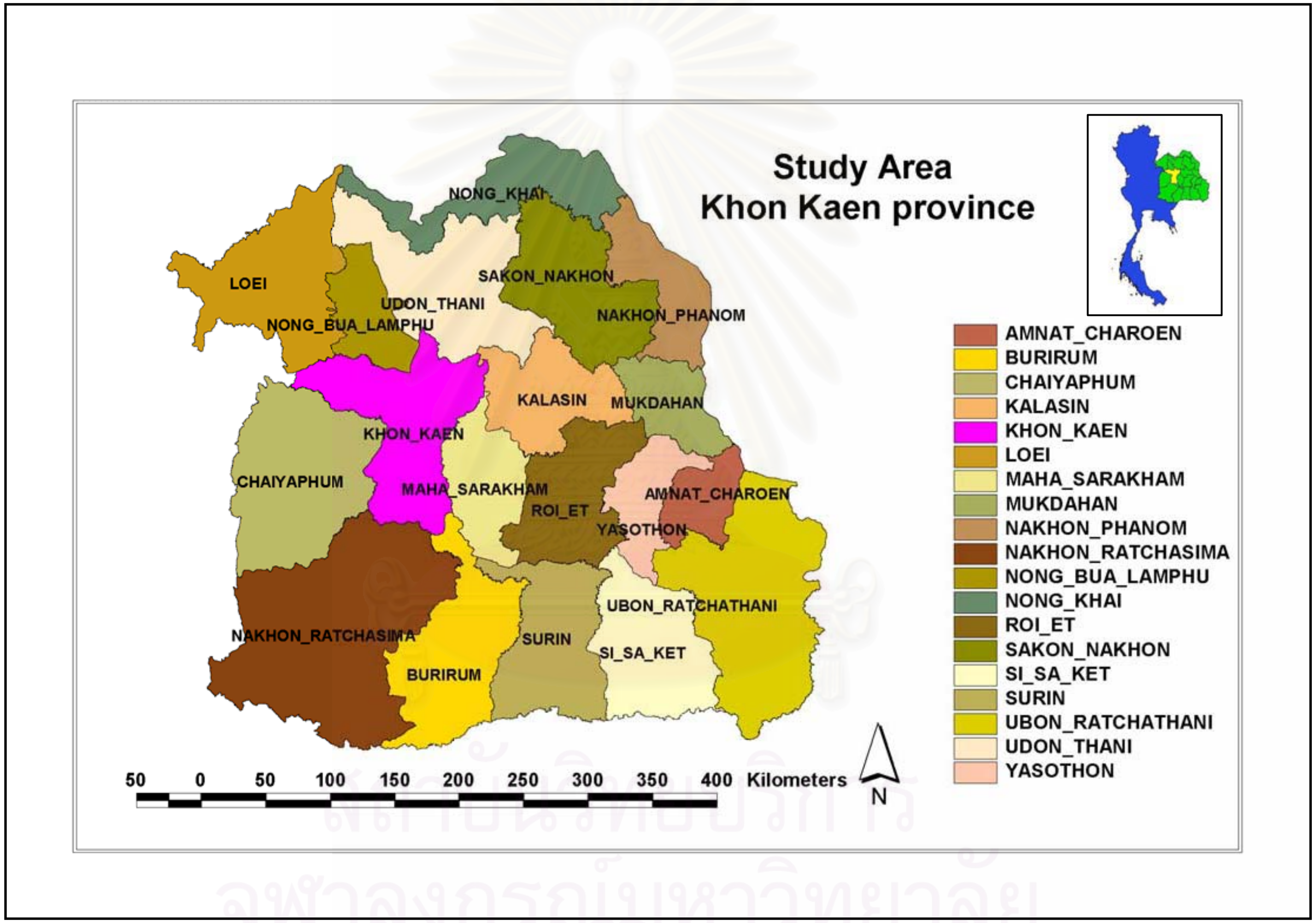


Figure 1.1 Map of study area covering the whole Khon Kaen province.

CHAPTER II

THEORY AND LITERRATURE REVIEW

2.1 Theoretical Background

2.1.1 Municipal Landfill and Siting Criteria

In the account of the amount of wastes has been continually increased, the management of wastes including wastes disposal play an important role on the solution of the environmental problems caused by such wastes. The conventional way to dispose municipal solid waste is landfill or land disposal which has been universally used. According to the USEPA definition, municipal solid waste landfill (MSWLF) unit means a discrete area of land or an excavation that receives household waste, and that is not a land application unit, surface impoundment, injection well, or waste pile (CFR Title 40 Part 257 § 257.2, USEPA). In the same way, sanitary landfill refers to the engineered facility for disposal of municipal solid waste designed and operated to minimize public health and environmental impact (*Tchobanoglous, 1993*). In addition, the Pollution Control Department (PCD) of Thailand defines the meaning of landfill facility in the Regulation and Guideline of Municipal Solid Waste Management is as a solid waste facility which is designed for placement of compacted wastes in a well prepared land area with successive layers of daily and intermediate coverings, provisions of mitigation measure for leachate contamination to groundwater, odor and vector control to the surrounding environment. PCD also compares three different kinds of waste disposal as shown in Table 2.1.

From Table 2.1, a landfill method is possible to cause environmental effects. The factors related to environmental protection would consequently be set for landfill construction. In Thailand, PCD conducts the criteria for landfill siting that landfill should not be constructed in the areas as follows:

a) 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.

b) 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.

Table 2.1 Comparison of three different waste disposal methods (Pollution Control Department, 1993).

Item	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
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

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

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

e) 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.

f) In an area where geological formations or other subsurface features will not provide support for the solid waste.

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

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

i) Unless in stretch of sufficient large area which can be landfilled at least 20 years.

Moreover, the United States Environmental Protection Agency also develops the criteria governed municipal solid waste landfills in 40 CFR Parts 258 as following (*http://www.epa.gov*):

Specific limitations must be met regarding the location of new, existing, or lateral expansions as follows:

a) Within 10,000 ft (3048 m) of any airport runway end used by turbojet aircraft or within 5000 ft (1524 m) of any airport runway end used by only piston- type aircraft [40 CFR 258.10(a) through 258.10(c) and 258.16].

b) In 100 year floodplains [40 CFR 258.11(a) and 258.16]. Wetlands Limitations regarding the location of new MSWLFs and lateral expansions in wetland [40 CFR 258.12(a)(1) through 258.12(a) (3) and 258.16].

c) In fault areas that have had displacement in Holocene time [40 CFR 258.13(a) and 258.16].

d) In seismic impact zones [40 CFR 258.14(a) and 258.16].

e) In unstable areas [40 CFR 258.15(a) and 258.16].

For Germany, regulates the *Technical Guidance of Municipal Solid Waste* to define the requirements for all activities associated with siting, designing, operating, maintaining and closing a landfill. The guidance requires that before siting a landfill, the site-specific geology, hydrogeology, soil, and geotechnical conditions must be taken into account to reduce the possibility of releasing contaminants into the environment. Landfills in Germany have to be located at the distance from the nearest residence at least 300 meters. Moreover, soil below the landfill and the surrounding terrain should act as a geological barrier *(Bilitewski, et al., 1994)* and must meet the following requirement:

a) Be at least several meters thick.
b) Be comprised of low permeability unconsolidated or consolidated material.
c) Have a high potential for attenuating contaminants.
d) If the natural soil liner at the landfill site or the surrounding area is less than 3 meters thick, it have to install clay or synthetic layer ($k_f \leq 1x10^{-7}$ cm/s).
e) The bottom of the landfill should be at least 1 meter above the highest expected water table

Towards the sustainable waste management, *The landfill guideline of New Zealand* given the key issues to minimize the future risk from landfill are shown below.

a) Geology: suitable geology is important to ensure containment of leachate in the long term, or in the case of failure of engineered containment systems. Due the risk of off-site movement of leachate and landfill gas , it is generally undesirable to site a landfill in areas with the following characteristics:
   - high permeability soils, sands, gravels, or substrata
   - high permeability seams or faults; and/or
   - Karst geology-regions with highly soluble rocks sink and caverns.

   An assessment of geology and site soils should consider:
   - the availability of on-site materials for lining, cover and capping. Soils with a high percentage of clay particles (but which are workable in wet conditions) are generally the prefered soil type;
   - the suitability of on-site materials for the construction of dams and drainage systems;

- potential sediment management problems, with highly erodible soils;
- existing site contamination and discharges, if present;
- suitability for on-site disposal of leachate by surface or subsurface irrigation; and
- The potential effects of failure of leachate containment and collection systems.

b) Site stability: Site stability should be considered from both short and long-term perspectives, including the effects of settlement. It is generally undesirable to site a landfill in the following areas:

- areas subject to instability, except where the instability is of a shallow or surface nature that can be overcome, in perpetuity, by engineering works;
- active geological faults; and
- areas of geothermal activity; and/or

c) Hydrogeology : A suitable hydrogeological location is important to protect groundwater resources and understand the likely fate and rate of discharge of contaminants which may enter groundwater.It is generally undesirable to site a landfill in the following areas:

- areas overlying drinking water aquifers; and/or
- areas where, after taking into account specific design proposals, there could be a risk of causing unacceptable deterioration of the groundwater quality in the locality.

In assessing the suitability of a site for a landfill with respect to hydrogeology, the following need to be considered:

- depth to water table and seasonal water table fluctuations;
- location of aquifer recharge areas, seeps or springs;
- distance to water users;
- sensitivity of water users;
- dispersion characteristics of aquifers;
- variations in groundwater levels;

- rate and direction of groundwater flow;
- existence of groundwater divides;
- baseline water quality; and
- the potential effects of failure of leachate containment and collection systems.

d) Surface hydrology: There are risks of surface water pollution if landfills are sited in close proximity to waterways. The potential impact of water pollution is greater in those waterways used for drinking water or aquaculture. It is generally undesirable to site a landfill in the following areas:

- flood plains — these are generally areas which could be affected by a major (1 in 100 year) flood event;
- land that is designated as a water supply catchment or reserves for public water supply;
- gullies with significant water ingress, except where this can be controlled by engineering works without risk to the integrity of the landfill;
- water courses and locations requiring culverts through the site and beneath the landfill (if waterways are unable to be diverted); or
- estuaries, marshes and wetlands. In assessing the suitability of a site for a landfill, the local surface hydrology needs to be considered with respect to the sensitivity of the receiving environment, including the following:
- the proximity of waterbodies or wetlands;
- the risks of pollution of waterbodies used for drinking water or aqua-culture;
- sensitive aquatic ecosystems; and
- potential for impact from cyclones and tsunamis.

e) Topography : Site topography can reduce or increase the potential for adverse effects on the environment from odour, noise, litter, and visual effects on neighbouring properties. In considering potential landfill sites an assessment of the potential for existing topographical features to assist in minimising impacts should be made. Modest slopes enable easier stormwater control, leachate control and site stability measures, as well as facilitating the operation of the site. Engineering techniques can also improve site stability.

f) Climatic conditions: Climatic conditions will have an influence on the choice of a preferred site. The following should be considered during site selection.

- Rainfall: Areas where topographical features are likely to cause higher than average rainfall is generally undesirable. Landfills in higher rainfall areas require greater attention to drainage than those in drier areas.
- Sunshine: Higher sunshine areas and north facing slopes reduce infiltration by increased evaporation
- Wind: Natural shelter from winds will reduce the nuisance of windblown refuse and dust. Escarpments or valleys facing the prevailing wind should normally be avoided.

g) Environmentally Sensitive Areas **:**Landfills should generally be located to avoid areas where sensitive natural ecosystems would be adversely affected, such as:

- significant wetlands;
- inter-tidal areas;
- significant areas of native bush including the Forest Park and areas able to comply with the requirements for QEII Trust status;
- recognized wildlife habitats;
- national/regional and local parks and reserve lands (for example, cemeteries); and

- Any areas where release of contaminants from the site could severely affect fish/wildlife/aquatic resources.
- sites of historical or cultural significance; and
- Historic and scenic reserves.

h) Access and traffic: Landfill development and operations can generate significant flows of heavy vehicle traffic. Therefore site access should be as close as possible to main feeder routes. The following need to be considered when locating and determining access to landfills:

- type and number of vehicles accessing the site;
- other types of traffic using feeder roads;
- the standard and capacity of the road network, with respect to accommodation of traffic generated by the landfill;
- whether the traffic can avoid residential areas;
- Road safety considerations with respect to the landfill entrance (vehicles using the landfill should not be required to queue on the highway).

In Thailand, there is no the particular regulation associated with waste management, except Department of Industrial Work Notification No.1 B.E.2531 who determines waste collection, disposal, and transportation methods. The criteria on site selection that were mandated in this notification are as follows:

- Landfill must line with synthetic or geological liner material which has permeability of $1x10^{-7}$ cm/s; and
- The depth between landfill base and groundwater table must not less than 5 feet.

Reviewed data show that many countries considered and intensively emphasized on groundwater contamination. Therefore, the criteria involve in groundwater and soil characteristics were established. By mean of soil permeability, as the property of a porous media that permits the transmission of water through it (Harl D. Sharma, 2004). Low permeability soil was expected to be geological barrier of landfill to protect groundwater resources from hazardous substances. Thence, soil characteristics of selected areas have to be kept in view.

2.1.2 Leachate and Groundwater Contamination

Though, the municipal landfill is likely economical feasible and broadly used, it could be harmful to people and environment because of the leachate generated from the landfill. The leachate is the major concern for landfill disposal as it would lead to contamination of the groundwater. USEPA enacted the definition of leachate in CFR Title 40 Part 257 § 257.2, as liquid that has pass through or emerged from solid waste and contains soluble, suspended or miscible materials removed from such waste. In the same way, Guidelines for the siting, design and Management of Solid Waste Disposal Sites in the Northern Territory (2003) reported that the surface and groundwater pollutions from leachate is principal concern in relation to landfill location. The data *in Summary of research on mercury emissions from municipal landfills* show that mercury can exceed in groundwater from older and unlined landfills. Washington State Department of Ecology (1996) presented the potential environmental impact to Bellingham bay caused from chromium from leachate is the contaminant from landfill nearby. Detected chromium is consistently exceeded the Model Toxic Control Act (MTCA) cleanup level. J.H.Huddleston also reported that soil characteristics and water table conditions are factors that govern the potential for groundwater pesticides contamination. Additionally, landfill gas as VOCs have a good opportunity to migrate and be absorbed with leachate into the groundwater (Prosser and Janechek, 1995). Figure 2.1 shows the mechanism of landfill gas. Landfill gases can pollute groundwater resource via direct contact, condensate water formation, and infiltration and absorption.

These are the evidences of environmental risk from leachate. In Thailand, the Notification of Department of Industrial Work No.1 B.E. 2531 governed site characteristics of landfill facilities related to the groundwater protection which are the depth to groundwater from landfill base and the permeability of geological barrier.

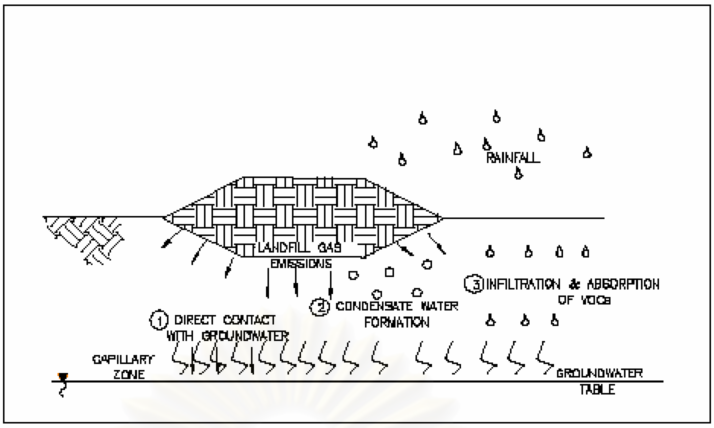


Figure 2.1 Landfill gas contamination mechanism (Prosser and Janechek, 1995)

2.1.3 Geographic Information System

Geographic Information System is the system designed to store, retrieve, manipulate, analyze, and map geographic data. It is a system of computer software, hardware, data, and personnel to help manipulate, analyze and present information that is tied to a spatial location (*http://www.GIS.com*, *2003*). GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modeling, representation and display of geo referenced data to solve complex problems regarding planning and management of resources (NCGIA, 1990). Burrough (1986) define GIS as a powerful set of tools for storing and retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes. GIS has been widely used on environment tasks including siting aspect. Siting process generally requires an evaluation of many factors and criteria to avoid impact to human and environment. As a result a GIS plays the leading role in an environmental management.

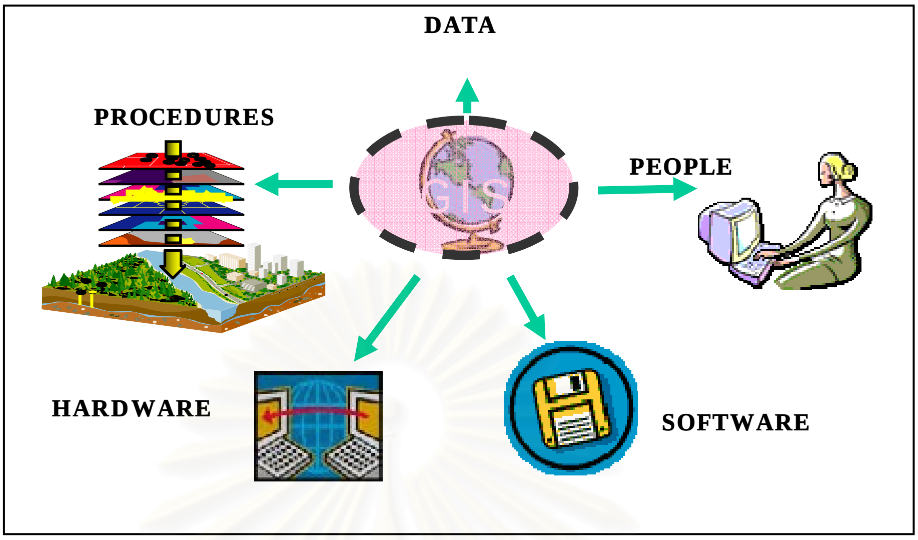


Figure 2.2 Major components of GIS.

2.1.4 Model application and Visual HELP computer program

At the presence, the models were used widely in many disciplines. More complex problems can be solved by the use of various techniques of models. Groundwater model is the one of commonly used model. Groundwater modeling is a useful tool for preliminary studies prior to field investigations, for interpretive studies after the field study and for predictive studies to estimate the potential; groundwater situation. In addition, the groundwater model could be applied to use in environmental management. The **HELP** model (**H**ydrologic **E**valuation of **L**andfill **P**erformance), is a versatile program used to design, evaluate and optimize landfill hydrology, and estimate groundwater recharge rates. The HELP model is used and recognized all over the world as the accepted standard for modeling landfill hydrology, and has become an integral component for projects involving landfill operating and closure permits. The HELP model is a quasi-two-dimensional, multi-layer hydrologic model requiring the following input data for each model profile:

• Weather data (precipitation, solar radiation, temperature, evapotranspiration parameters);

• Soil properties (porosity, field capacity, wilting point, and hydraulic conductivity); and

• Design information (liners, leachate and runoff collection systems, surface slope)

The landfill profile structure can consist of a combination of natural (soil) and artificial materials (waste, geomembranes) with the options to install horizontal drainage layers. The HELP model also accounts for the change in slope for different parts of the landfill profile. HELP uses numerical solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembranes, or composite liners. The HELP model (Schroeder, et al., 1994) predicts an infiltration rate under quasi two-dimensional influences through one or more uniform soil layers. The HELP model (Schroeder, et al., 1994) has been applied by contemporary groundwater practitioners to substantiate values of net recharge from precipitation obtained from historical studies for use in groundwater flow and contaminant transport models.

2.2 Relevant Studies

2.2.1 GIS Applications on Environmental Aspect.

There are many researches involved in GIS application on environmental aspect. For example, Chasheng He (2003) integrates GIS and agricultural non point source pollution model to analyze the effect of land use change on non point source pollution in Dowagiae River watershed. Similarly, M.Razack, O.Banton developed IDRISI GIS environment which is a simple GIS-linked Model for groundwater nitrate transport. Rungreung Lertsiriworakul applies GIS for identifying the recharge and discharge areas of groundwater system in Khon Kaen province. Spatial analysis system had been used in his work to built databases map on geological science.

2.2.2 Siting Discipline with GIS

GIS application is a highly useful tool for selection of the environmental suitability site. Kontos Td, Komills DP, and Halvodkis CR.(2003) present GIS based methodology to identify and rank the candidate MSW landfill sites for the entire island of Lesvos in Greece. They include all areas unsuitable for any waste disposal facility; likewise, Jehng-Jung Kao, Hong –Yue Lin, and Wei-yea Chen (1997) developed a prototype network GIS to improve the effectiveness of a complex MSW landfill siting procedure and assist local environmental protection agency in maintaining a GIS. Similarly, Simone Leao, Ian Bishop, and David Evans presented a method to quantify the relationship between the demand and supply of suitable land for waster disposal overtime using a GIS and modeling techniques. The procedures provide information to guide the design and schedule of programs to reduce and recover wastes, and can potentially lead to a better use of the land resource. In Thailand, Chonticha Disathien (1992) uses GIS to select the potential sites for solid waste disposal of Saraburi province. The suitable area in Suphanburi province has been selected for the residential settlement by using GIS (Puthachad Kittiphongpattana, 2002). In the meantime, Amnuay Sumpatphong (2002) selected waste treatment systems sites in Saraburi province. He use Arc View program for arranging and management data. Also, Surasak Boonlue (1998) uses GIS to select the potential area for the sanitary landfill facility in Mae Sai, Mae Chan, and Chiang Saen district of Chiang Rai province. Kamolporn Kerdput (1999) uses a GIS to select the potential solid waste disposal area in Pathumthani.

2.2.3 Changwat Action Plans of Environmental Management Project (CAPEQM)

The CAPEQM-Project is the support and technical assistance of the Holistic Plan for Khon Kaen Province. The project was executed from 2000 to 2003 by the Ministry of Natural Resources and Environment in cooperation with the Ministry of Interior and with Regional Environment Office 10, Khon Kaen as the Implementing Agency. The project set-up a comprehensive information system providing easy access to data and maps for all partners, and facilitated a planning process that comprised various participatory methods to ensure active involvement of all partners and the public at large.A significant part of this project is focused on establishment of a few central waste disposal sites considering sensitive areas and popular acceptance. The Khon Kaen area was screened for environmental sensitive area and divided into 3 levels as, highest, high, and medium to low sensitive. The criteria for the screening were set as Table 2.2

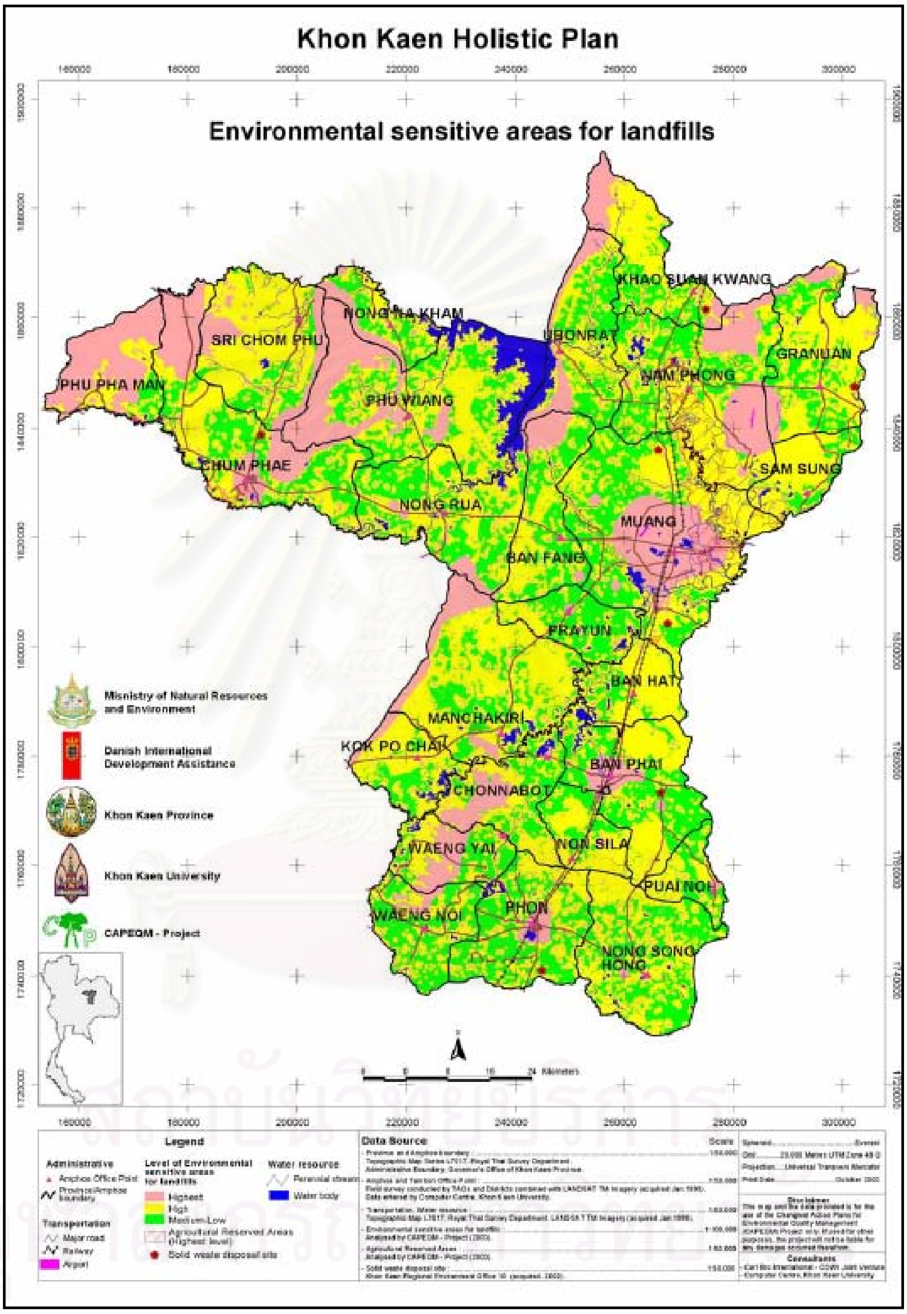


Figure 2.3 Environmental sensitive area for landfill map of CAPEQM-project

Table2.2 The criteria of CAPEQM-project for sensitive area for sanitary landfill

Layers	Layers Factors/Resulting Maps
Administrate Boundaries	Provincial Boundary
	Comprehensive Plan
Forestry	National Parks
	Resources & Land use in Reserved Forest (A,C, E)
	Status of Forest in 1999
Water	Water bodies
	Rivers and Streams
	Watershed Classification
	Location of Waterworks system in the village
	Location of Low-power Pump Station
	Irrigation Area
Soil	Land use
	Area for Land Reform for Agriculture (Sor Por Kor)
Heritage Site	Heritage Sites (registered)
Infrastructure	Airports
	Potential, Protected and Critical Areas for Groundwater
	Flood Prone Areas

CHAPTER III

MATERIALS & METHODOLOGY

3.1 Materials

This research focused an evaluation of the sanitary landfill using Geographic Information System (GIS) and Visual Hydrologic Evaluation of Landfill Performance (HELP) computer program. Numerous materials had been subsequently employed for data analyzing to find the potential landfill area, of which they were as follows.

3.1.1 Maps

The topographic maps of Khon Kaen province from the Royal Thai Survey Department were used for identification of sites position. They were indicated on series L 7017 in scale of 1:50,000. The maps were specified as follows:

- Sheet 5441 I Amphoe Nong Rua
- Sheet 5442 II Amphoe Phu Wiang
- Sheet 5442 III Amphoe Chum Phae
- Sheet 5540 IV Amphoe Phon
- Sheet 5542 III Ban Khok Sung

3.1.2 Computer Hardware and Software/Implemental Accessories

- Personal computer Pentium IV, 2.8 GHz, DDR RAM 512 MB, Hard disk 80GB.
- Hydrologic Evaluation of Landfill Performance (HELP) version 2.2.0.3 (U.S. Army Corps of Engineers, Waterways Experiment Station ,WES)
- ArcView GIS Version 3.1 program (Environmental Systems Research Institute, ESRI)
- Rockwork 2002 program, Arc view 3.1 program
- Digital camera model Canon Digital IXUS500
- Global Position System (GPS) model GARMIN eTrex Legend
- Stationeries

3.2 Methodology

Following the scope of study, the methodology was subsequently performed as follows (Figure 3.1).

3.2.1 Collecting and Reviewing Data

a) Landfill Siting Criteria

The factors of landfill siting data from various sources were reviewed for selecting and setting the criteria for the new potential site. The sources of data were as follows:

- MSW management guideline of Pollution Control Department.
- Laws and regulations of Thailand and the other countries (Table 3.1).

b) GIS Database

This research reviewed the data from the Changwat Action Plan of the Environmental Quality Management Project (CAPEQM-project) of which the areas in Khon Kaen province were formerly analyzed for sanitary landfill sites by using GIS techniques. The databases for inputting onto the GIS are tablet 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, the databases were aiding to present the areas that are sensitive to landfill site construction in form of spatial planning map.

c) Lithologic Log Data

Lithologic log data from the Department Groundwater Resource, Groundwater Research Center, and the private companies were reviewed to create the soil profiles of the areas. The data would identify soil characteristics of selected areas by means of soil type. Creating soil profile was performed by RockWork 2002 program.

d) Weather Data

The weather data of Khon Kaen province including temperature and precipitation were gathered from the Thai Meteorological Department. The data was taken for the period of 23 years (between 1981 and 2004). These data were used in Visual HELP for leachate simulation.

3.2.2 Establishing GIS and Mapping

The databases were analyzed by ArcView 3.1 program. They were reformed and demonstrated as the applied maps, which are easy to comprehend. This step was divided into 3 processes.

a) Compile the Criteria Databases

The collected criteria databases were complied to screen for environmental sensitive areas map.

b) Editing Groundwater Data and Create Contour

Groundwater level data was edited, and then groundwater contour layer was subsequently created from the edited groundwater level data.

c) Adding Groundwater Contour and Create New Map

After editing the groundwater data, a groundwater level criterion was added onto the criteria data of the CAPEQM-project by GIS technique. The improved sanitary landfill site was created as a new map.

3.2.3 Investigating Soil Profiles and Conducting Field Survey

The medium to low environmental sensitive areas for sanitary landfill were selected to create a soil profile of which it was from the lithologic log data. RockWork 2002 program was managed, analyzed, and visualized for the geological data, result the soil type in the area profile. Site survey was also conducted to characterize the areas, such as land use, etc. The results from this step were used for site assessment.

3.2.4 Assessing the Areas Using Visual HELP Computer Program

The Visual HELP computer program was employed to calculate the amount of water or leachate distributed from the selected areas. This step included following tasks.

a) Simulating Leachates by Visual HELP Computer Program

The Visual HELP computer program was employed to calculate the amount of water or leachate distributed from the landfill. The program automatically solicits input from the user based on the option selected. In general, the Visual HELP model requires the following data:

1) **Weather Data**, the data was taken from Thai Meteorological station as mentioned above
2) **Soil Data Requirement**, soil data drawn from the first step was entered using the default soil/material textures option. If the user selects a default soil texture, the program would display the porosity, field capacity, wilting point, and hydraulic conductivity values of the soil that is stored as default. If the soil textures of the selected sites do not match with the default soil, the properties of soil have to be entered manually.
3) **Landfill Design Information,** the following information were entered: project title, landfill area *(Customary or Metric)*, percentage of landfill area where runoff is possible, and method of initialization of moisture storage.

Layer data The following layer data were entered: the layer type (four types of layer are permitted: 1. vertical percolation, 2. lateral drainage, 3. barrier soil liner and 4. geo-membrane liner), layer thickness *(Customary or Metric)*, soil texture, initial volumetric soil water content (storage), in vol./vol. (optional, it is only needed when the initial moisture storage is user-specified), and rate of subsurface inflow to the layer *(Customary or Metric)*.

Lateral drainage layer design data. The lateral drainage layer design data as the maximum drainage length *(Customary or Metric)*, drain slope percent, percentage of leachate collected from the drainage layer that was recirculated, and the layer that receive recirculated leachate from the drainage layer was entered.

Geo-membrane liner data. This research used the condition of soil liner only. Therefore, geo-membrane liner data would not be entered.

Runoff curve number information. Surface slope, slope length, default soil texture, and the quantity of the vegetative cover were input and the program would compute the runoff curve number.

After complete inputting the data, the program would compute the amount of runoff, drainage, and leachate for each site.

b) Result Analysis and Ranking

To assess the sites by using the amount of distributed water, the site that has the least amount of leachate would be the most suitable sanitary landfill site. The sites would be ranked based on the amount of water distribution.

3.2.5 Mitigation Measures Development

The mitigation was developed to minimize the impact from the leachate based on adding the synthetic liners. The results obtained above would be the information used for develop the mitigation measures.

3.2.6 Re-evaluating the uses of Visual HELP Computer Program

This step would prove whether the mitigation is effective or not. The results showed the water quantity of the modified sites. The Visual HELP model does not permit two barrier soil liners to be adjacent to each other. If a design has two soil layers adjacent to each other, they would be expected to act as a single liner and both soils would remain nearly saturated and contribute significantly to the head loss and restriction of vertical drainage. Then, the thickness of the two layers should be summed and an effective saturated hydraulic conductivity would compute for the combined liner. The result would show the amount of water of the sites in the new design by adding the synthetic liner. Then, the sites would be assessed on environmental terms. This step proved whether the mitigation was effective or not.

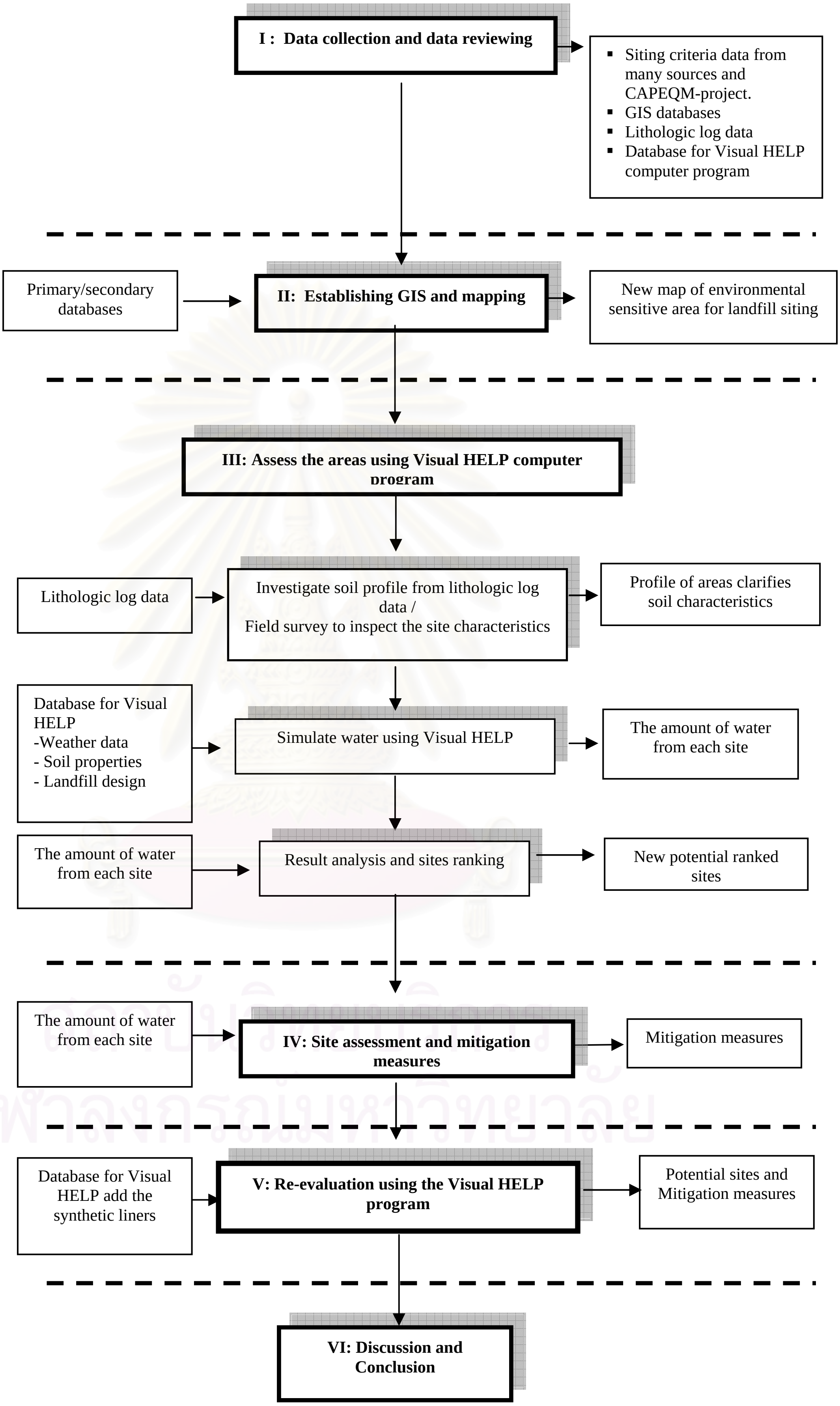


Figure3.1 Research methodology applied in this study

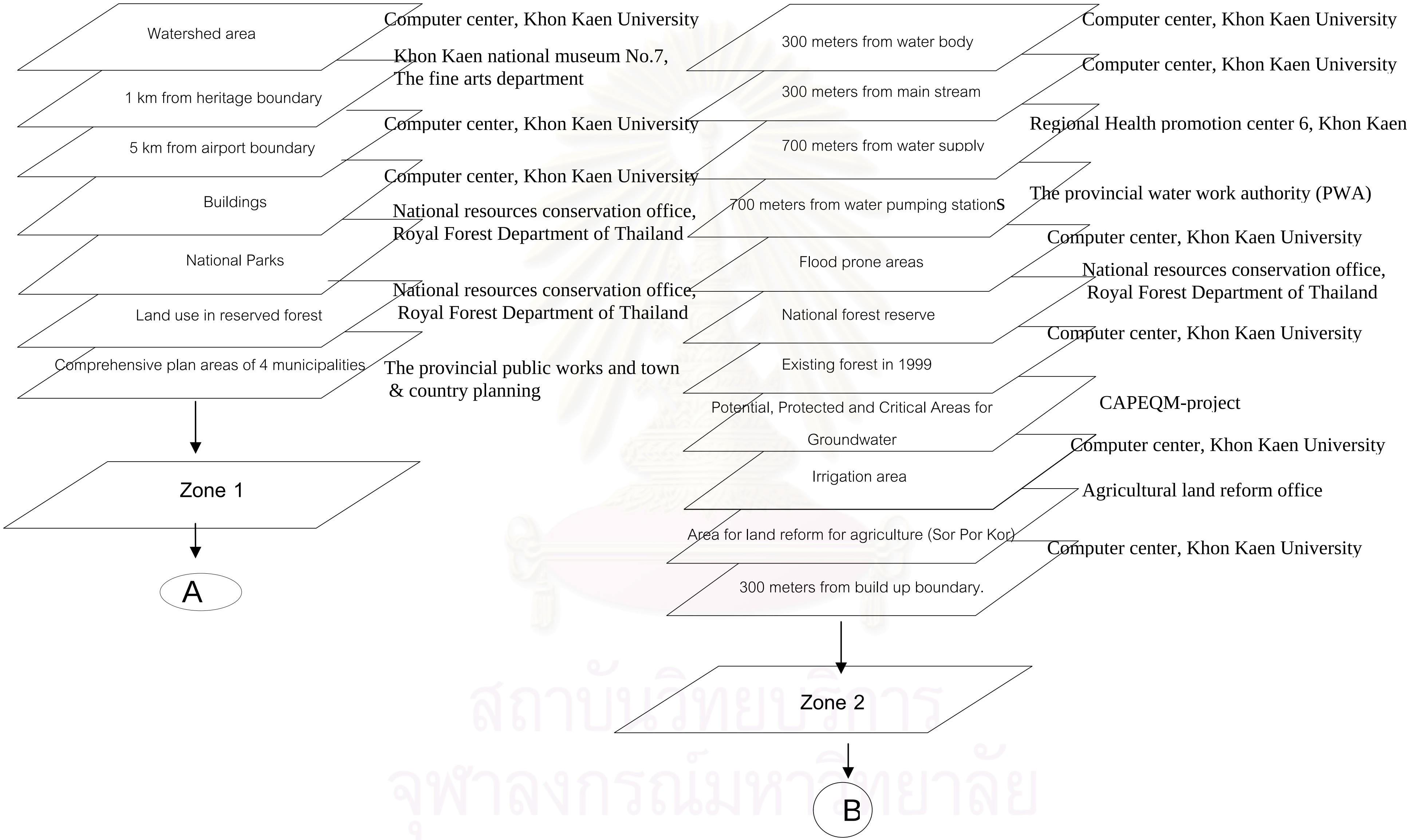
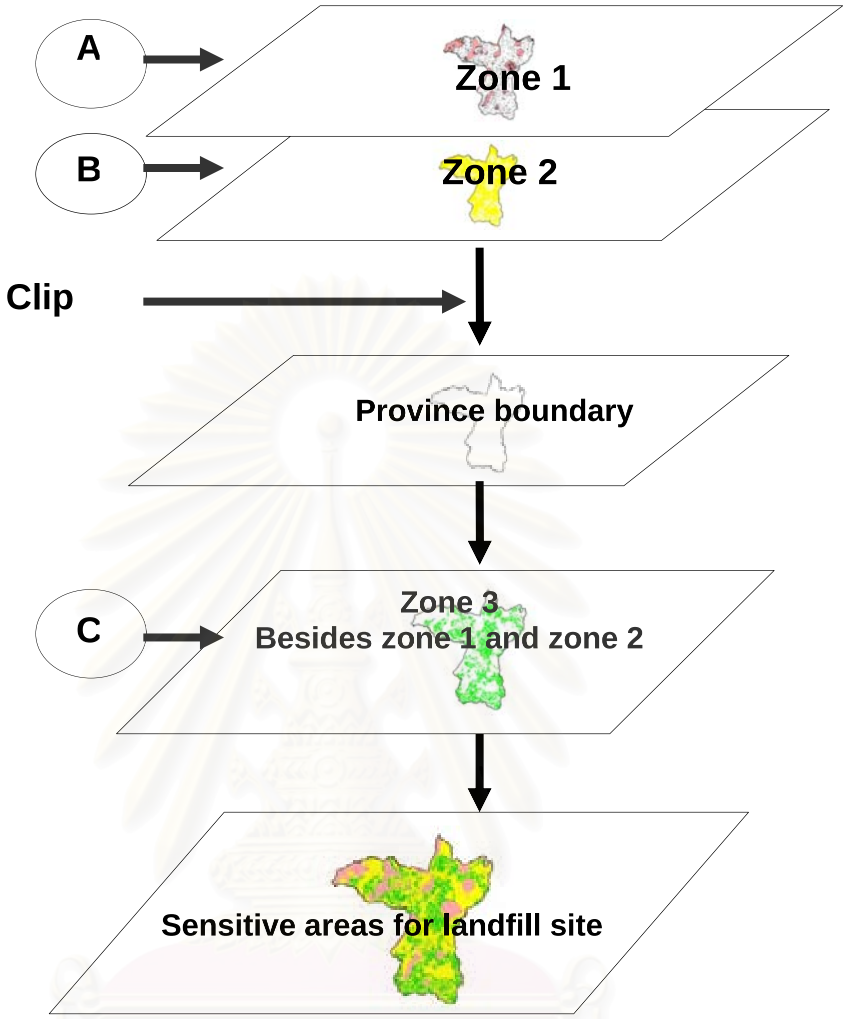


Figure 3.2 GIS technique on screening the environmental sensitive areas for landfill site.



A = highest sensitive area for landfill

B = high sensitive area

C = medium-low sensitivity area

Figure 3.2 (*cont.*) GIS technique on screening the environmental sensitive areas for landfill site**.**

Table3.1 Landfill facility siting criteria

criteria	Tasmania landfill sustainability guide (landfill type B)	The Landfill (Scotland) regulation 2003	USA (CFR title 40 258)	Landfill criteria for municipal solid waste, Ministry of water, land, and air protection, British Columbia,CN	Environmental guideline, solid waste landfills, New SouthWales	Landfill (Eng&Wales) regulations 2002	Regulation and guideline of municipal solid waste management, PCD	Surasak Boonlue ,1998	Design of landfills and integrated solid waste management,Bagchi;2004	Notification of DIW No.1 BE.2531	Kamolporn Kerdput,1999
Distance from major highway	-	-	-	-	-	-	-	-	within 300 m.	-	-
Distance from community	500 m. from residence	250 m. from residence	-	- Set the buffer zone 50 m. from property boundary, residence. - other facilities minimum 300 m.	-	-	-	1000 m.	-	-	5 km. from communities
Fault zones	-	-	not be located within 200'(60m) from fault zones	-	-	-	-	-	within 60 m.	-	-
Karst condition	must not be able to located on	must not be able to located on	must not be able to located on	-	-	-	-	-	-	-	-
Distance to water/water sources	100 m. from permanent water courses	- 3 km from the top water resources -exclude within water courses or 40 m. permanent or intermittent watercourse	-	100 m. minimum	- within3 km. of the top level of water resource - 40 m. from watercourse	-	within 300 m. of water body	-	- Within 300 m. of any navigable lake and pond. - Within 90 m. of river or stream	-	within 300 m. of water body

Table3.1(*cont.*) Landfill facility siting criteria

criteria	Tasmania landfill sustainability guide (landfill type B)	The Landfill (Scotland) regulation 2003	USA (CFR title 40 258)	Landfill criteria for municipal solid waste, Ministry of water, land, and air protection, British Columbia,CN	Environmental guideline, solid waste landfills, New SouthWales	Landfill (Eng&Wales) regulations2002	Regulation and guideline of municipal solid waste management, PCD	Surasak Boonlue, 1998	Design of landfills and integrated solid waste manageme nt,Bagchi;2 004	Notificati on of DIW No.1 BE.2531	Kamolporn Kerdput,1999
Distance to water supply well	-	-	-	-	-	-	within 700 m. from well	-	within 365 m.	-	within 700 m. from well
Depth to water table	5m.at seasonal peak	-	-	1.2 m.	-	-	no less 1 m.	10 m.	-	≥ 5' (1.524 m)	at least 1 m.
Floodplains	-	-	-	Within 200 year floodplain must design to prevent washout.	must not be able to located on	-	must not be able to located on	-	must not be able to located on	must not be able to located on	-
Restrict areas	-	1:100years flood plain area	must not be able to located on	-	-	-	-	-	-	-	-
Geo barrier	- $K<1.0x10^{-9}$ m/s -Thickness of geo barrier >1m.	- $K<1.0x10^{-9}$ m/s -Thickness of geo barrier >1m.	-	- K= 1x10-6 cm/s or less Thickness of geo barrier ≥2m.	-	K≤1x10-9 m/s ; thickness ≥1 m.	K≤1x10-5 cm/s; ≥thickness 3 m.	-	not less than 1.5 m. in thickness; K≤1x10-7 cm/s	K ≤ 1x10-7 cm/s	K ≤ 1x10-7 cm/s
Archeological areas	-	must not be able to located on	-	-	-	-	within 1 km	-	-	-	must not be able to located on
national park	-	250 m. from the areas	-	-	-	-	-	-	-	-	-

Table3.1 (*cont.*)Landfill facility siting criteria

criteria	Tasmania landfill sustainability guide (landfill type B)	Scotlands regulation 2003	USA (CFR title 40 258)	Landfill criteria for municipal solid waste, Ministry of water, land, and air protection, British Columbia,CN	Environmental guideline, solid waste landfills, New SouthWales	Landfill (Eng&Wales) regulations2002	Regulation and guideline of municipal solid waste management, PCD	Surasak Boonlue, 1998	Design of landfills and integrated solid waste management,Bagchi; 2004	Notification of DIW No.1 BE.2531	Kamolporn Kerdput,1999
high environmental value areas	-	avoid 250 m. from the areas	-	must not be able to located on	within 250 m	-	Watershed areas class I and II	within 2000 m.	must not be able to located on	-	-
wilderness areas	-	avoid 250 m. from the areas	-	-	-	-	-	-	-	-	-
Airport	10000m from airground	-	within 10000'(3048 m.) of any airport runway(turbojet aircraft	minimum 8 km.	-	-	5 km. from airport	-	within 3048 m.	-	5 km. from airport
Wetlands	-	-	must not be able to located on	-	-	-	-	-	-	-	-
tertiary fault line	within 1 km.	-	-	-	-	-	-	-	-	-	-
gullies/deep valley	must not be able to located on	-	-	-	-	-	-	-	-	-	-
unstable area	-	-	-	must not be able to located on	-	-	-	-	must not be able to located on	-	-

CHAPTER IV

RESULTS AND DISCUSSION

4.1 GIS Database for MSW Landfill Siting

From the data reviewing, various criteria were considered to find out the suitable area for landfill site. GIS has been taken place as a valuable tool for database manipulating. The criteria for area classification were categorized as 3 levels including the highest, high, and medium to low sensitive areas.

4.1.1 The Highest Environmental Sensitive Areas for Landfill

The highest environmental sensitive area for landfill was set by the approach of the CAPEQM-project processes of which the criteria were drawn from the Pollution Control Department regulation and CAPEQM-project recommendation as described below. In accordance with the specific characteristics, this area could not be used for the sanitary landfill sites including areas of 1,363,451 rais or about 2,181 square kilometers (20.5 % of the whole province area).

a) Watershed Area

According to the Cabinet Resolution on May 28, B.E. 2528, watershed Class 1 should be particularly preserved because the area, when changed, leads to the tremendous effects on the environment. Watershed areas Class 1 is divided into two sub-watersheds, Class 1A is the watershed consisting of abundant forests and Class 1B is the watershed of which its forests has been deteriorated or changed for development or other land use patterns. In order to protect the watershed Class 1A, changing forest in this watershed by any means is restricted. On the other hand, the activities conducted in the watershed Class 1B, for example road construction or mining, the responsible organizations have to implement for soil erosion protection. In case that land use done by any governmental organizations, the organizations are subject to report the analysis of its environmental impact to the National Environmental Committee to be considered. Watershed Class 2 can be used for some certain activities such as mining. The area is allowed to be used in timber industry and mining under restrictive control. Agricultural activities should also be avoided. The watershed area is the most important ecological resource, particularly for the water.

Table 4.1 Criteria for area classification

Environmental sensitive areas	**Total area (km^2)**	**Criteria**
Highest environmental sensitive areas 2,181.5 km^2	411.49	a) Watershed area
	51.06	b) 1 km. from heritage boundary
	231.88	c) 5 km. from airport boundary
	338.51	d) Build-up areas
	887.79	e) National parks
	1,271.05	f) National reserved forest zone C
	336.66	g) Comprehensive plan of four municipalities
High environmental sensitive areas 5,576.5 km^2	3,863.2	a) 300 m. from water bodies and main stream
	505.7	b) 700 m. from water supply and water pumping stations
	278.44	c) Flood prone areas
	1,735.14	d) National reserved forest zone A and E and existing forest 1999
	1,233.39	e) Potential, protected and critical areas for groundwater
	420.55	f) Irrigation areas
	1,420.86	g) Area for land reform for agriculture (Sor Por Kor)
	1,489.33	h) 300 m. from build up area
Medium to low environmental sensitive areas 2,869.78 km^2		

sources, which directly effect to human life. As a consequence, the activities having environmental risk such as landfill facilities must be restricted in the areas. In Khon Kaen province, there is a watershed area Class 1A of 257,182.04 rais or 411.5 square kilometers, watershed class 2A areas of 157,836.255 rais or 252.5 square kilometers, and watershed class 2B areas of 12,007.42 rais or 19.2 square kilometers.

b) Distance of 1 km. from Heritage Boundary

Currently, Thailand's has encountered the problem of cultural environment damage. The major cause would be from human interference which conducts the development without consideration for the environment. Heritage considered as one of the environmental culture component has not been valued and unaware of its importance. For some occasions, degradation would be caused by lack of proper conservation knowledge. Development or construction of the activities can cause problems on heritages in terms of vibration to structure and/or aesthetic (visual) pollution. The heritage sites in Khon Kaen province were identified by the Fine Arts Department are as follow.

- Ku Bann Non Ku
- Pra Yeun
- Non Tan
- Ku Kaew
- Ku Pra Pa Chai
- Pra Sat Peuy Noi
- Pra Tat Kham Kaen
- Tat Don Ku
- Kut Tat
- Wat Po Tat
- Ban Chum pae
- Hor Tri Mai Wat Sri Chom Cheun
- Ku Bann Maey
- Pra Putta Bat Hin Lad
- Sim Wat Beung Kaew
- Sim Wat Ban Lan
- Wat Sawang Suttha Ram

The heritage sites including 1 kilometers buffer area cover area about 51.06 square kilometers.

c) Distance of 5 km. from Airport Boundary

Landfill must be located far from the airport boundary. The distance of 5 km. buffer has been set up to avoid disturbance from birds inhabited on the landfill sites. There are two airports in Khon Kaen located in Amphoe (District) Nam Phong and Amphoe Muang. The airport sites including 5 km. buffer zone cover the area of about 231.88 square kilometers.

d) Build-Up Areas

According to the impacts from landfill such as leachate containing hazardous substances, flies and odor, the landfill facilities must not be located in the communities and built up areas. Otherwise, it would be harmful or risky to the people who live nearby landfill sites. The locations of urban areas, villages, institutes, industrial areas, buildings and build up areas in Khon Kaen were considered as the sensitive areas where have to be protected. The build up area cover area about 338.51 square kilometers.

e) National Parks

National Park is an area occupied with natural resources of ecological importance or uniqueness such as beautiful scenery, waterfall, caves, and mountains, or biodiversity of flora and fauna. National Park, in the sense of protected areas, play significant roles in maintaining ecological stability and preserving biological diversity. These protected areas also are invaluable places for recreation and education. The national parks in Khon Kaen province cover area of about 887.79 square kilometers.

f) National Reserved Forest (Zone C)

The national reserved forest was also identified as the significant area for natural resources protection. National Reserved Forests Act, B.E. 2507 enact National Reserved Forests as the forest must be reserved for its nature, timber, forest products or other natural resources, and no person shall occupy, possess, exploit and inhabit the land, develop, clear, burn the forest, collect the forest products nor cause by any other means whatsoever any damage to the nature of the national reserved forests. The national reserved forest zone C covers area of about 1,271.05 square kilometers.

g) Comprehensive Plan of Four Municipalities

For the municipalities and comprehensive plan boundary of 4 municipalities as Ban Phai, Chum Pae, Muang Khon Kaen, and Muang Phon, were set for land use identification. In accordance with the City Planning Act B.E. 2518, the comprehensive plan means the goals, objectives, and policies, plan, and general guidance for land use development. The municipalities cover area of about 336.66 square kilometers.

4.1.2 High Environmental Sensitive Areas for Landfill

The high environmental sensitive area for landfill was set by means of the CAPEQM-project processes. This area includes the areas of 3,485,309 rais or about 5,576 square kilometers (52.5 % of the whole area). The criteria applied for setting the high environmental sensitive areas for landfill were taken from the Pollution Control Department regulation with some criteria supplemented by the CAPEQM-project.

a) Distance of 300 meters from Water Body and Main Stream

The distance of 300 meters was created as buffer of any natural or man-made water body including wetland. As of the important of surface water, this factor must be set for surface water protection. In addition, the adverse impact might be occurred by contamination from leachate distributed to the water body under the effluence of topography and groundwater movement. The water body and main stream area including 300 meters buffer area cover area of about 3863.2 square kilometers.

b) Distance of 700 meters from Water Supply and Water Pumping Station

Water supply well of the community is the significant factor that should be concerned because people consume water from this source directly. Water is not only used for consumption, but also used for agricultural activites. The buffer distance of 700 meters of the existing potable water well or existing community water pumping stations was set for reducing the contamination possibility. The water supply well and water pumping stations including 700 meters buffer area cover area of about 505.70 square kilometers.

c) Flood Prone Areas

According to the USEPA definitions, flood prone area is the lowland and relatively flat areas adjoining inland and coastal waters, including flood prone areas of offshore islands, which are inundated by the base flood. The landfill must not be situated onto the flooding area or the lowland area where is the storage of the high volume of water. Flooding also poses the hazard substances from landfill to human health and environment. The flood prone area covers about 278.44 square kilometers.

d) National Reserved Forest (Zone A and E) and Existing Forest 1999

The forest is the ecological source of flora and fauna diversity. It also plays the major role as for the origin of water sources for people usage. The degradation of forest has induced the severe problems for environmental and human health. Hence, the activities leading to the forest deterioration must not be created. The reserved forest zone A and E cover area about 1,735.14 square kilometers.

e) Potential, Protected and Critical Areas for Groundwater

In account to the groundwater problems in Khon Kaen areas due to salt rock deposits cause saline groundwater, over-pumping in critical areas, and lack of protection and management of potential groundwater resources for future use, groundwater resource must be protected from the hazard activities. The potential, protected and critical areas for groundwater include about 1,233.39 square kilometers.

f) Irrigation Areas

According to the State Irrigation Act (No. 4) B.E. 2518, "Irrigation" means any undertaking carried out by the Royal Irrigation Department to procure water or to retain, store, reserve, control, supply, drain or allocate water for agriculture, energy, public utilities or industry and includes the prevention of damage caused by water as well as navigation within the Irrigation area. The irrigation areas in Khon Kaen province include a large scale irrigation project which is Nampong-Nong Wai project. There are 15 medium scale irrigation projects and 369 small scale irrigation projects. The over all projects contain the areas of 420.55 square kilometers which benefit from the projects. In order to, people gain the benefit from the irrigation projects completely, the other activities that are not involved in the irrigation should not establish.

g) Area for Land Reform for Agriculture (Sor Por Kor)

The Sor Por Kor area is the land reformed for agriculture. It has been provided to the farmers for farming and dwelling by the government agency. Thus, the areas located in Sor Por Kor areas have been reserved for agricultural sector. The Sor Por Kor area covers about 1,420.86 square kilometers.

h) Distance of 3oo meters from Build Up Areas Boundary

People who live in the communities nearby landfill sites could possibly be harmed and high potential risk to human health. Buildup areas were set 300 meters as the buffer distance from urban, villages, institutes, industrial area, buildings and build up areas in Khon Kaen. This criteria would reduce the risk occurred from the landfill sites. The build up area including 300 meters buffer area cover area about 1,489.33 square kilometers.

4.1.3 Medium-low Environmental Sensitive Area for Landfill

The medium-low environmental sensitive sites for sanitary landfill are the areas besides 4.1.1 and 4.1.2. These sites occupy the areas of 1,793,610 rais or about 2,870 square kilometers (27% of the whole area).

GIS application plays the important role to help people on siting discipline. In this study, the large databases of Khon Kaen province were used for landfill siting. GIS technique was applied to makes them faster and easier to access and accomplish.

4.2 Groundwater Level Contour

As the leachate containing hazardous substances would impact to groundwater resource, this vulnerable resource must be intensively considered for the waste disposal siting. Contamination of hazardous substances into groundwater would potentially be harmful to the environment and human heath, especially to the people who use groundwater as the major water source. Referring to the criteria for landfill siting mentioned in chapter 2, groundwater resource is conventionally considered as one of the significant criteria. However, it is not considered for the groundwater level. This step had accounted for the groundwater level and create groundwater contour map.

The groundwater contour was divided into 3 levels by mean of the depth of groundwater table from the ground surface. The depth of groundwater is the critical factor for groundwater contamination with leachate. Evidently, more shallow groundwater depth, the higher risk to contamination. The hazardous substances leaking from the liner of landfill site rapidly seep through the groundwater. Distance between the landfill base and groundwater table have to be assessed for minimizing the risk to groundwater contamination. In this study, the depth of groundwater in Khon Kaen province were divided into 3 levels, 0-5 m, >5-10 m, and >10 m, respectively.

4.2.1 Groundwater Contour at the Depth 0-5 meter

The areas having groundwater level at the depth of 0-5 meters were defined as the highest sensitive areas for landfill siting. Regarding the design of new and existing landfill sites, an excavated cell/trench method has been widely employed. Conventionally, in Khon kaen province, landfill construction excavates into the ground not deeper than 4 meters from the ground surface. In accordance with the Notification of Department of Industrial Work No.1 B.E. 2531, landfill base must be far from water table about 1.5 meters. With such reasons and uncomplicated to organize, the areas having the groundwater level at the depth of 0-5 meters were considered as the highest environmental sensitive areas for landfill, where cover the area of 4,579 square kilometers.

4.2.2 Groundwater Contour at the Depth >5-10 meter

The areas having the groundwater level at the depth of more than 5 to 10 meters were defined as the high sensitive areas for landfill site. From the groundwater database of Khon Kaen, the greater part situate on area at the range of 5-10 meters. Moreover, according to the greater part of boring log data, the depth to the impervious rock is not more than 10 meters. In such that, the areas having the groundwater level at the depth of 5-10 meters were assessed as the high environmental sensitive areas for landfill, where cover the area of 5,806 square kilometers.

4.2.3. Groundwater Contour at the Depth Exceeding 10 meters

The areas having the groundwater level at the depth exceeding 10 meters were defined as the medium-low sensitive areas for landfill site. From the groundwater database of Khon Kaen , a minority part situate on the area with the depth exceeding

10 meters. Thus, the areas having the groundwater level at the depth exceeding 10 meters were assessed as the medium-low environmental sensitive areas for landfill, where cover the area of 243 square kilometers. This circumstance mitigates the possibility to contaminate of hazardous substances on groundwater resource.

In addition, as the fluctuation of groundwater level, this study varied the range of groundwater level criteria between 1-2 meters and find out the sensitive area. The levels also were separated onto 3 levels. Table 4.2 shows the various groundwater level representing the groundwater fluctuation were used in this study.

Table 4.2 Various groundwater levels represented groundwater fluctuation.

GW depth Level / Various	Highest environmental sensitive (km^2)	High environmental sensitive (km^2)	Medium – low environmental sensitive (km^2)
1	0-4 m	>4-9 m	>9 m
2	0-6 m	>6-11 m	>11 m

Results from GIS (Appendix A) revealed that the 3 levels of new environmental sensitive areas with various groundwater ranges were not significantly difference. The medium to low environmental sensitive area were decreased as shown on Tables 4.3 and 4.4.

Table 4.3 Environmental sensitive areas for landfill with groundwater level in range of 0-4m, >4-9 m, and > 9 m.

Highest environmental sensitive (km^2) 0-4 m	High environmental sensitive (km^2) >4-9 m	Medium – low environmental sensitive (km^2) >9 m
5,364	4,506	704

Table 4.4 Environmental sensitive areas for landfill with groundwater level in range of 0-6m, >6-11 m, and > 11 m.

Highest environmental sensitive (km^2) 0-6 m	**High environmental sensitive (km^2) >6-11 m**	**Medium – low environmental sensitive (km^2) >11 m**
6,789	3,354	488

Manipulation with GIS showed that the variation of groundwater level range has no significantly effect to categorization of environmental sensitive areas. As shown in Tables 4.3 and 4.4, 3 levels of environmental sensitive areas for landfill which are not critically different.

4.3 New Environmental Sensitive Areas Map

As the scope of this study, the groundwater contour maps would be added onto the environmental sensitive area maps, the new environmental sensitive areas maps were resulted as following outputs.

4.3.1 The Highest Environmental Sensitive Areas for Landfill

The areas could not be the sanitary landfill sites including the areas that have the groundwater level at the depth of 0-5 meters were defined as new highest sensitive areas for landfill siting. The new highest sensitive areas cover area of about 5,249 square kilometers (49.39 % of the whole area).

4.3.2 High Environmental Sensitive Areas for Landfill

The areas that have the groundwater level deeper than 5 to 10 meters were defined as the new high sensitive areas for landfill siting. To take advantage of this area for landfill siting, the stringent measures must be mandated. The map shows high sensitive areas which were decreased to 3,975 square kilometers (37.40 % of the whole area).

4.3.3 Medium-low Environmental Sensitive Areas for Landfill

The areas existed with the groundwater level deeper below10 meters were defined as the medium to low sensitive areas for landfill site. To use this area for landfill site, the conventional measures should be implemented. The map shows the medium to low environmental sensitive areas decreased to 572 square kilometers (5.38 % of the whole area). The medium to low environmental sensitive areas were selected based on the size of areas. According to the guideline of PCD, the suitable size for 500 tons of waste generated per day is 0.99 square kilometers (620 rai) for disposal facilities. Comparison of the sensitive areas between with and without groundwater contour is summarized in Table 4.5.

Table 4.5 Comparison between the areas without and with groundwater contour maps.

Sensitively levels / Areas	Highest environmental sensitive (km^2)	High environmental sensitive (km^2)	Medium – low environmental sensitive (km^2)
Without groundwater contour	2,181.5	5,576.5	2,869.78
With groundwater contour	6,081	3,975	572

In accordance with the importance of groundwater resources, landfill siting should emphasize that the groundwater table must be far from the landfill base. Figures 4.1- 4.2 show the difference between old and new maps. As a result of groundwater contour adding, the area was screened by using groundwater levels. The highest environment sensitive area was increased to 6,081 square kilometers. While, the high environment sensitive area was decreased to 3,975 square kilometers, and the medium to low sensitive area was decreased to 572 square kilometers.

Afterwards, the existed landfill sites were compared with new environmental sensitive areas (Appendix A). The existing landfill sites mostly locating on new highest and high environmental sensitive areas. Therefore, there is highly possible to encounter problems from the leachate.

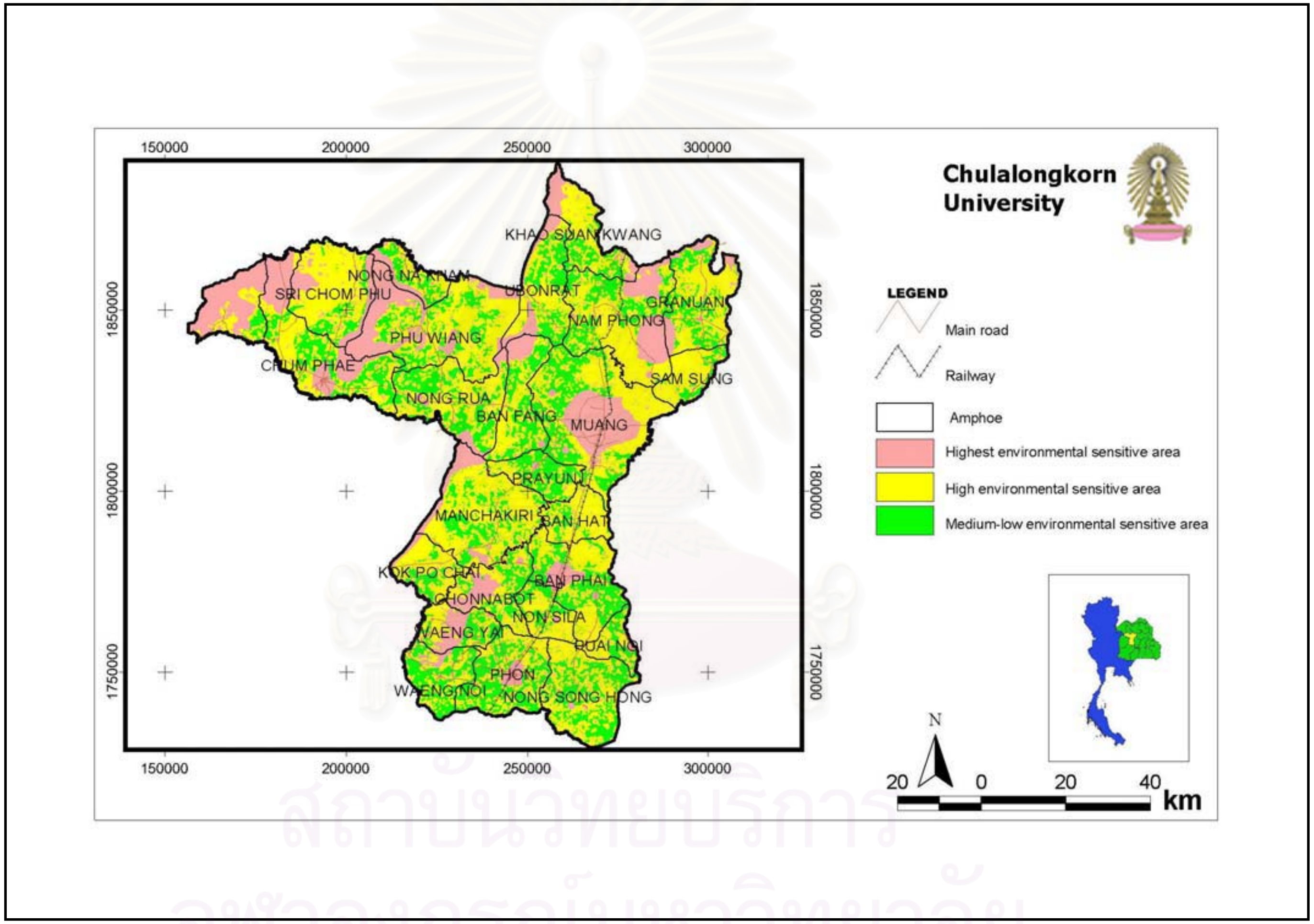


Figure 4.1 Map of environmental sensitive areas without groundwater contour factor.

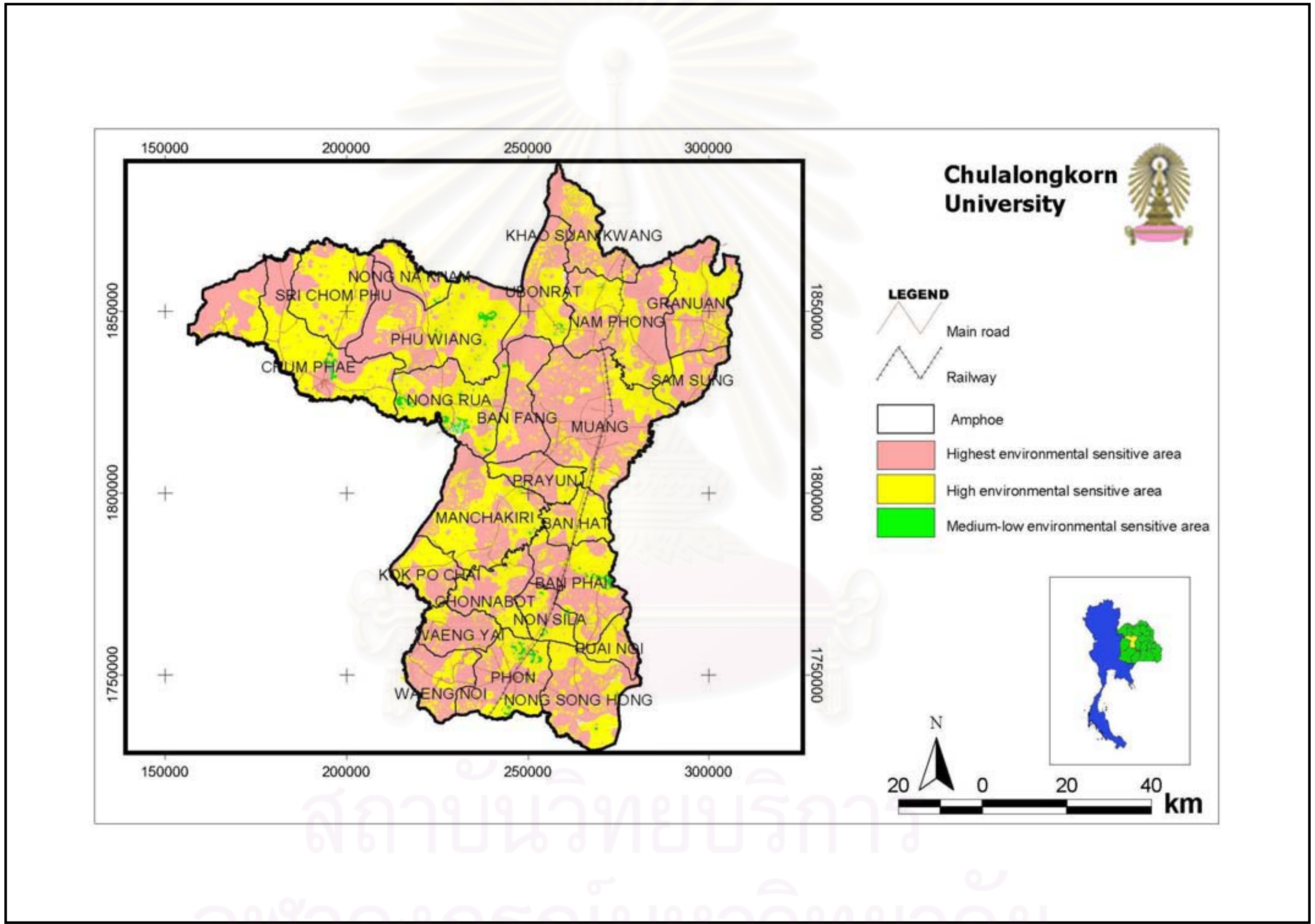


Figure 4.2 Map of environmental sensitive areas with groundwater contour factor.

4.4 Sites Characteristics

In order to study the impact of soil characteristics of the landfill site to the ground water based on the leachate distribution, the landfill sites located in the low-medium sensitive areas map were selected and investigated by field survey and collecting a secondary data. The physical characteristics of each site were drawn up to use for landfill site consideration. Furthermore, the soil profiles of each site were created from the boring log data (Figure 4.3) presenting as the subsurface characteristics of the selected areas. The cross sections were traversed for such areas. These characteristics accommodate the invaluable data for the assessment.

4.4.1 Site 1

a) Land use and Topology

Site 1 locates in Amphoe (District) Chum Phae, Tambon Nong Phai and Tambon Wang Hin Lat, Khon Kaen province. This site has a total area of about 9.99 square kilometers situated along the Highway No.228 and nearby Ban Nong Pai Nue in the north. The site is adjacent to the paddy field and highland Phu Wiang in the east, to the built up area of Amphoe Chum Phae in the south, and to the plantation area and the residence area in the west. The villages existed in the surrounding area are Ban Nong Phai Tai, Ban Nong Phai Nue, Ban Non Thong Lang, and Ban Non Tun.

Land use of site 1 consists of agricultural area presented by paddy field as the most with some abandon areas (Figure 4.4). Beside that there is a build up area such as school, temple, residential, and commercial areas. Ban Nong Pai Nue School locates at the north of the site. The south is near the area of Amphoe Chum Pae.

Topographically, this site situates on the undulating rolling area with the average elevation of about 230 meters above mean sea level (MSL). The area is counted as the highland having the maximum elevation of about 800 meters MSL. The highest elevation exists in the north and east of the area and decrease south-westerly (Figure 4.5).

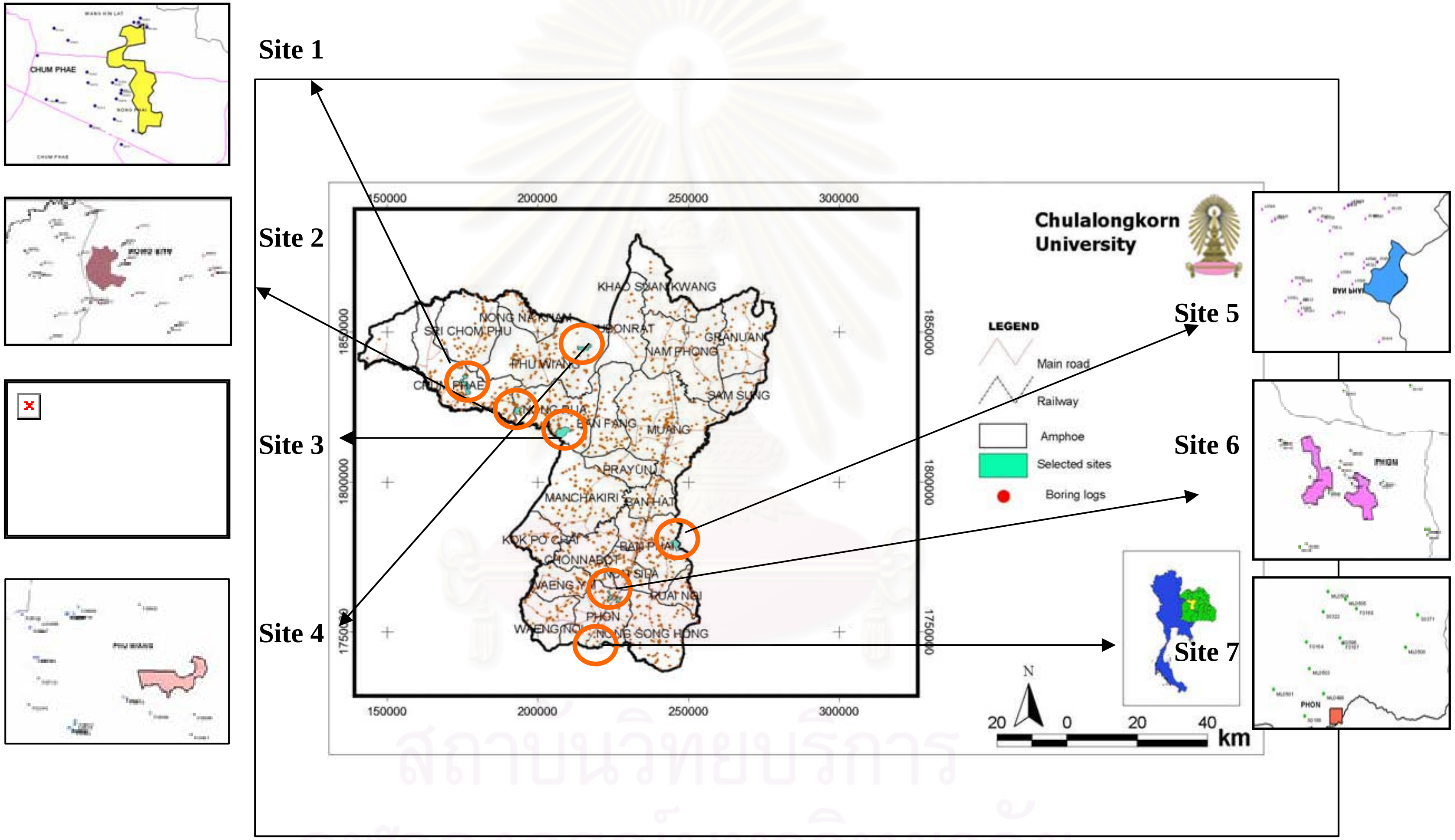


Figure 4.3 Location of proposed sites

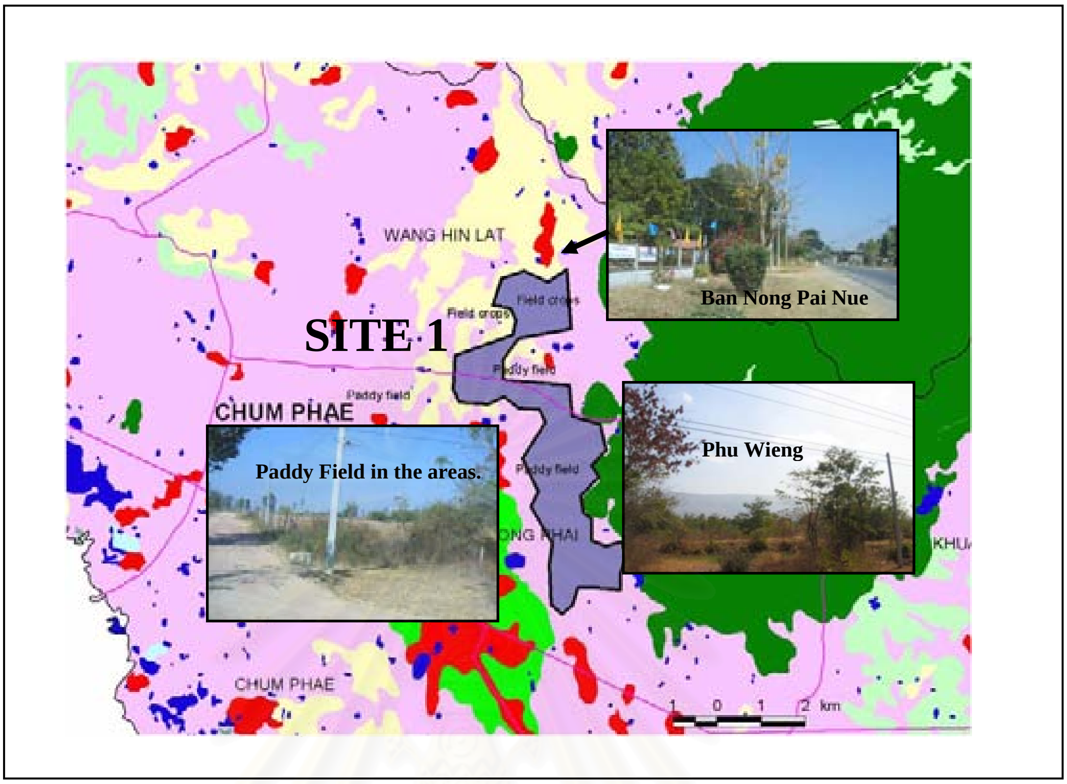


Figure 4.4 Map showing location and land use of site 1 and surrounding area.

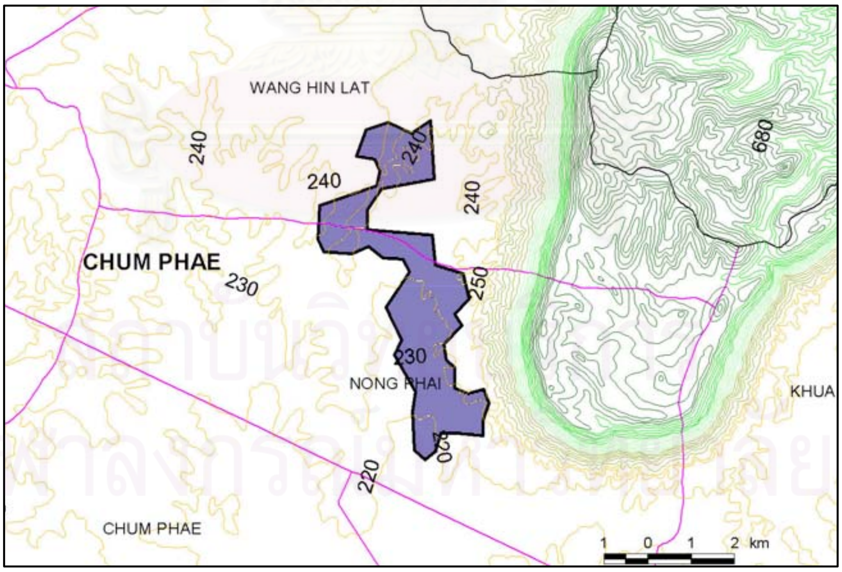


Figure 4.5 Map showing the contour lines of site 1 and surrounding area (meters above Mean Sea Level).

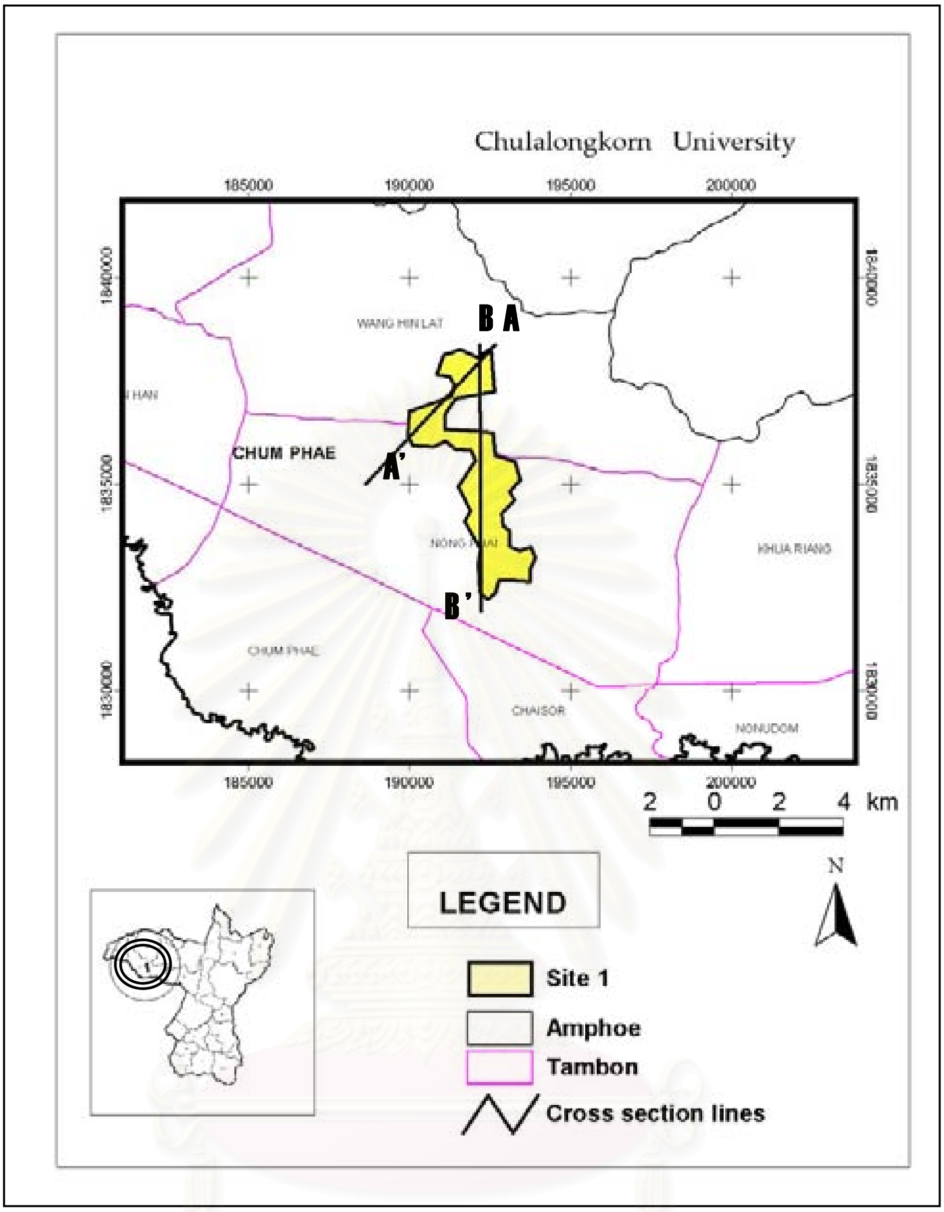


Figure 4.6 Index map of site 1 showing lines of sections (see Fig.4.7-4.8).

b) Subsurface Characteristics

Site 1 was separated into 2 sections, 1AA' and 1BB'. In soil profiling process, 21 databases of boring log were used for site 1. Figure 4.6 shows section 1AA' located in Tambon (Sub district) Wang Hin Lat boundary and section 1BB' located in Tambon Nong Phai boundary.

Sections 1AA' and 1BB' have the same characteristic profiles as shown in Figures 4.7 and 4.8, respectively. The section line presents sediments and sedimentary rock from ground surface to the depth of 20 meters. The profile presents silty clay from ground surface to the depth of 5 meters. Siltstone layer representing as the impermeable layer is capable to resist the liquid passing through.

Figures 4.7 and 4.8 indicate that site 1 consisting of very fine grained materials of silty clay. The soil particle size is less than 0.002 mm in diameter with a large surface areas compared with the other inorganic fractions. It is also very chemically active and is able to hold substances onto the surfaces. Like nutrients, water also attach to the surfaces of clay and difficult to pass through. The saturated hydraulic conductivity value of clay is in the range of 10^{-6} – 10^{-8} cm/s. The sedimentary rock found in this site is siltstone. Siltstone is composed of silt-sized sediment grains, which are transitional in size between clay and sand grains. Thus, siltstone represents a natural depositional environment transitional between those of shale and sandstone. Noting that it is very similar in appearance to shale, but it is a bit grittier.

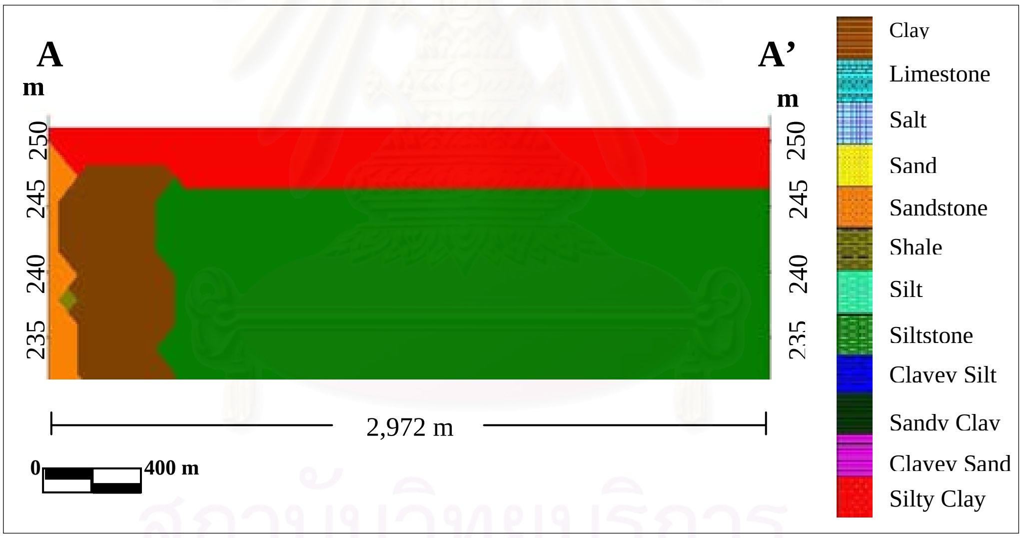


Figure 4.7 Cross section of line AA’ in area 1 (Fig.4.6) showing the profile of sediments and sedimentary rock

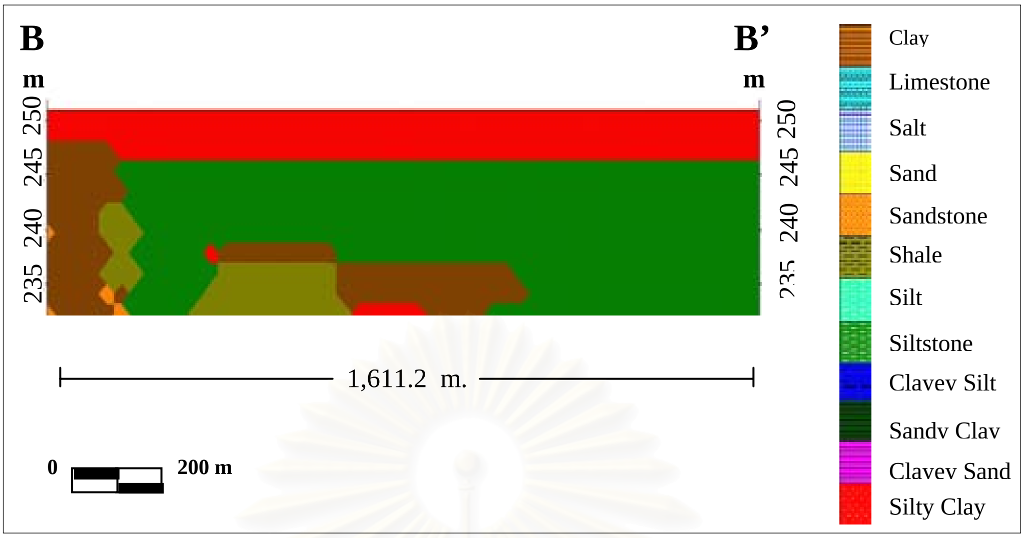


Figure 4.8 Cross section of line BB' in area 1 (Fig.4.6) showing the profile of sediments and sedimentary rock

4.4.2 Site 2

a) Land use and Topology

Site 2 locates in Amphoe Nong Rue, Tambon Kut Kwang. The total area of this site is about 4.51 square kilometers. It is adjacent to Highway No.12. The site is bounded by the paddy field, residential area (Ban Non Sathorn and Ban Nong Ko), and field crops area in the east, adjacent to the paddy field and the residential area in the south, and adjacent to local road, paddy field, residential area, plantation in the west.

Land use of site 2 include agricultural area of which paddy is the most with some abandon areas (Figure 4.9). The surrounding areas are also the paddy field, bush, and shrub. Moreover, there are the communities such as, Ban Non Sathon, Ban Nong Ko. There are field crops which are cassava and sugar cane plantation.

Based on the field survey and map, site 2 situates on the flat plain area with the average elevation about 205 meters MSL. The south-west area is higher and the slightly decreases north-easterly (Figure 4.10).

b) Subsurface characteristics

Site 2 was separated to 3 sections (Figure 4.11). In soil profiling process, 38 databases of boring log were used (Figure 4.3) for site 2. Sections 2AA’ and 2BB’ have almost the same characteristic profiles (Figures 4.12 and 4.13). Both sections cross the area from the northeast to the southwest direction. The section line presents sediments and sedimentary rock from ground surface to the depth of 18 meters. The soil profile presents clay as the first layer with the depth of 1.5 meter from ground surface. The next layer is silty clay which present a slight difference between both sections, ie. silty clay of section 2AA’ is at the depth of 1.5 to 9.5 meters and section 2BB’ is 1.5 to 11.5 meters. Then both sections have sandstone underlain soil layer represents the impervious rock. Section 2CC’ crosses the area from the north to the south direction. The characteristics of profile 2CC’ (Figure 4.14) is the same profile as section 2BB’. It is existed with clay from ground surface to the depth of 1.5 meters, followed with silty clay at the depth of 1.5 to 11.5 meters. As same as profiles 2AA’ and 2BB’, it is underlain with sandstone acted as the impervious layer.

Site 2 characteristics are generally similar to site 1 characteristic. Figures 4.12 to 4.14 of such 3 sections indicate that site 2 comprising of very fine grained materials of clay as top layer followed with silty clay. These soils have particles size less than 0.002 mm in diameter with the very large surface areas compared with the other inorganic fractions. They are also very chemically active and is able to hold substances on their surfaces. Likewise, water attached to the surfaces of clay is difficult to pass through. The saturated hydraulic conductivity value of clay is in the range of $10^{-6} – 10^{-8}$ cm/s. The saturated hydraulic conductivity value of silty clay is in the range of $10^{-6} – 10^{-8}$ cm/s. The sedimentary rock was found in this site is sandstone. Sandstone refers to a sedimentary rock with grains between 1/16 millimeter and 2 mm in size.

Figure 4.9 Map showing location and land use of site 2 and surrounding area.

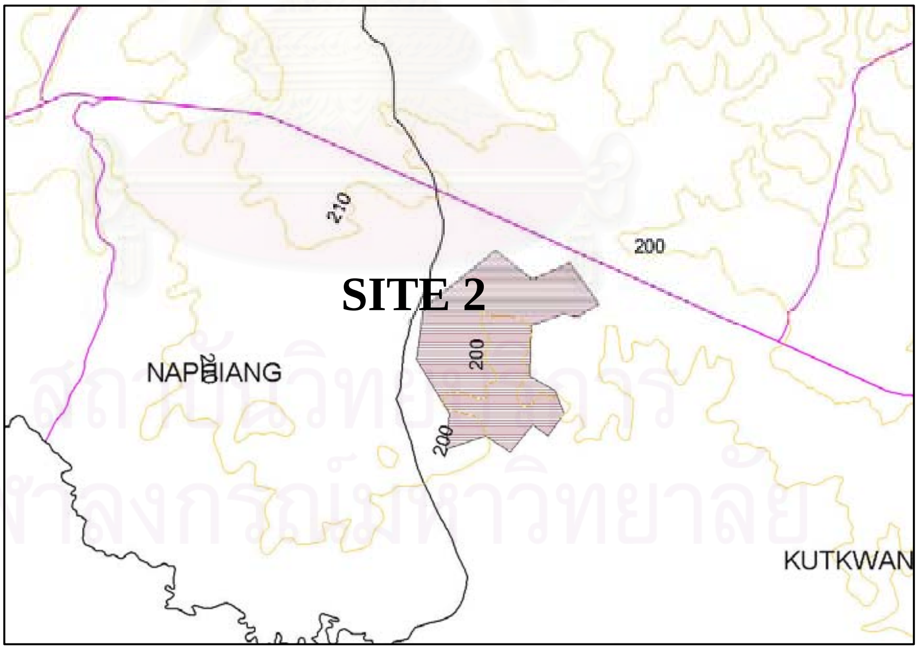


Figure 4.10 Map showing the contour lines of site 2 and surrounding area (meters above Mean Sea Level).

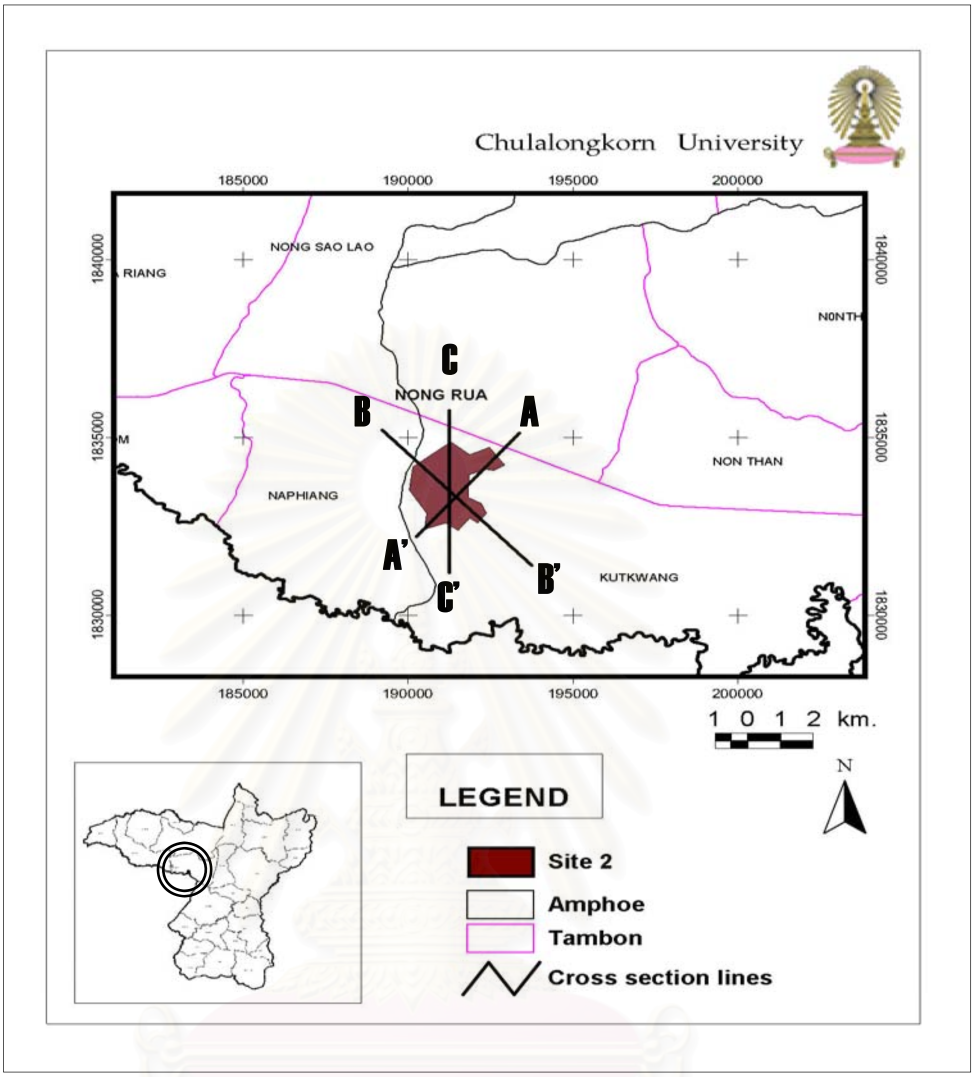


Figure 4.11 Index map of site 2 showing lines of sections (see Fig.4.12-4.14).

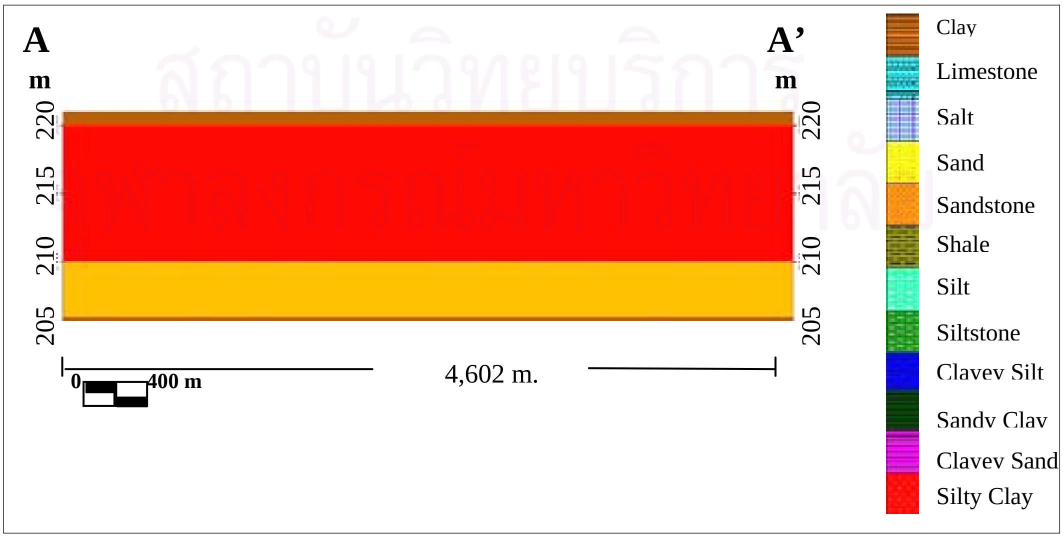


Figure 4.12 Cross section of line AA' in area 2 (Fig.4.11) showing the profile of sediments and sedimentary rock.

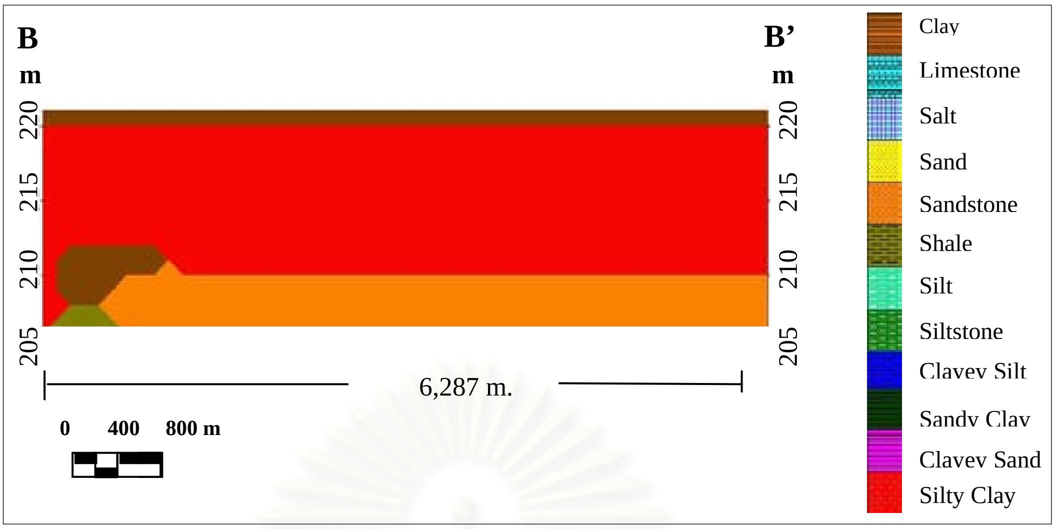


Figure 4.13 Cross section of line BB’ in area 2 (Fig.4.11) showing the profile of sediments and sedimentary rock.

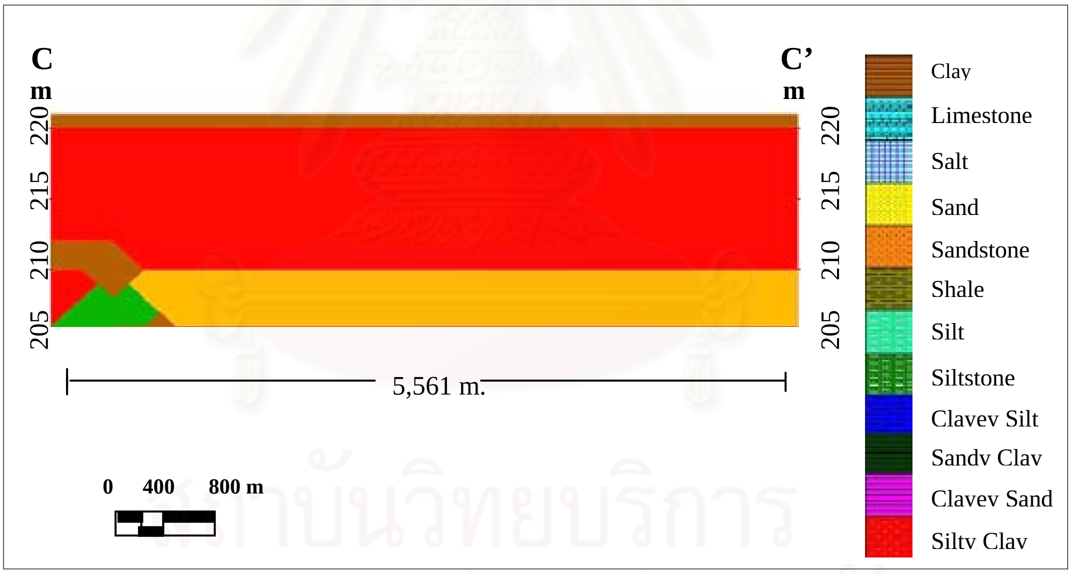


Figure 4.14 Cross section of line CC’ in area 2 (Fig.4.11) showing the profile of sediments and sedimentary rock.

4.4.3 Site 3

Site 3 has been separated to 2 sections. In soil profiling process, 28 databases of boring log were used (Figure 4.3) for site 3.

a) Land use and Topology

This site locates in Amphoe Nong Rue, Tambon Ban Meng and Tambon Yang Kham, Khon Kaen province. The site covers a total area about 14.52 square kilometers. The boundary of the site is Ban Nong Ko and Ban Meng, paddy field, bush and shrub in the north; paddy field, bush and shrub in the east; adjacent to Phu Meng in the south and southeast; and adjacent to Highway no. 2187, residence area, and plantation in the west, respectively.

Land use in the area occupy with agricultural area where paddy field is at most alternated with some field crops such as sugar cane and abandon areas (Figure 4.15). Beside, there is some forest area which is deciduous dipterocarp forest, and the buildup area which is Ban Don Chang close to the site in the northeast area. In the north and west of the site is the local road.

Topographically, site 3 locates on flat plain by hillside. The average elevation of the area is about 215 meters MSL. Elevation of the eastern side area is about of 220 meters MSL sloping down westward. In the southeast of the site, there is the highland so called Phu Meng having the maximum height of about 600 meters MSL (Figure 4.16).

b) Subsurface characteristics

Site 3 was separated to 2 sections (Figure 4.17). For soil profiling process, 28 databases of boring log were used (Figure 4.3) for site 3.

Sections 3AA’ and 3BB’ are mostly similar, except the line direction. Section 3AA’crosses the area on west-east direction. While, section line 3BB’ crosses the area from northeast to southwest direction. The same characteristics of both section lines (Figures 4.18 and 4.19) are as follows; sediments and sedimentary rock from ground surface to the depth of 10 meter, silty clay from ground surface to the depth of 1 meter followed by the clay layer of about 7 meters, and the shale layer acting the impervious layer.

In conclusion, site 3 comprise of very fine grained materials which are silty clay as top layer and 7 meters thick of clay. These soils have particles size less than 0.002 mm in diameter and have very large surface areas compared with the other inorganic fractions. They are also chemically very active and is able to hold substances on their surfaces. Likewise, water attached to the surfaces of clay is difficult to pass through. The saturated hydraulic conductivity value of silty clay is in the range of 10^{-6} – 10^{-8} cm/s. The saturated hydraulic conductivity value of clay is in the range of 10^{-6} – 10^{-8} cm/s. The sedimentary rock found abundantly in this site is shale. It is composed of tiny clay-sized sediment grains. Other components may be iron oxides or organic matter. Shale normally has a fine lamination structure.

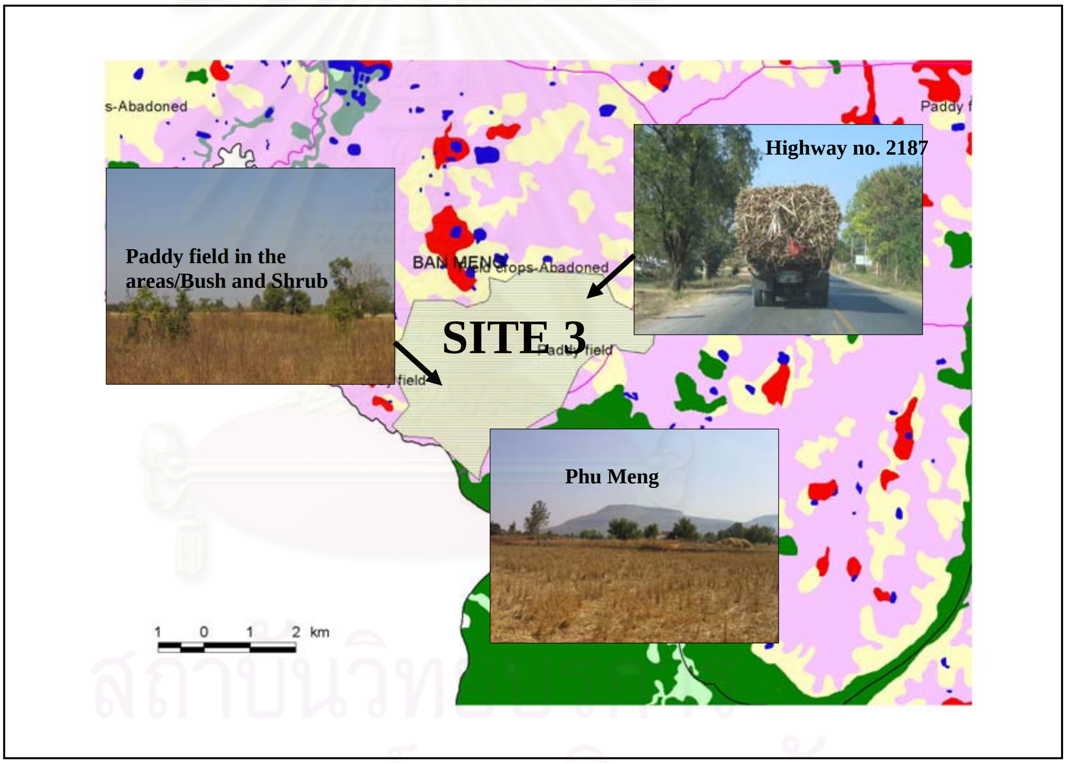


Figure 4.15 Map showing location and land use of site 3 and surrounding area.

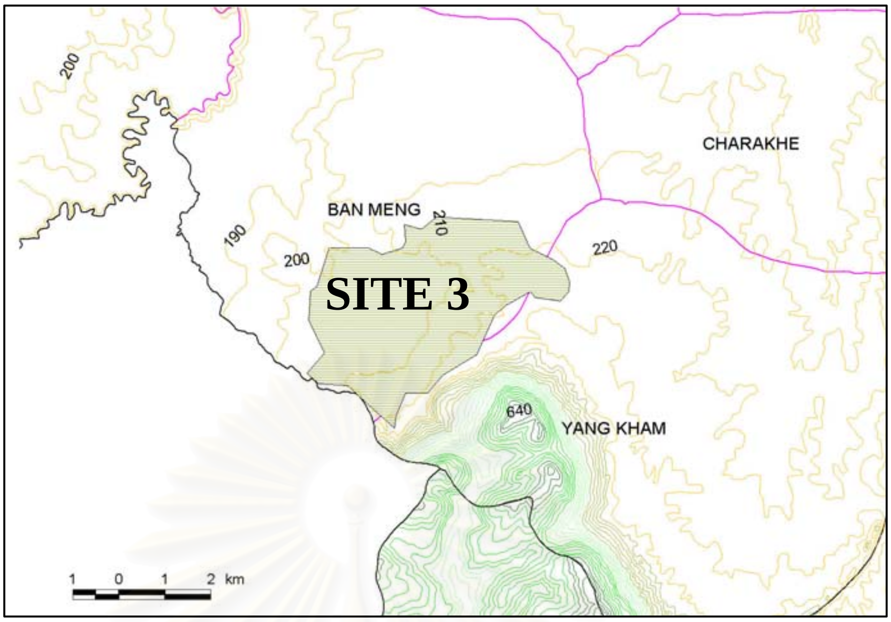


Figure 4.16 Map showing the contour lines of site 3 and surrounding area (meters above Mean Sea Level).

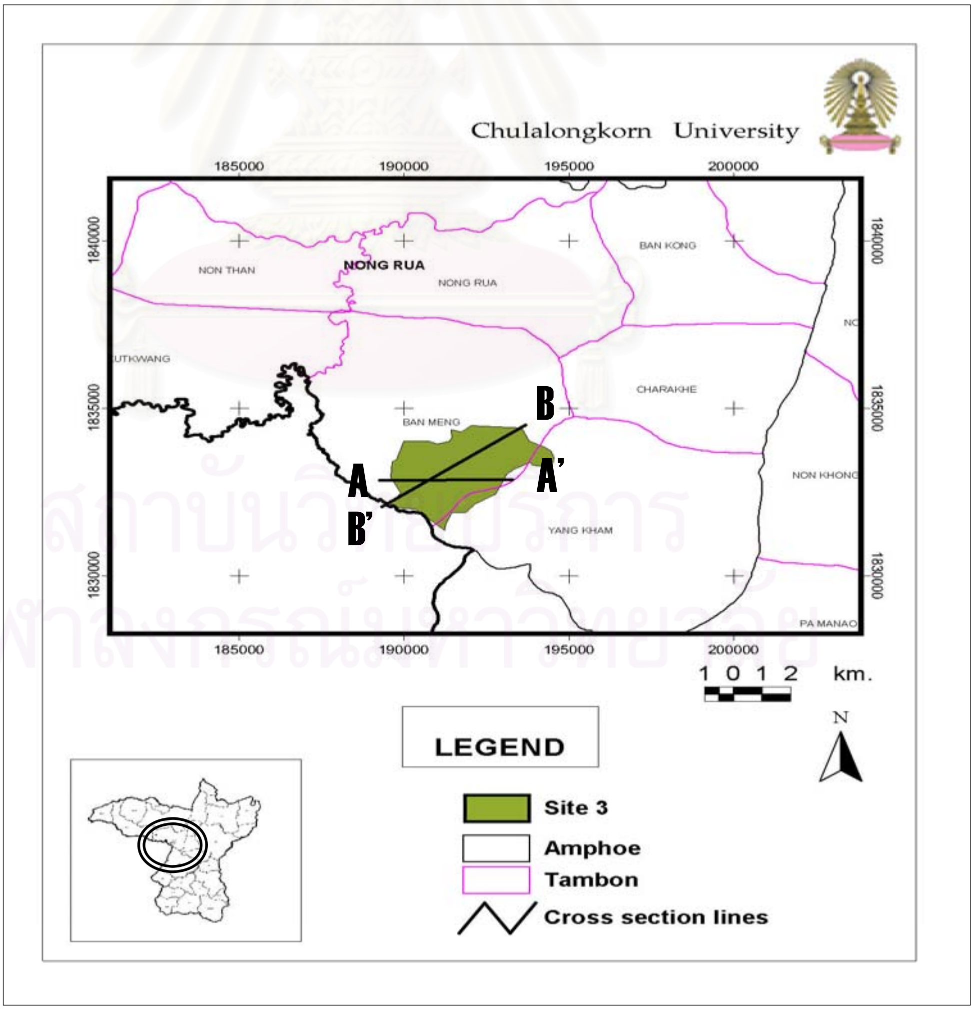


Figure 4.17 Index map of site 3 showing lines of sections (see Fig.4.18-4.19).

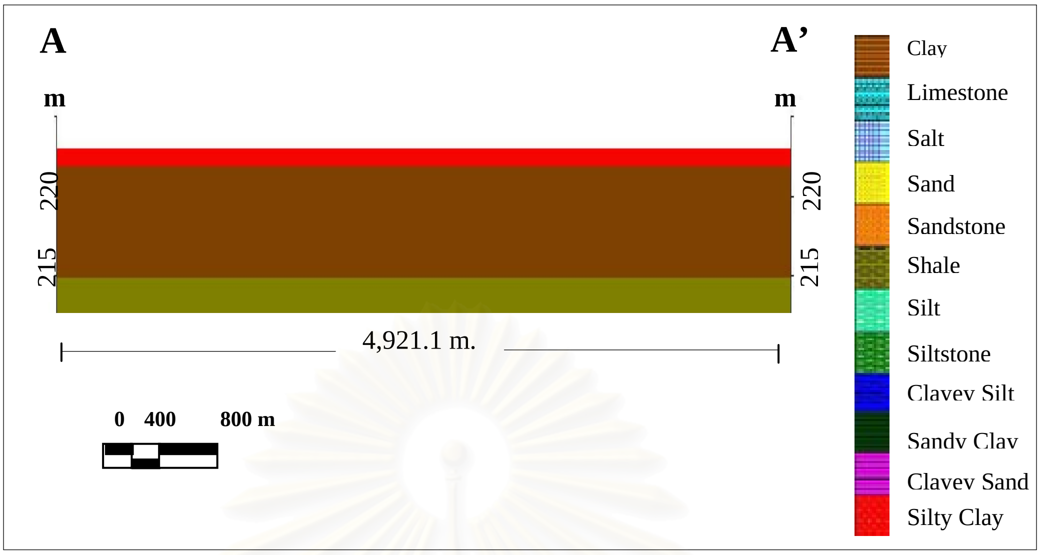


Figure 4.18 Cross section of line AA’ in area 3 (Fig.4.17) showing the profile of sediments and sedimentary rock.

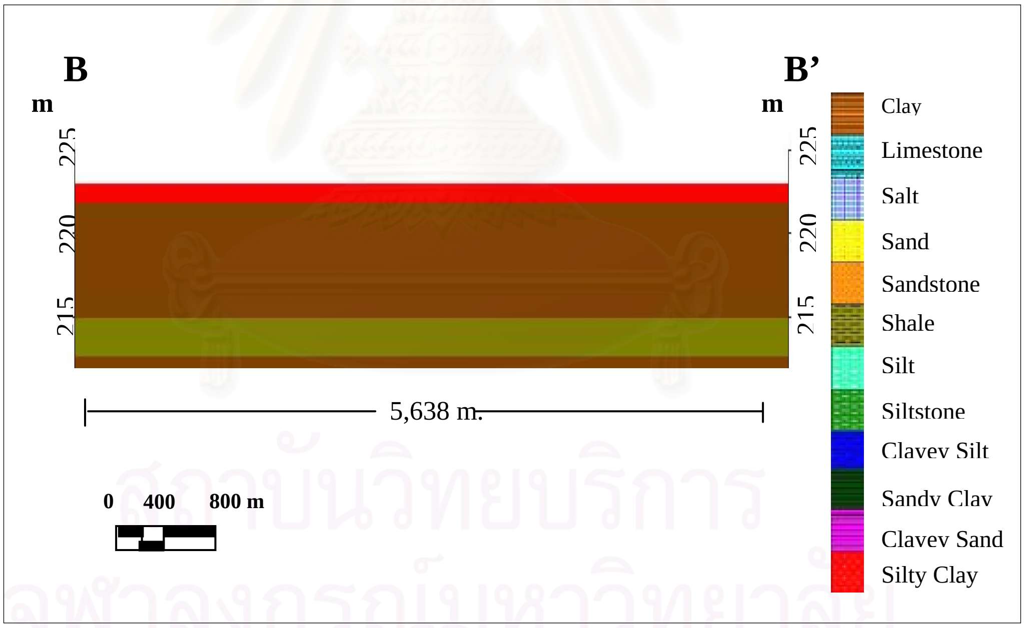


Figure 4.19 Cross section of line BB’ in area 3 (Fig.4.17) showing the profile of sediments and sedimentary rock.

4.4.4 Site 4

a) Land use and Topology

This site locates in Amphoe Phu Wiang, Tambon Na Wah, Khon Kaen province. The site has total area about 6.11 square kilometers. The boundary of the site is paddy field area of Ban Nong No in the north, close to Ban Non Udom in the east, and far from the Nam Phong reservoir and Phu Phan Kham hill for 4 km.

Land utilization of site 4 comprise of agricultural area with paddy field is the most mixed with grass field for livestock. Some is the abandon area. In addition, land use of the surrounding areas is residential area of Ban Non Udom and Ban Nong No. Moreover, there are agricultural land use such as cassava and sugar cane (Figure 4.20).

Topographically, the area situates on flat plain at where the average elevation of site 4 is about 200 meters MSL. The west of the area is the highest elevation in the range of 210-215 meters. The elevation decreases westward sloping down to the Nam Phong reservoir in the east (Figure 4.21).

b) Subsurface Characteristics

Site 4 was separated to 2 sections (Figure 4.22). In soil profiling process, 23 databases of boring log were used (Figure 4.4) for site 4.

Sections 4AA’ (Figure 4.23) and 4BB’ (Figure 4.24) have mostly similar characteristics, except the direction. Profile 4AA’ crosses the area from north-west to south-east direction. Profile 4BB’ crosses the area from west - east direction. Both sections are occupied with sediments and sedimentary rock from ground surface to the depth of 20 meters. Clay layer exist from ground surface to the depth of 2 meters for section 4 AA’ and 2.5 meters for section 4BB’. Next layer is silty clay at the depth of 2-18 meters for section 4AA’ and 2.5-17 meters for section 4BB’. The sandstone layer represents the impervious rock acting like a barrier for water passing through.

In conclusion, site 4 comprise of very fine grained materials which are clay as top layer and 16 meters thick of silty clay. These soils have particles size less than 0.002 mm in diameter and have very large surface areas compared with the other inorganic fractions. They are also chemically very active and is able to hold substances on their surfaces. Water attached to the surfaces of clay is difficult to pass through. The hydraulic conductivity value of clay is in the range of $10^{-6} – 10^{-8}$ cm/s. The hydraulic conductivity value of silty clay is in the range of $10^{-6} – 10^{-8}$ cm/s. The sedimentary rock was found in this site is sandstone. Sandstone refers to a sedimentary rock with grains between 1/16 millimeter and 2 mm in size (coarser grain than siltstone). Sandstone is usually almost all quartz. Most sandstones, however, have small amounts of other minerals—clays, hematite, ilmenite, feldspar, and mica—that add color and character to the quartz matrix.

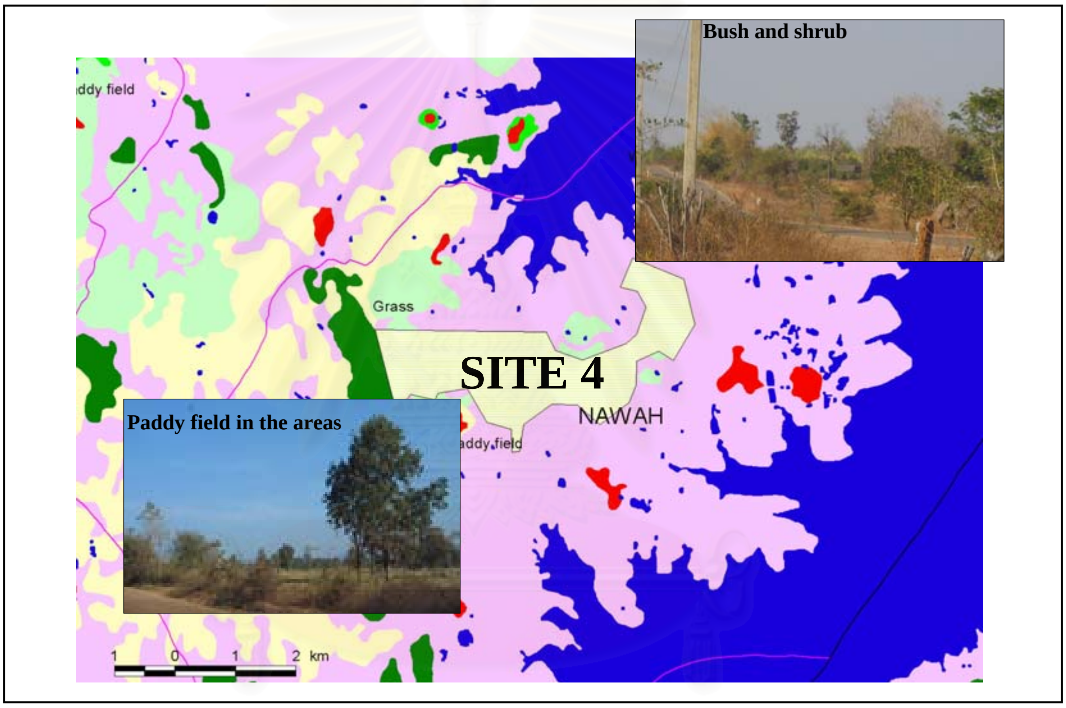


Figure 4.20 Map showing location and land use of site 4 and surrounding area.

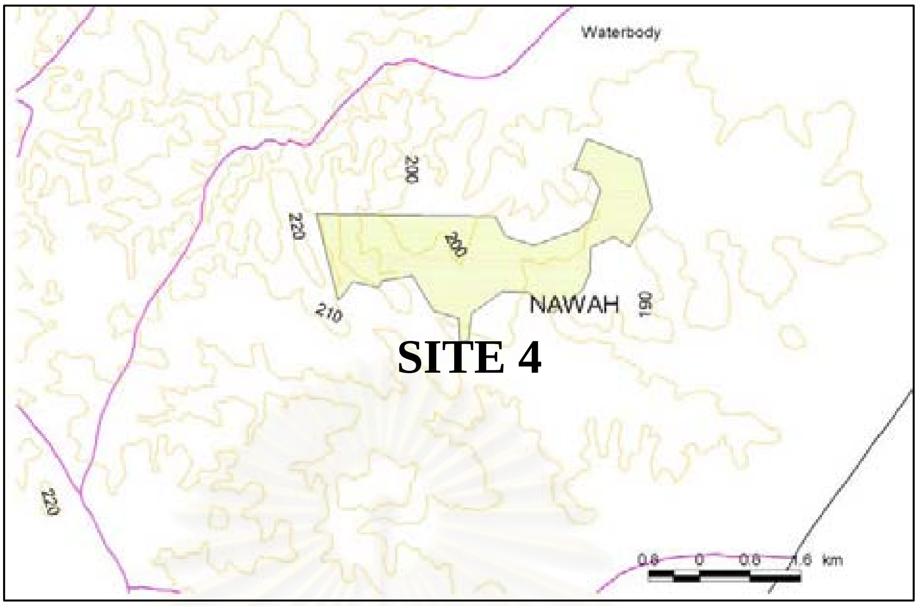


Figure 4.21 Map showing the contour lines of site 4 and surrounding area (meters above Mean Sea Level).

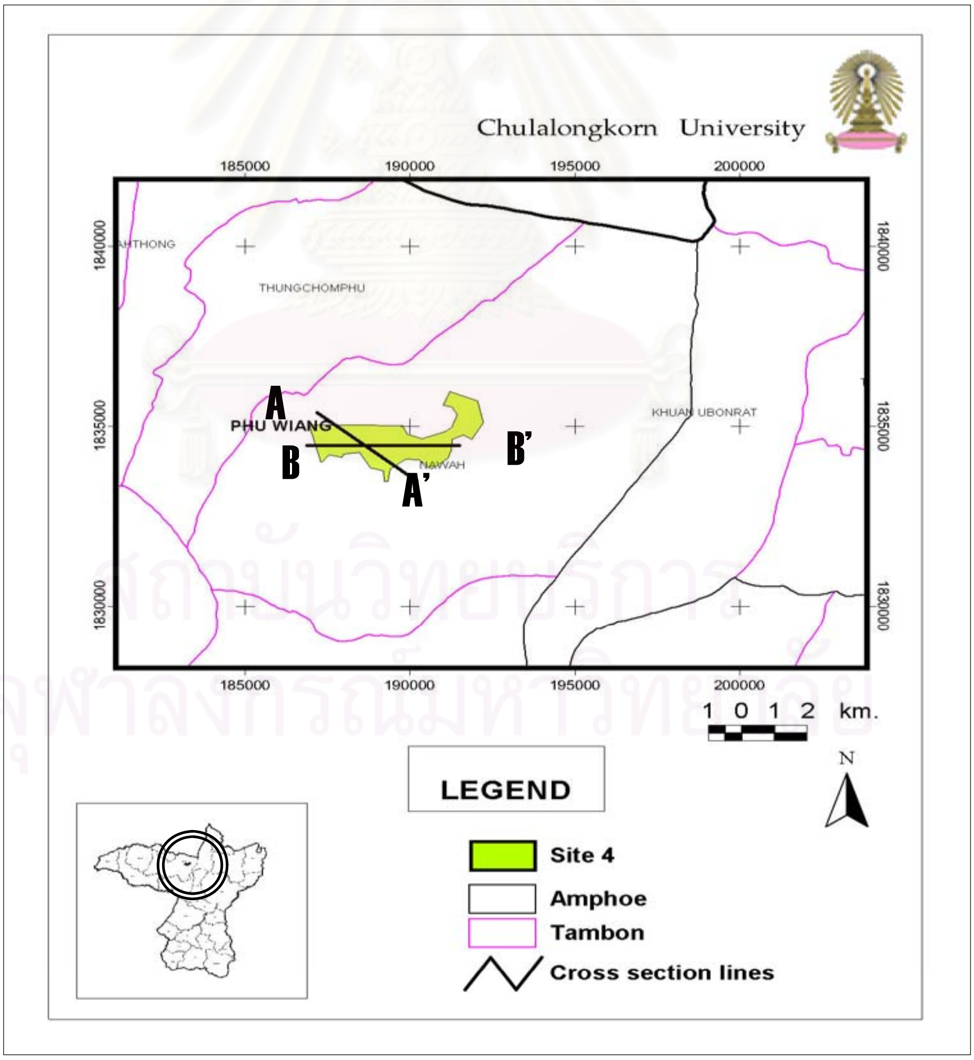


Figure 4.22 Index map of site 4 showing lines of sections (see Fig.4.23-4.24).

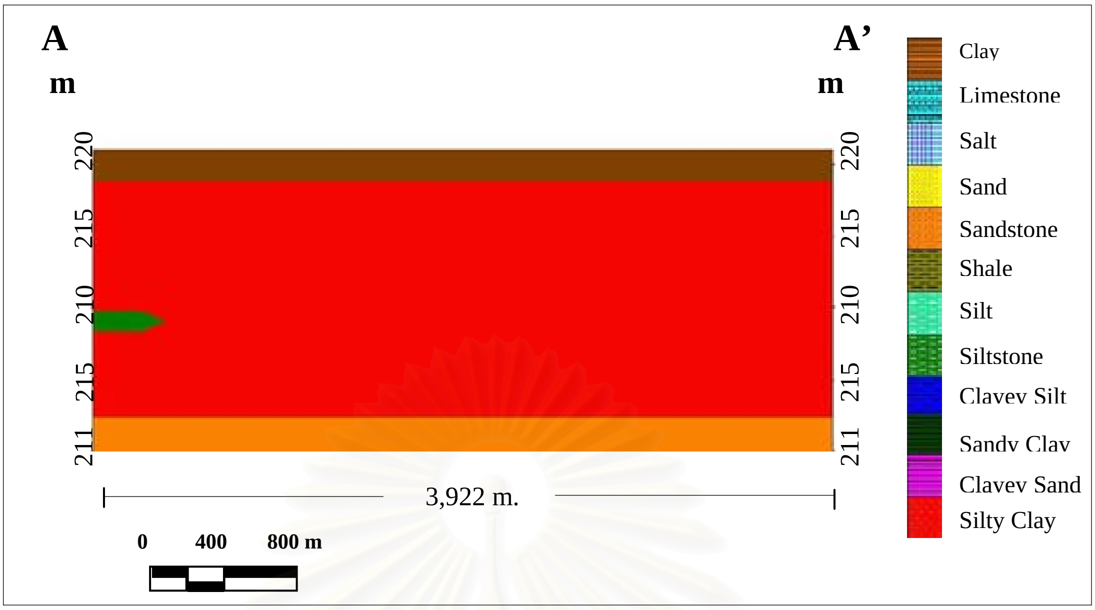


Figure 4.23 Cross section of line AA' in area 4 (Fig.4.22) showing the profile of sediments and sedimentary rock.

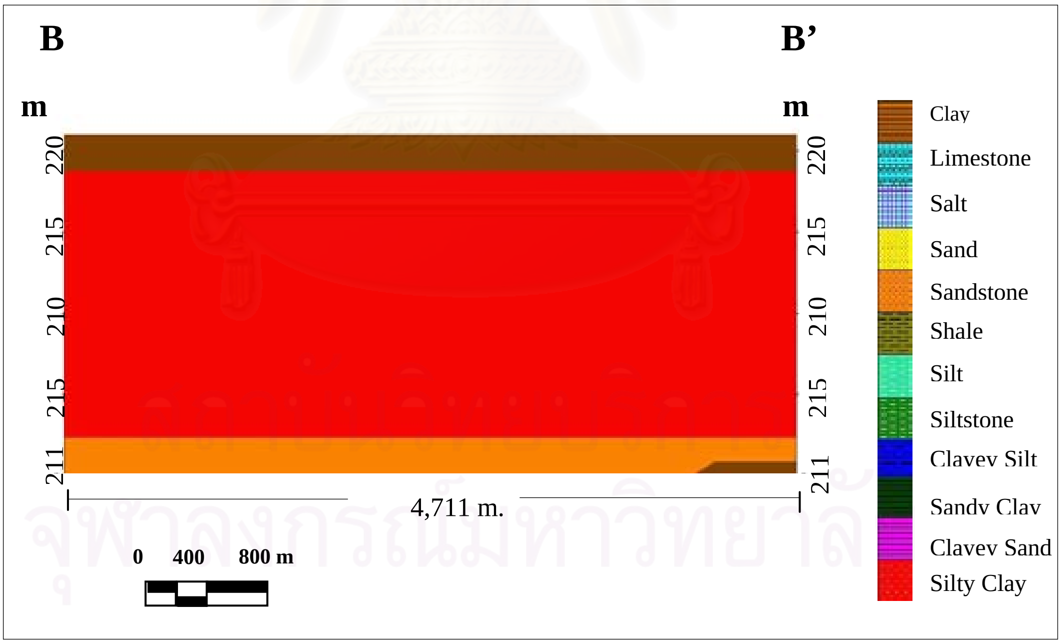


Figure 4.24 Cross section of line BB' in area 4 (Fig.4.22) showing the profile of sediments and sedimentary rock.

4.4.5 Site 5

a) Land use and Topology

Site 5 locates in Amphoe Ban Phai, Tambon Hin Thang nearby Ban Hin Thang Village. This site has the total area about 7.62 square kilometers. Highway No. 23 traverses the south of the area. Next to the north of the area is Tambon PhuLek. The area closes to Mahasarakham province boundary in the east (Figure 4.25).

Land utilization of the surrounding area consists of abandon area and agricultural area as paddy field and field crops consisting of sugar cane and cassava crops. Some of them are bush and shrub. Also, there are some abandoned areas in site 5 (Figure 4.25).

Topographically, site 5 area is situated on a gentle sloping area with the average elevation of about 215 meters. The highest area is at the northeast with the the elevation of 230 meters MSL. The area slopes downward from the northeast to the southwest (Figure 4.26).

b) Subsurface Characteristics

Site 5 was separated to 2 sections (Figure 4.27). In soil profiling process, 27 databases of boring log (Figure 4.3) were used for site 5.

Profiles 5AA’ (Figure 4.28) and 5BB’ (Figure 4.29) are mostly the same except the direction. Profile 5AA’ crosses the area from the north to the south While Profile 5BB’ crosses the area from the northwest to the southeast direction. Both profiles show sediments and sedimentary rock for 21 meters from ground surface. The profile presents that the area cover with sand from ground surface to the depth of 8 meters. Next layer are scattered silt soil and sandstone to the depth of 15 meters. Sandstone and siltstone underlain represents the impervious rock

In conclusion, site 5 is occupied with coarse grained material of sand, of which particle size more than half of coarse fraction is smaller than 0.04 mm. in diameter. Sand has less surface areas compared with the clay. The saturated hydraulic conductivity value of sand is in the range of 10^{-3} - 10^{-6} cm/s. The sedimentary rock found in this site is sandstone. Sandstone refers to a sedimentary rock with grains between 1/16 millimeter and 2 mm in size (coarser grain than siltstone). Sandstone is usually almost all quartz. Most sandstones, however, have small amounts of other minerals—clays, hematite, ilmenite, feldspar, and mica—that add color and character to the quartz matrix.

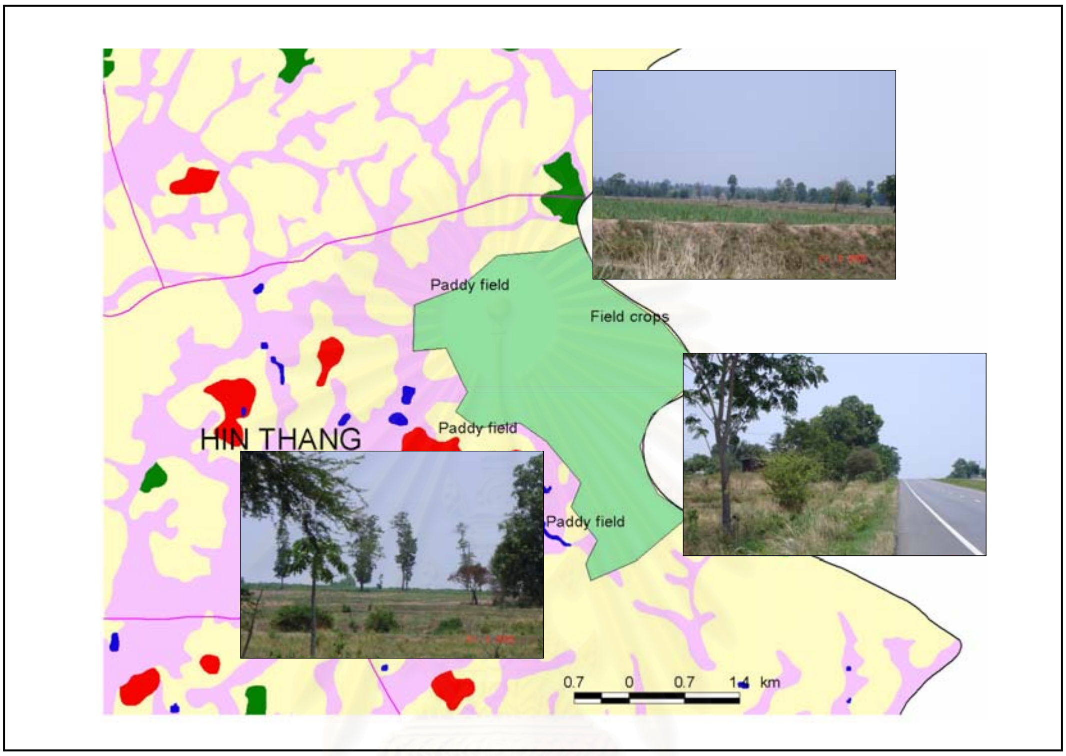


Figure 4.25 Map showing location and land use of site 5 and surrounding area.

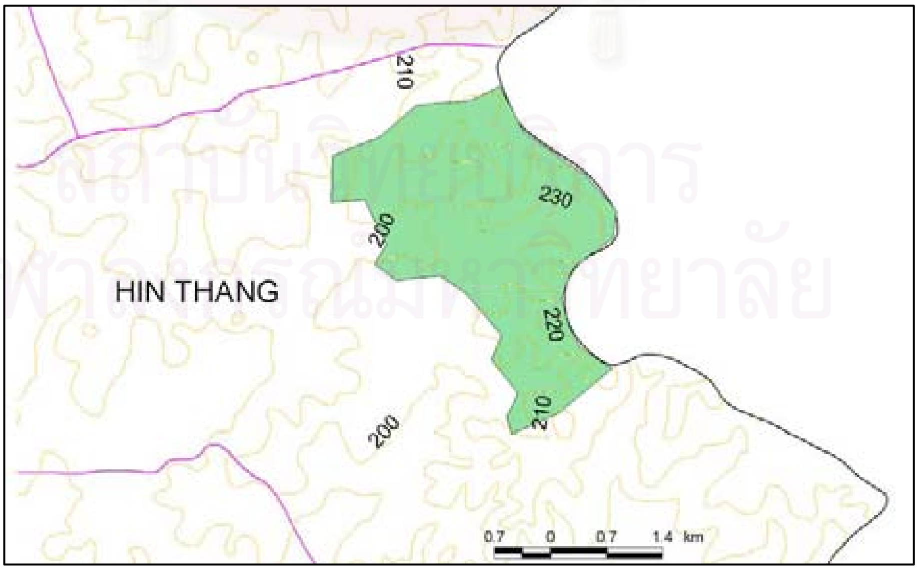


Figure 4.26 Map showing the contour lines of site 5 and surrounding area (meters above Mean Sea Level).

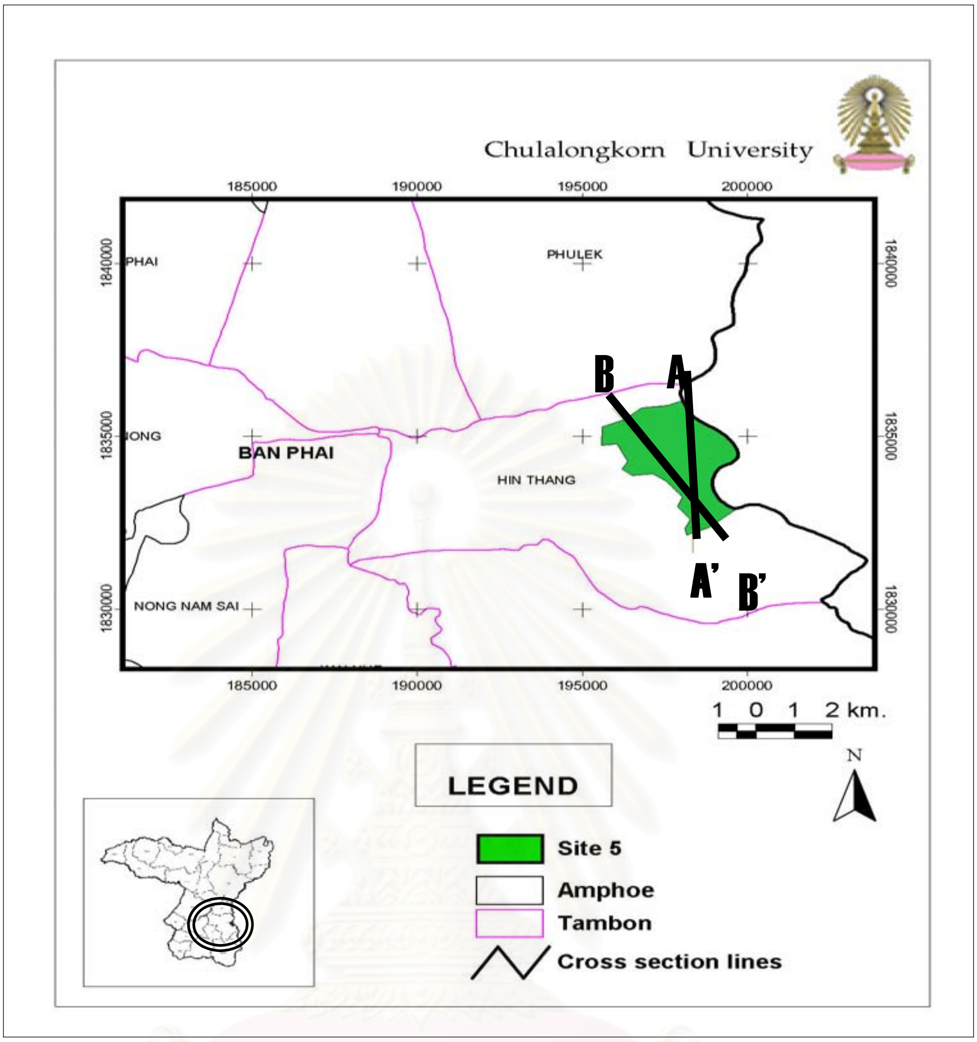


Figure 4.27 Index map of site 5 showing lines of sections (see Fig.4.28-4.29).

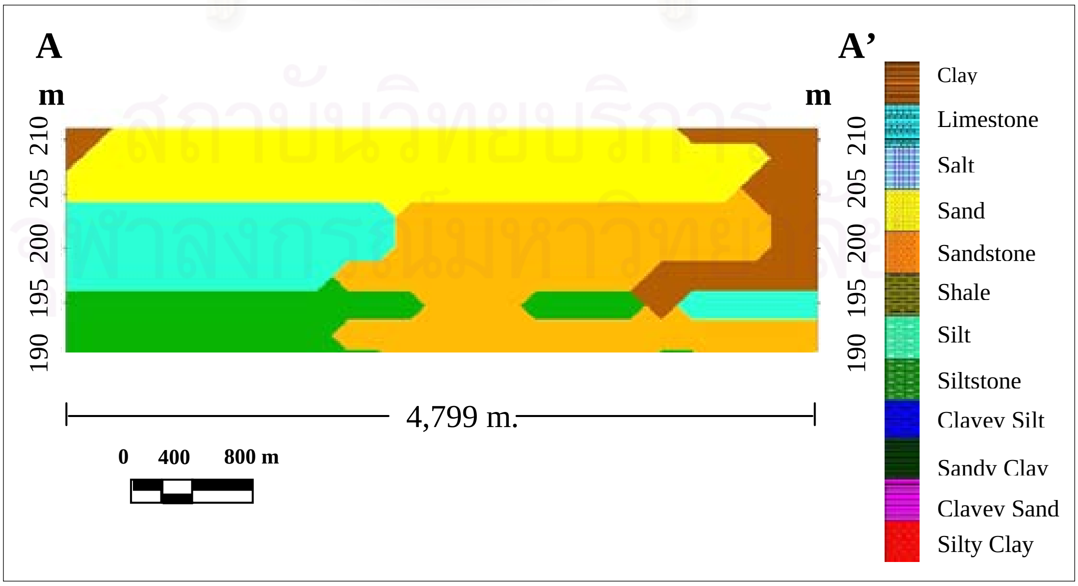


Figure 4.28 Cross section of line AA' in area 5 (Fig.4.27) showing the profile of sediments and sedimentary rock.

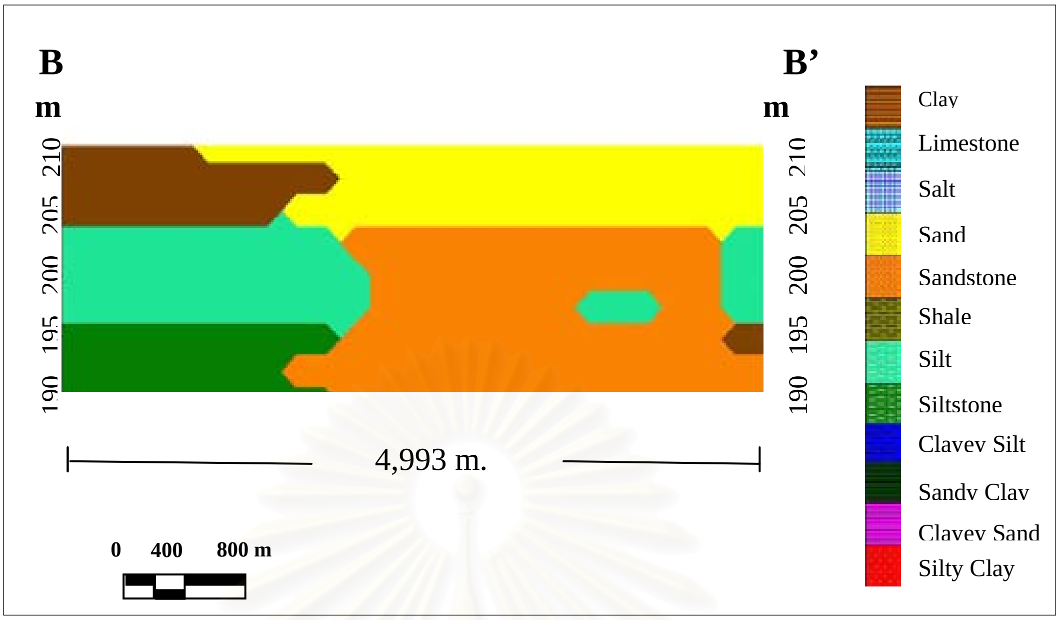


Figure 4.29 Cross section of line BB’ in area 5 (Fig.4.27) showing the profile of sediments and sedimentary rock.

4.4.6 Site 6

a) Land use and Topology

This site locates in Amphoe Phon, Tambon Nong Weang Nang Pao, and Tambon Chot Nong Kae, Khon Kaen province. Site 6 has a total area about 5.87 square kilometers. The site is separated into 2 areas by highway no. 2 (Figure 4.30). The area situate on the east of highway no.2 having the total area about 2.60 square kilometers and is nearby the railway. In addition, the adjacent villages are Ban Chot Nong Kae and Ban Nong Waeng. The other area has the total area about 3.26 square kilometers and close to the villages which are Ban Wang Chan and Ban Nong Waeng Nang Pao.

The areas of site 6 have been used for field crops of eucalyptus, cassava and sugar cane. Some of the areas are the paddy field and abandon areas. The surrounding area consists of communities, such as Ban Chot Nong Kae, Ban Nong Waeng, Ban Wang Chan, and Ban Nong Waeng Nang Pao. Also, there are cattle farming and field crops (Figure 4.30).

Topographically, this site situated on the flat plain with the average elevation about 210-215 meters. The area slopes down from the northwest to the southeast. The highest is the northwest area which is about 235 meters (Figure 4.31).

b) Subsurface characteristics

Site 6 has been separated to 3 sections (Figure 4.32). In soil profiling process, 17 databases of boring log were used (Figure 4.3) for site 6.

Three sections (Figures 4.33 - 4.35) have similar characteristics except the direction. Section 6AA' crosses the area located in the east side of high way no. 2. Both sections 6BB' and 6CC' cross the area located in the west side of high way no.2. The depth of sediments and sedimentary rock counted from the ground surface for 3 sections are slightly different, 5 meters for section 6AA', 8 meters for section 6BB' and 9 meters for section 6CC', respectively. The rest characteristics of 3 sections are the same presenting the silty clay as the first layer with the thickness about 4 meters. Beneath this layer, it is impermeable layer of siltstone.

In conclusion, site 6 is comprised of very fine grained 4 meters thick materials of silty clay. This soil has the particles size less than 0.002 mm in diameter and have very large surface areas compared with the other inorganic fractions. It is also chemically very active and is able to hold substances on the surfaces. Likewise, water attached to the surfaces is difficult to pass through. The saturated hydraulic conductivity value of silty clay is in the range of 10^{-6} – 10^{-8} cm/s. The sedimentary rock was found in this site is shale. Shale is the most abundant type of sedimentary rock. It is composed of tiny clay-sized sediment grains. Other components may be iron oxides or organic matter. Shale normally has a fine lamination structure.

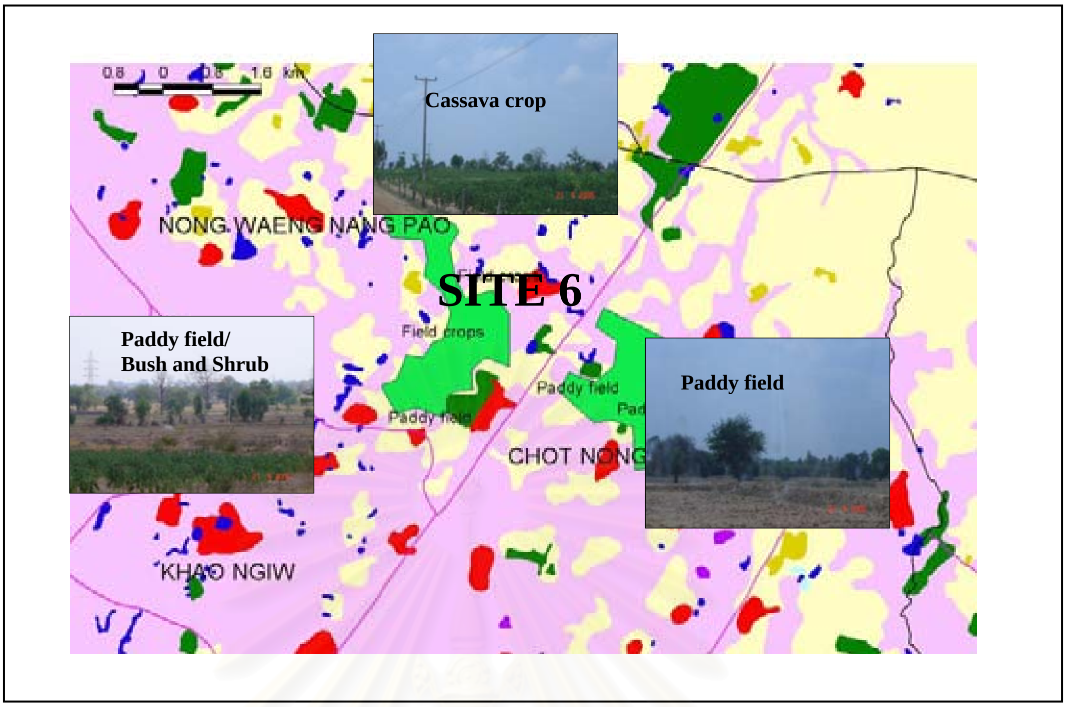


Figure 4.30 Map showing location and land use of site 6 and surrounding area.

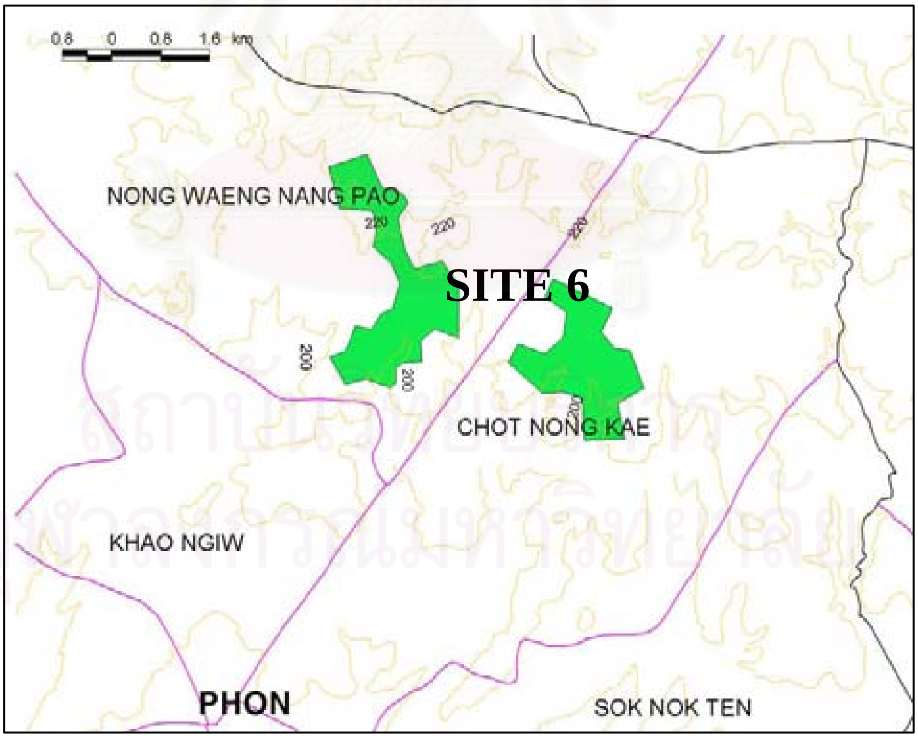


Figure 4.31 Map showing the contour lines of site 6 and surrounding area (meters above Mean Sea Level).

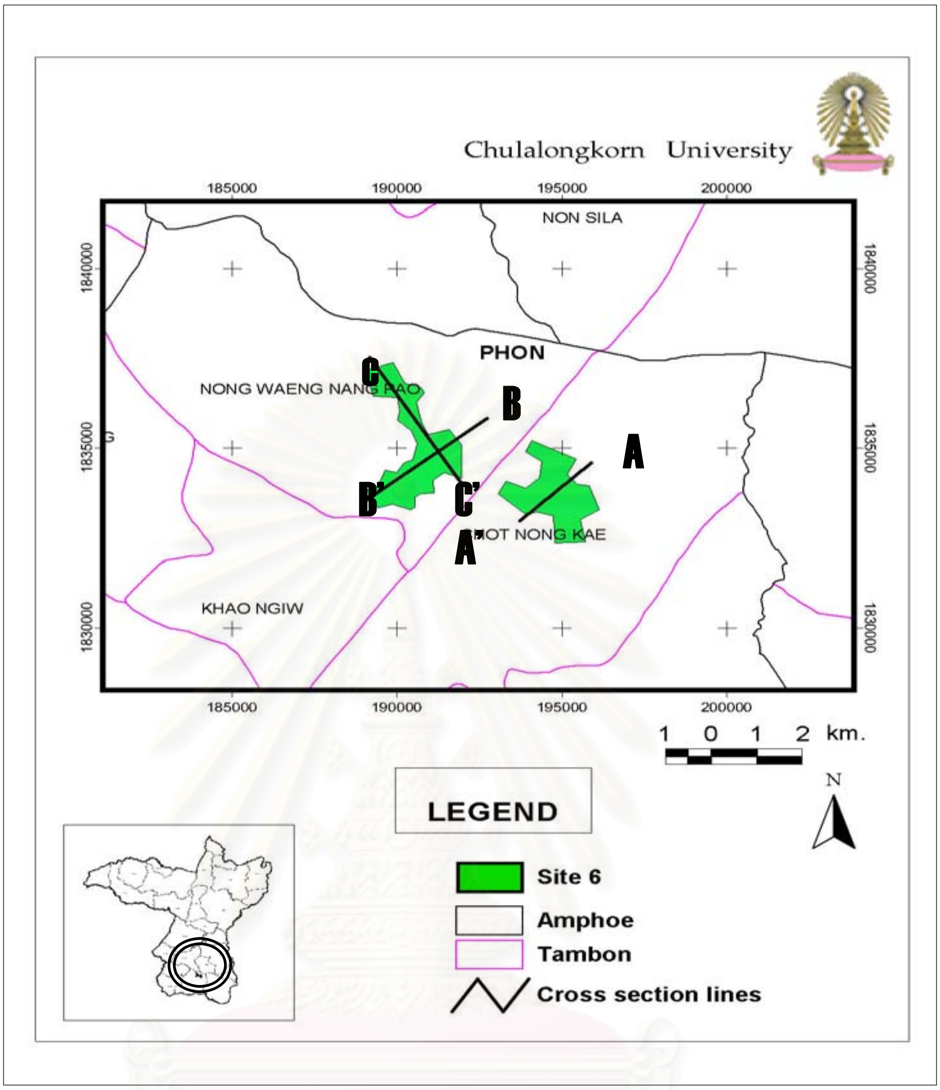


Figure 4.32 Index map of site 6 showing lines of sections (see Fig.4.33-35).

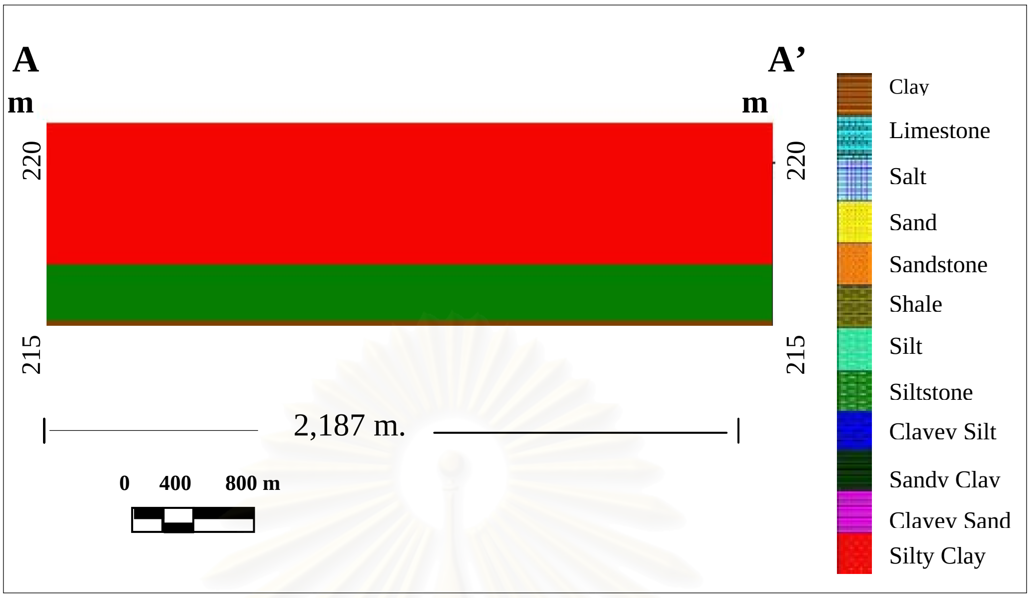


Figure 4.33 Cross section of line AA’ in area 6 (Fig.4.32) showing the profile of sediments and sedimentary rock.

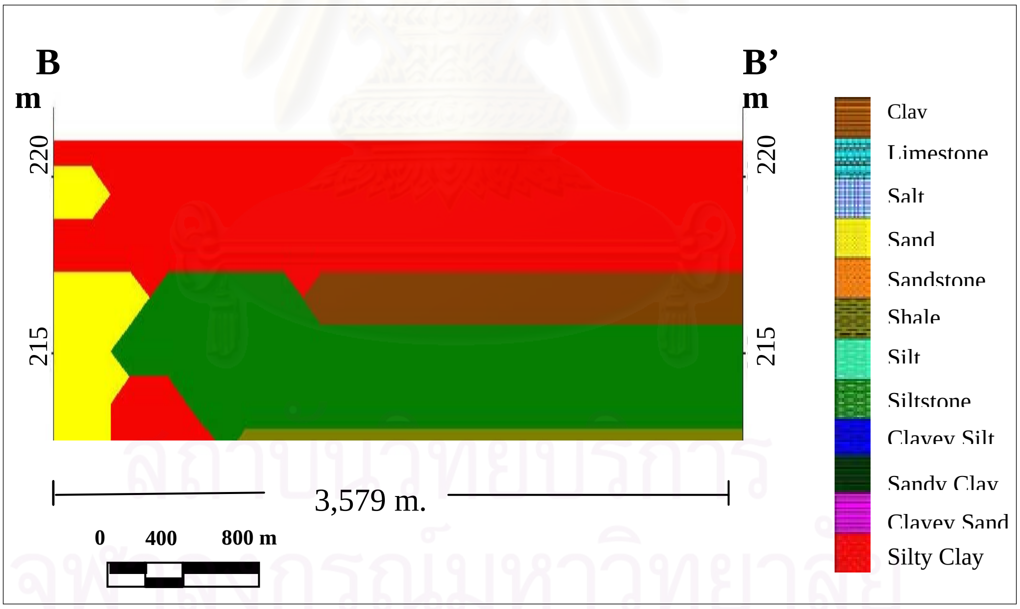


Figure 4.34 Cross section of line BB’ in area 6 (Fig.4.32) showing the profile of sediments and sedimentary rock.

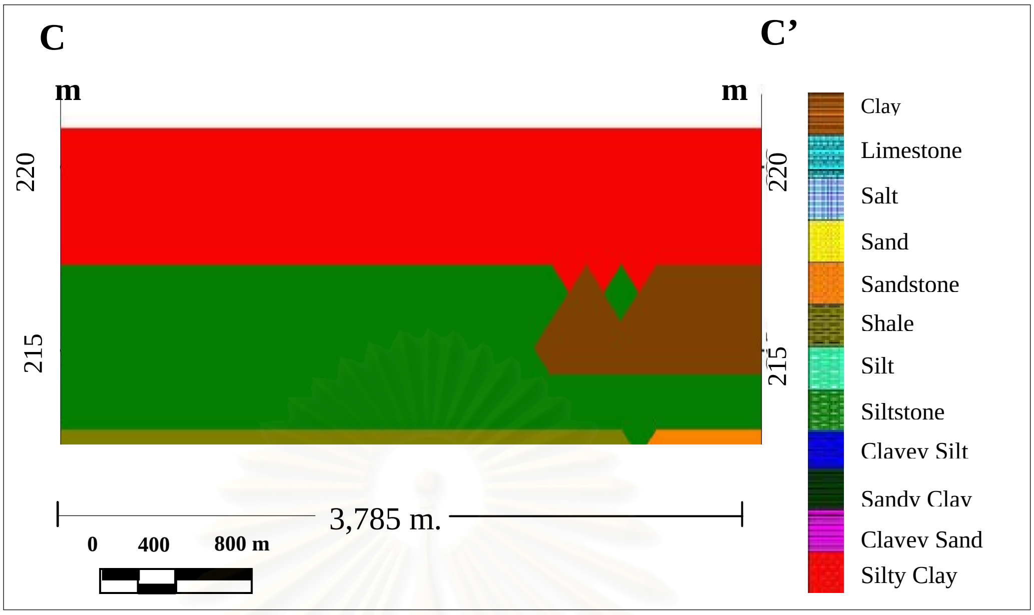


Figure 4.35 Cross section of line CC' in area 6 (Fig.4.32) showing the profile of sediments and sedimentary rock.

4.4.7 Site 7

a) Land use and Topology

Site 7 locates in Tambon Nong Waeng Sok Phra, Amphoe Phon, Khon Kaen Province. This site has the total area about 0.99 kilometers. The site is adjacent to highway no.2 in the east. It is adjacent to Nakorn Ratchasima province boundary. The area of site 7 has been used for paddy field. Some of the areas are bush and shrub. The surrounding areas are community of Ban Non Ngui and the agricultural area (Figure 4.36). This site situates on the flat plain area with the average elevation of about 195 meters MSL (Figure 4.37).

b) Subsurface characteristics

Site 7 has been separated to 2 sections (Figure 4.38). In soil profiling process, 14 databases of boring log were used (Figure 4.3) for site 7.

Both sections (Figures 4.39 and 4.40) have almost the same characteristics except the direction. Section 7AA' profile crosses the area on the north-west and south-east direction. Section 7BB' crosses the area on the north-east and south-west direction. The section presents sediments and sedimentary rock from ground surface to the depth of 10 meters for section 7AA' and 11 meters for section 7BB'. The soil profile of both sections are the same presented by clay layer from the top to the depth of 1 meter following by silt soil layer from the depth of 1 meter to 9 meters (for section 7AA') and 1 meter to 10 meters for section 7BB'. Sandstone underlay the soil layers acts as an impermeable layer.

In conclusion, site 7 is comprised of very fine grained materials of clay as a top layer. The 10 meters thick silt overly the top soil. These soils have more than a half of materials smaller than 0.002 mm in diameter and have very large surface areas compared with the other inorganic fractions. It is also chemically very active and is able to hold substances on the surfaces. Likewise, water attached to the surfaces and difficult to pass through. The hydraulic conductivity value of clay is in the range of $10^{-6} – 10^{-8}$ cm/s and silt is 10^{-4}-10^{-6} cm/s. The sedimentary rock found in this site is shale. Shale is the most abundant type of sedimentary rock. It is composed of tiny clay-sized sediment grains. Other components may be iron oxides or organic matter. Shale normally has a fine lamination structure.

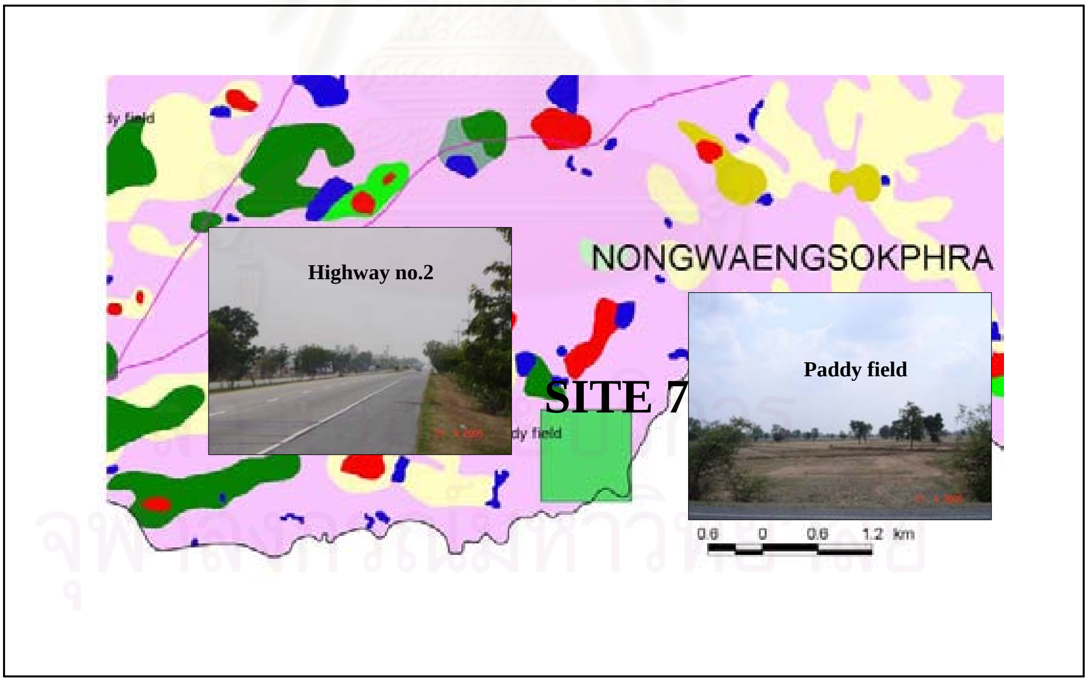


Figure 4.36 Map showing location and land use of site 7 and surrounding area.

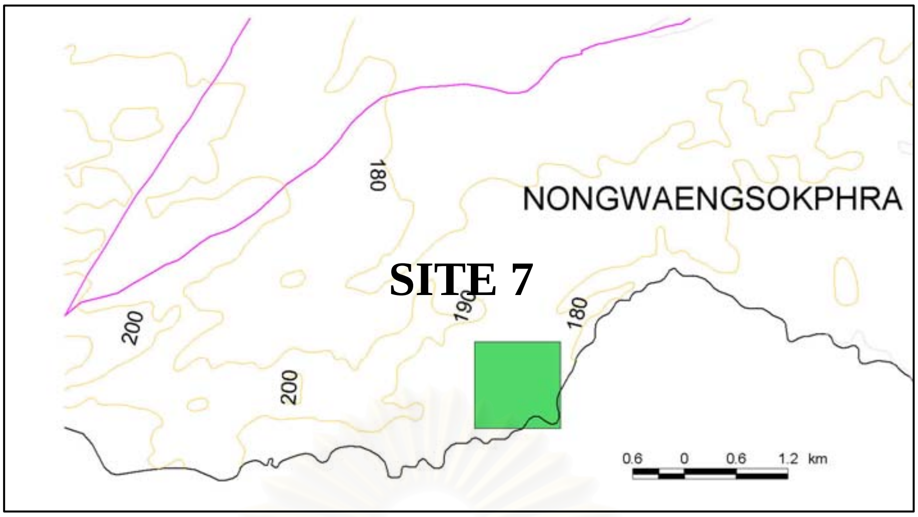


Figure 4.37 Map showing the contour lines of site 7 and surrounding area (meters above Mean Sea Level).

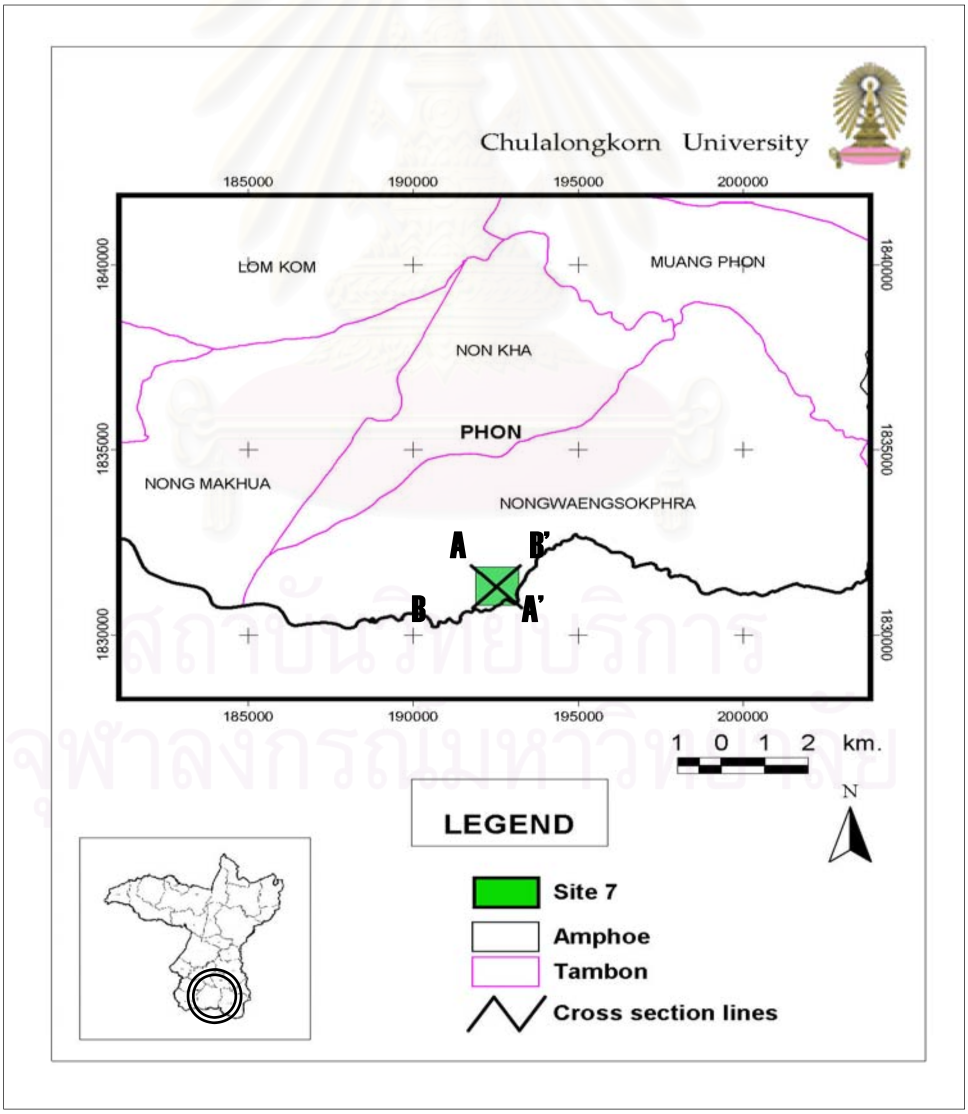


Figure 4.38 Index map of site 7 showing lines of sections (see Fig.4.39-4.40).

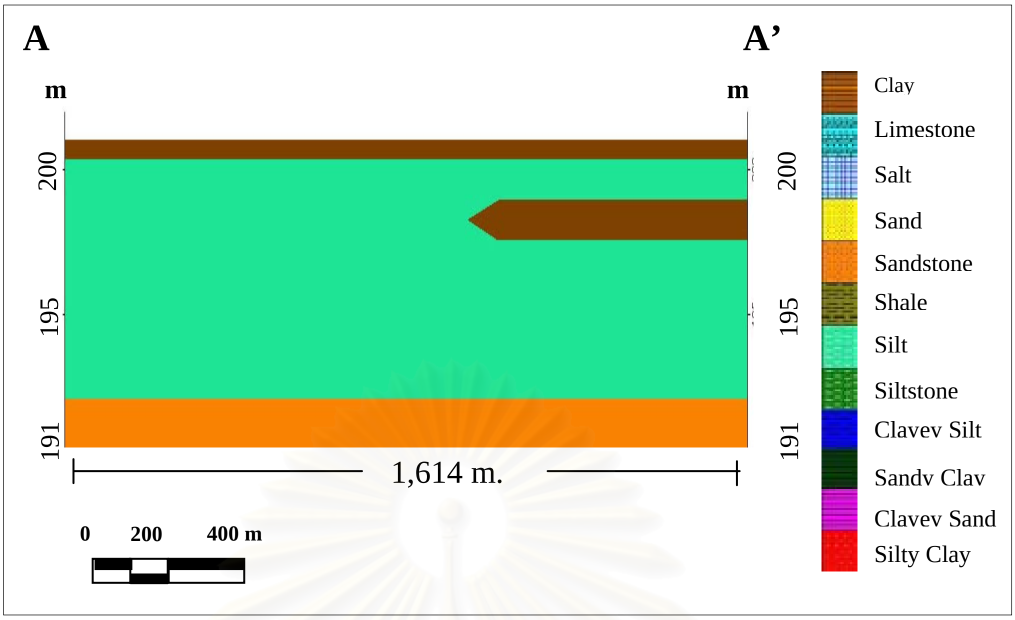


Figure 4.39 Cross section of line AA' in area 7 (Fig.4.38) showing the profile of sediments and sedimentary rock.

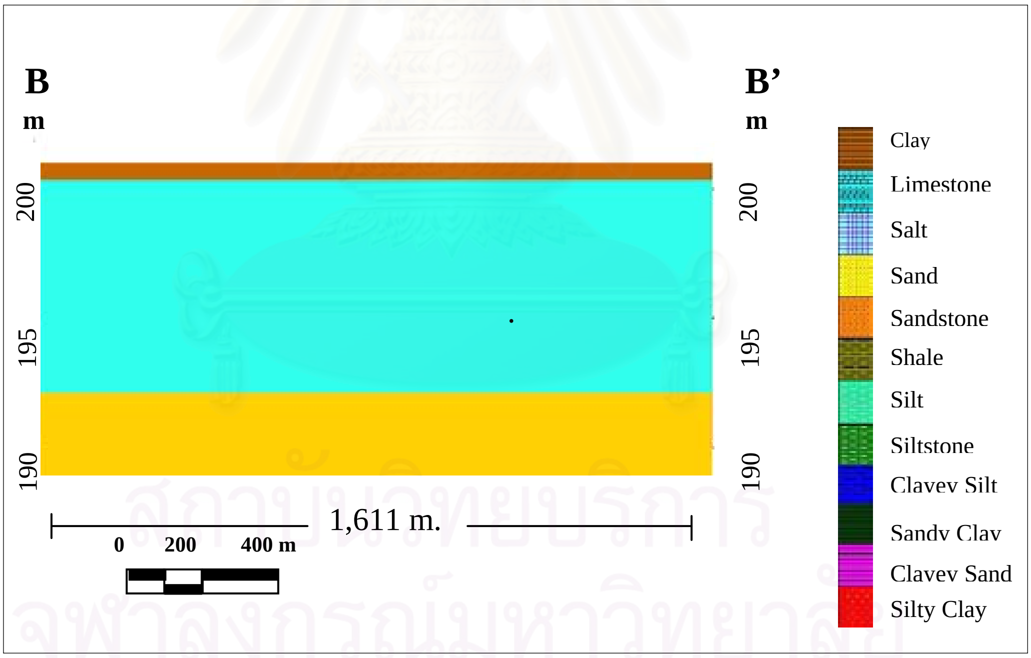


Figure 4.40 Cross section of line BB' in area 7 (Fig.4.38) showing the profile of sediments and sedimentary rock.

Site surveying is the important process for landfill siting. As a result the general characteristics of each site are specified. In the first process, the communities and high environmental potential areas were set aside and confined for restrict area to be landfill. Land use of 7 sites are quite similar which are agricultural areas and the abandoned area. Agricultural areas consist of paddy field, cassava, eucalyptus, and sugar cane. Particularly, sites 5, 6, and 7, which locate in the south are more abundant with water. Some areas in site 1 area were set for community forestry which has not yet been registered. It can be concluded that the surrounding areas are agricultural areas.

According to the addition of groundwater contour, the areas with groundwater depth less than 10 meters were set aside. The subsurface characteristics of each site were specified to clarify the suitability of sites in term of groundwater contamination. Boring logs databases of surrounded areas were collected from many sources. Afterward, they were processed by the program as a result subsurface characteristics. Soil profiling by ROCKWORK program show the differences of subsurface characteristics of selected sites. This is truly important for leachate prediction in the following process.

4.5 Results from Visual HELP Simulation

Visual HELP program was used for water simulation of the selected sites. Regarding the amount of percolating water simulation, the default method was used to calculate runoff number. The initial moisture storage was also calculated by the model. In the account of worst case simulation, runoff area was changed to 0 percentage of the profile's surface area. In the meantime, the vegetation class was set as the bare soil for worst case condition.

4.5.1 Landfill structures and percolated water simulation

The profile structure of landfill plays the role as a control factor. Each profile was set as the same except for geological barrier. This study defined excavation for landfill construct as 3 meters. And landfill consists of 4 layers of which each layer is 200 cm. of solid waste with loam soil cover of 30 cm. The final landfill cover was set as 60 cm. of silt loam. The geological barrier was differed based on soil profile stated previously. The default data correspond to geological barrier of each site were selected for model simulation. Therefore, landfill structures of such 7 sites would have the same structure from layers 1-9 and different for laver 10. as shown in Tables 4.6 and 4.7, respectively.

Table 4.6 Landfill structure**.**

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
1. Silty Loam	0.0000	-60.0000	60.0000
2. Loam1	-59.9995	-89.9995	30.0000
3. Municipal Waste (312 kg/cub.m)1	-89.9990	-289.9990	200.0000
4. Loam2	-289.9985	-319.9985	30.0000
5. Municipal Waste (312 kg/cub.m)2	-319.9980	-519.9980	200.0000
6. Loam3	-519.9975	-549.9975	30.0000
7. Municipal Waste (312 kg/cub.m)3	-549.9970	-749.9970	200.0000
8. Loam4	-749.9965	-779.9965	30.0000
9. Municipal Waste (312 kg/cub.m)4	-779.9960	-979.9960	200.0000

Table 4.7 Layer 10 of each site.

Site	Layer 10	Top (cm)	Bottom (cm)	Thickness (cm)
1	**Silty Clay**	-979.9955	-1179.9955	200.0000
2A	**Silty Clay**	-979.9460	-1629.9460	650.0000
2B/2C	**Silty Clay**	-979.9460	-1829.9460	850.0000
3A/3B	**Clay**	-979.9955	-1479.9955	500.0000
4A	**Silty Clay**	-979.9460	-2379.9460	1500.0000
4B	**Silty Clay**	-979.9460	-2479.9460	1400.0000
5A/5B	**Loamy sand**	-979.9460	-1379.9460	500.0000
6A/6B/6C	**Silty Clay**	-979.9460	-1629.9460	100.0000
7A	**Silty Loam**	-979.9460	-2379.9460	600.0000
7B	**Silty Loam**	-979.9460	-2479.9460	700.0000

The natural barrier of site 1, site 2, site 4, and site 6 is silty clay soil which has grey color. It is consist of under 20% sand, between 40-60% clay, and between 40-60% silt. The natural barrier of site 3 is 5 meters thick of clay soil which has grey color. The components of clay are sand under 45%, clay between 40-100%, and silt under 40%. The following properties of this type were default input data of the program. According to soil profiling, site 5 consist of sand layer as a natural barrier.

Visual HELP program could not add sand as a geological barrier. Loamy sand which has soil properties close to sand was used. The natural barrier of site 5 composed of 5 meters thick loamy sand. It has yellow color. It is consist of sand between 70-90%, under 15% clay, and under 30% silt. Moreover, site 7 consists of silt layer as a natural barrier. In contrast, Visual HELP program could not add silt as a geological barrier. Silty loam which has soil properties close to silt was used (Appendix C). The natural barrier of site 7composed of 6 meters thick silty loam. It is consist of sand 50%, under 28% clay, and between 50-90% silt. The properties of silty clay which are the default input data of the program show in Table 4.8.

Table 4.8 The properties of soil barrier

Parameters	Silty clay	Clay	Loamy sand	Silty Loam
- total porosity(vol/vol)	0.479	0.475	0.437	0.501
- field capacity(vol/vol)	0.371	0.378	0.105	0.284
- wilting point(vol/vol)	0.251	0.265	0.047	0.135
- saturated hydraulic conductivity(cm/sec)	2.5E-5	1.7E-5	0.0017	1.9E-4

Using Visual HELP program could be useful for landfill siting. This program simulated the amounts of water that percolate through geological barrier of selected sites. According to difference subsurface characteristics and geological barrier, the results of simulation were a bit different. Sites 1, 2, 3, 4, and 6 have the same total annual percolation or leakance through layer 10 of year 23 (Table 4.9). These sites consist of silty clay and clay soil as the geological barrier. On the other hand, the geological barrier of site 5 and site 7 are sand and silt. The volume of percolated water is less which are 9.84 million cubic meters (MCM) and 9.98 MCM orderly. From the results of water volume, the amount of percolated water through layer depends on type of geological barrier and thickness of layer. Despite the fact that site 5 and site 7 have high permeability soil as geological barrier, they generate less water because site 5 and site 7 have thicker geological barrier, which are 5 meters of sand and 7 meters of silt orderly.

Table 4.9 Total simulated percolation or leakance through layer 10 (m^3) of 7 sites in 23 years.

Site	section	Total percolation or leakage through layer 10 (m3)
1	A and B	1.03E+07
2	A, B, and C	1.03E+07
3	A and B	1.03E+07
4	A and B	1.03E+07
5	A and B	9.84E+06
6	A and B	1.03E+07
7	A	9.98E+06
	B	9.91E+06

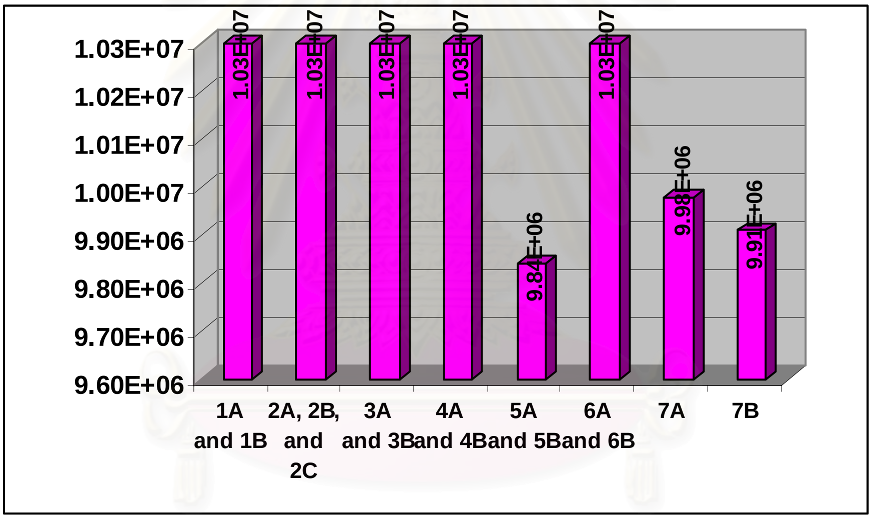


Figure 4.41 Chart of total simulated percolation or leakance through layer 10 (m^3) of 7 sites in 23 years.

4.6 Mitigation measures development

In accordance with leachate from landfill, hazardous substances can contaminate to groundwater resources. The mitigation measures in term of liner adding have been developed in this study. The 0.1 cm. thick of geomembrane was added between the first waste layer and geological barrier into landfill profile to reduce the amount of water. The properties of geomembrane were specified by the model as Table 4.10.

Table 4.10 Properties of geomembrane layer.

Parameter	Value	Units
Saturated hydraulic conductivity	2E-13	(cm/sec)
Pinhole density	2	(#/ha)
Installation defects	2	(#/ha)
Placement quality	4	(-)
Geotextile transmissivity	0	(cm2/sec)

Visual HELP program calculated water percolated from selected sites after geomembrane adding. Table 4.11 shows water volume comparison between landfill with and without liner adding. After liner adding, the amount of water generated in 23 years period decreased. Site 3 section A and sectionB is the first sites that generate the least water volume which is 6.39 MCM. Next, site 7 section B and section A are the second and third ranks.

Table 4.11 Comparison volume of water between with and without liner adding.

Site	section	Total percolation or leakage through layer 10 (m3)	Total percolation or leakage through layer 11 (m3) after geomembrane adding
1	A and B	1.03E+07	7.60E+06
2	A	1.03E+07	7.26E+06
	B, and C	1.03E+07	7.22E+06
3	A and B	1.03E+07	6.39E+06
4	A and	1.03E+07	7.15E+06
	B	1.03E+07	7.16E+06
5	A and B	9.84E+06	7.95E+06
6	A and B	1.03E+07	7.93E+06
7	A	9.98E+06	6.64E+06
	B	9.91E+06	6.59E+06

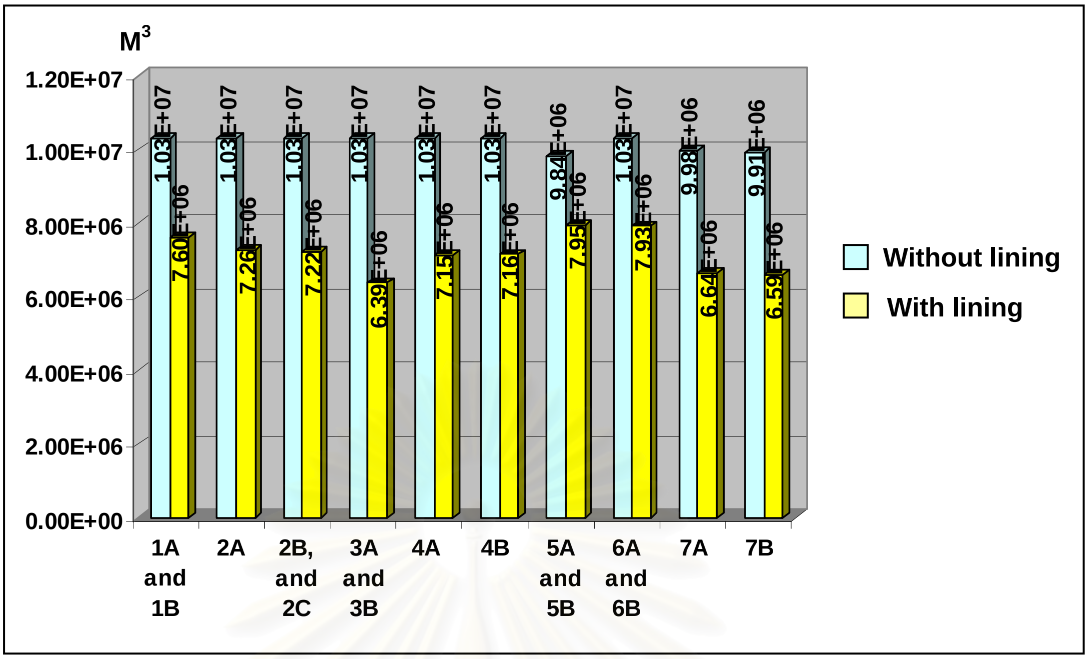


Figure 4.42 Chart showing the comparison volume of total simulated percolation or leakance between with and without liner adding.

Based on Visual HELP simulation, the difference of percolated water volume from each site was resulted in accordance with the difference of soil barrier. Groundwater would be affected by hazardous substances contaminated in the high volume of leachate. Accordingly, the impact could be potentially occurred if one do not consider soil characteristics as the main factor. In addition, barrier soil liner helps to restrict vertical flow. This layer should have substantially low hydraulic conductivities which is typically below 1 x 10^{-6} cm/sec (Schroeder, 2004). The program assumes that barrier soil liner is permanently saturated, in such that its properties do not change with time. The area having similar characteristics of soil would generate the same water volume such as, site 1, site 2, site 3, and site 4 (Figure 4.42). Even though site 7 consists of a little higher permeability (Appendix C) than the others, the lower water volume had been generated from this site under the influence of high thickness of soil barrier. In conclusion, type and thickness of geo barrier have the effect on percolated water volume. Similarly, Elsbury et al. (1990) indicated that the hydraulic conductivity of clay liners can be impacted by the soil workability, gradation, and swell potential; overburden stress on the liner; liner thickness; liner foundation stability; liner desiccation and/or freeze and thawing; and degree of compaction.

After addition of geomembrane, each site generated lower water volume as geomembrane is the low permeable material. The HELP program defines a geomembrane as a thin "impervious" sheet of plastic or rubber used as a liquid barrier. The low permeability soil component increases the breakthrough time and provides physical strength. In contact with a geomembrane the low permeability soil decreases the rate of leakage through the hole in the geomembrane. As a result, site 3 which consist of 5 meters of clay as a soil liner generated the lowest water volume. In contrast, site 5 which generated lower water volume consists of sand as soil barrier could increase the rate of leakage in geomembrane. As a result, this site generated a higher water volume.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Generally, one of the environmental problems is the contamination of hazardous substances in soil and groundwater. Landfill site could be counted as a major cause of such contamination problems due to an improper management. It is significantly to avoid such problems by investigation of the landfill site with environmental sensitive area consideration. Conventionally, the important areas based on Pollution Control Department were set aside in landfill siting process. Moreover, the previous study conducted by CAPEQM-project identified the areas in Khon Kaen province for landfill sites using spatial planning approach. However, the CAPEQM project employed the general criteria based on PCD criteria with some additional factors but not include groundwater depth. In order to intensively prevent contamination of hazardous substances to groundwater, this research focused on evaluation of the potential site for sanitary landfill using Geographic Information System (GIS) and Visual Hydrologic Evaluation of Landfill Performance (HELP) computer program. Groundwater contours of Khon Kaen were established and divided into 3 levels as highest (0-5m), high (>5-10m), and medium to low (>10 m) using GIS technique. Environmental sensitive area map with addition of such groundwater contours was established and classified into 3 levels as well. As a result of groundwater contour adding, the area was screened by using groundwater levels. The highest environment sensitive area was increased to 6,081 square kilometers. While, the high environment sensitive area was decreased to 3,975 square kilometers, and the medium to low sensitive area was decreased to 572 square kilometers.

The medium-low sensitive area was categorized and selected for investigation of general characteristics. The results of field survey showed that all sites have the similar land use which are agricultural area and the abandon area except for site 1. In addition, 7 selected sites were profiled and specified for the subsurface characteristics. Then they were used as input data for leachate simulation using Visual HELP program. The Hydrologic Evaluation of Landfill Performance (HELP) model was developed to help landfill designers and regulators evaluate the hydrologic performance of proposed landfill designs. The model accepts weather, soil and design data and uses solution techniques (Appendix C) that account for the effects of unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. The results of simulation represent a risk of groundwater contamination. Site with high water volume presents a high risk for contamination of hazardous substances. Results of Visual HELP prediction showed site 5 has least water volume percolated through geological barrier than the others which is 9.84 MCM. With geomembrane lining, the water simulated from such selected sites was decreased. Site 3 became the best site that generated least amount of water which is 6.39 MCM.

In conclusion, the subsurface characteristics represented by the different soil type and thickness would affect on water generation from landfill. Without lining of geomembrane, site 5 located in Amphoe Ban Phai, Tambon Hin Thang nearby Ban Hin Thang Village is suitable area due to less water percolation. On the other hand, with geomembrane liner, site 3 located in Amphoe Nong Rue, Tambon Ban Meng and Tambon Yang Kham, generated the least water volume. Also, they were separated from communities and sensitive areas. Moreover, this study also provided GIS and Visual HELP program as the meaningful tool to facilitate landfill siting. The combination of using GIS and Visual HELP program conducts less time-consuming in exploring an appropriated field study, including wages and site investigation budgets.

5.2 Recommendations

- Due to some limitations, this study could not drill bore holes. Therefore, the secondary databases used in this study were gathered from various sources. Despite the fact that landfill construction has to install bore holes drilling process to study the real characterization of the proposed sites before the construction.
- According to dealt with a large scale map, the location of detail features on earth’s surface could be error. Site survey and site investigation processes are necessary.
- Although geomembrane liner can reduce the percolated water, it can be leaked and allow hazardous substances seeping through and then contaminate

groundwater. Therefore landfill and disposal site have to avoid the shallow groundwater areas.

- Modification of criteria applied should be made according to site (e.g. groundwater level).

- Although, sites 5 and 3 are the most suitable sites in the study, the other sites can be used for landfill sites. if more mitigation measures such as put more geo synthetic liner and install the monitoring well to assess the groundwater contamination. The impacts can be minimized and safe for human health and environment.

REFFERENCES

Australia. Department of Primary Industry Water and Environment. Waste Managemenmt Branch. Landfill Code of Practice; A sustainability Guide to Landfilling in Tasmania. Australia, 2003.

Bilitewski, B. and Marek, G. Waste Management. Translated by Weissbach, A.and Boeddicker,. H. Berlin Heideberg: Springer-Vwelag, 1994.

Coates, D. R. Environmental Geology. Canada: John Wiley & Sons, 1981.

Environment office 10 . Natural Resources and Environmental State of [Online]. 2004. Available from: http://www.esanenvi.net [2004,June7]

Grim, R. E. Clay Mineralogy. 2nd. USA: McGraw-Hill Book, 1968. Summary of Research on Mercury Emissions from Municipal Landfills [Online]. 2002. Available from: http://www.newmoa.org[2004,June14]

Kamolporn Kerdput. Selection of Potential Solid Waste Disposal Areas in Pathum Province. Master's Thesis, Inter-Department of Envirnmental Science, Graduate School, Mahidol University, 1999.

Maryland Department of Natural Resources, Maryland Geological Survey. A Explanation of Shepard's Sediment Classification. Available from: http://www.mgs.md.gov [2005, April 4]

Ministry of Natural Resource and Environment. Environment Office 10, Regional office. CAPEQM-project. Spatial Planning for Sustainable Development. Khon Kaen., 2003.

Ministry of Science Technology and Environment. Pollution Control Department. Regulation and Guideline of Municipal Solid Waste Management. Bangkok: Pollution Control Department, 2000.

Northern Territory Government, Northern Territory Department of Infrastructure, Planning and Environment. Guidelines for the siting, design and management of solid waste disposal sites in the northern territory 2003[Online]. Australia: Northern Territory Government. Available from: http://www.ipe.nt.gov.au [2004, May 25]

Paul N., Gigliello, K. A., and O'Neil, T. K. Groundwater-Leachate Modelling/ Sampling. USA : Technolomic Publishing Company, 1984.

Pollution Control Department. Waste and Hazardous Substance Management Bureau. Municipal Waste Management; Manual for Local Administration[Online]. Pollution Control Department, 2002. Available from: http://www.pcd.go.th [2004, May 12].

Pollution Control Department. The State of Thailand's Pollution in Year 2002. [Online]. Pollution Control Department, 2002. Available from: http://www.pcd.go.th [2004, May 12]

Schroeder, P.R., Lloyd, C. M., and Zappi, P. A The Hydrologic Evaluation of Landfill Performance (HELP) Model User's Guide for Version 3. South Carolina : Waterloo Hydrogeologic, 2004.

Solenhofen, A. Rock and Their Importance to Stone Working, Carving, and Lapidary Working of Rocks and Minerals by the Ancient Egyptians [Online]. Available from: http://www.geocities.com/unforbidden_geology/ rock_properties.htm. [2005, May 23]

Surasak Boonlue. Soild waste disposal site selection: A case study of Sanitary Districts of Mae Sai, Mae Chan, and Chiang Saen. Master's Thesis, Department of Geography, Graduate School, Chulalongkorn University, 1998.

Tchobanoglous, G., Theisen, H., and Vigil, S. A.. Integrated Solid Waste Management: Engineering Principles and Management Issues. USA. McGRAW-HILL,1993 .

Utanawan Boonruang. Environmental Geology Appraisal Using GIS for Sanitary Landfill Site Selection in Changwat Chachoengsao. Master's Thesis, Department of Geology Faculty of Science Chulalongkorn university, 2001.

University of Canterbury. Centre for Advanced Engineering. Landfill Guidelines. Christchurch New Zealand: 2000.

Waterloo Hydrogeologic. Visual HELP user's manual. Canada: Waterloo Hydrogeologic, 2004.

Waterloo hydrogeologic. Visual HELP Lab Exercise Recharge. Estimating Groundwater Recharge with Visual HELP. Canada : Waterloo Hydrogeologic , 2004.

APPENDICES

APPENDIX A
LAYOUT

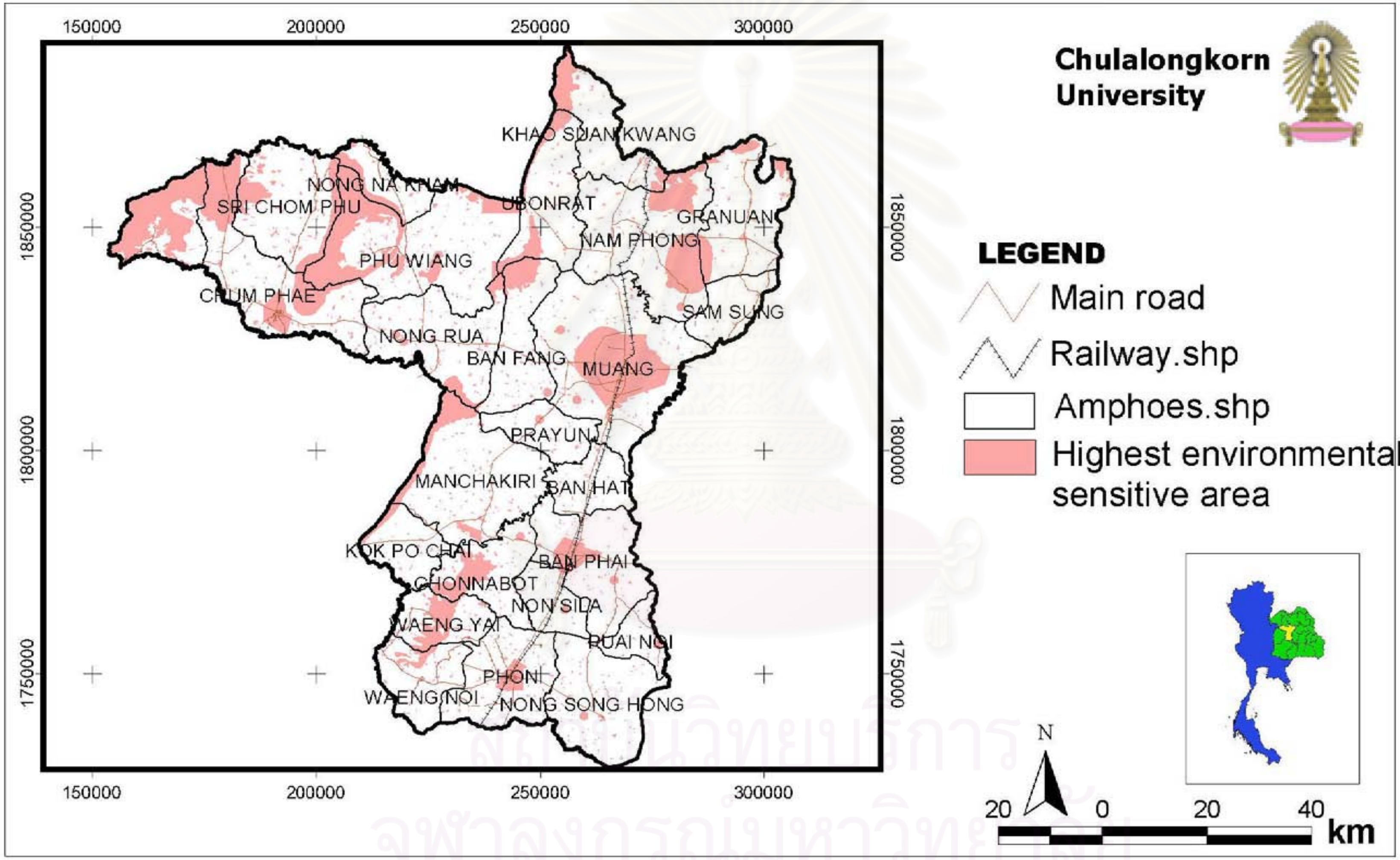


Figure A-1 The highest environmental sensitive areas for landfill

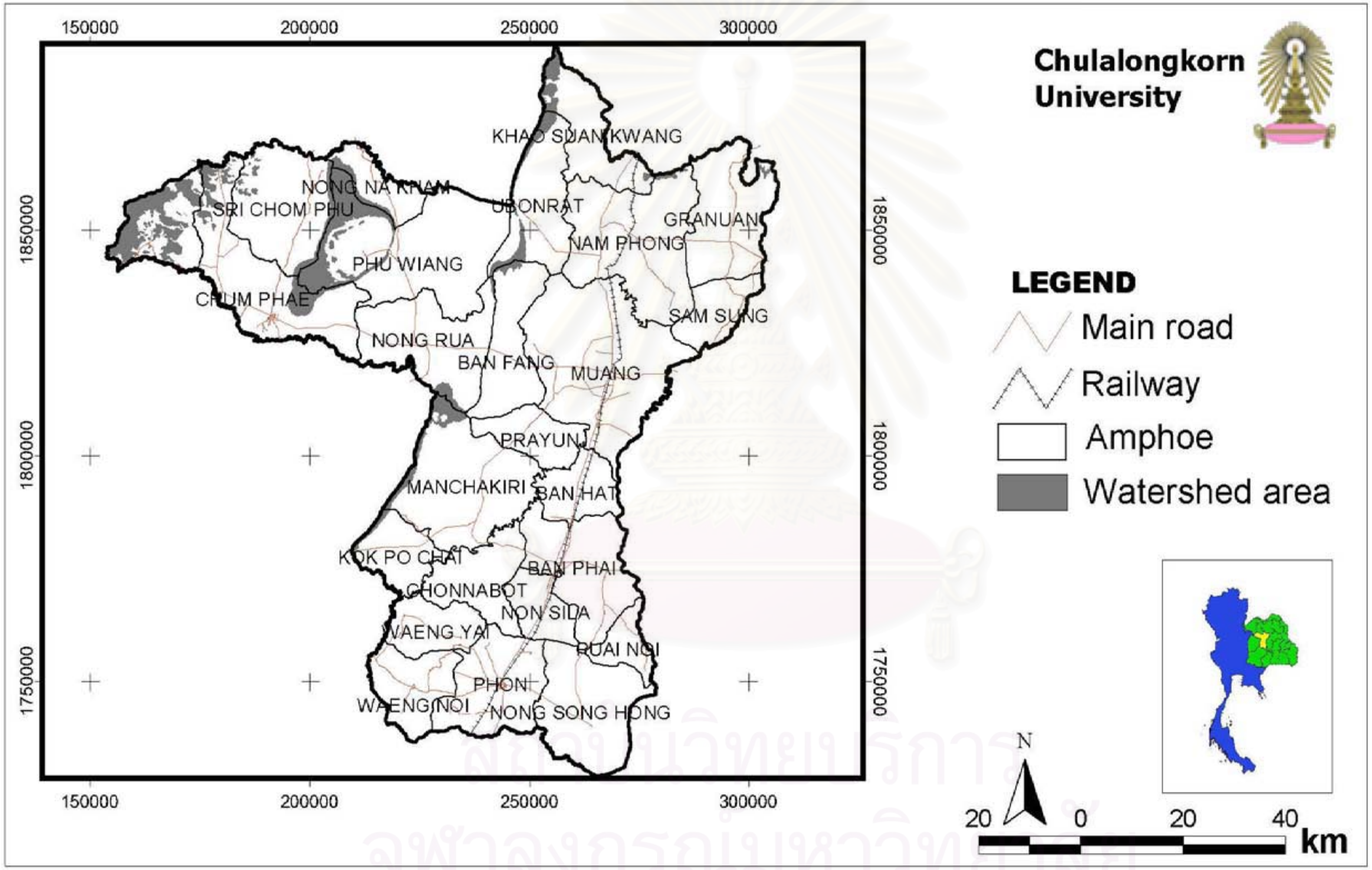


Figure A-2 Watershed Area

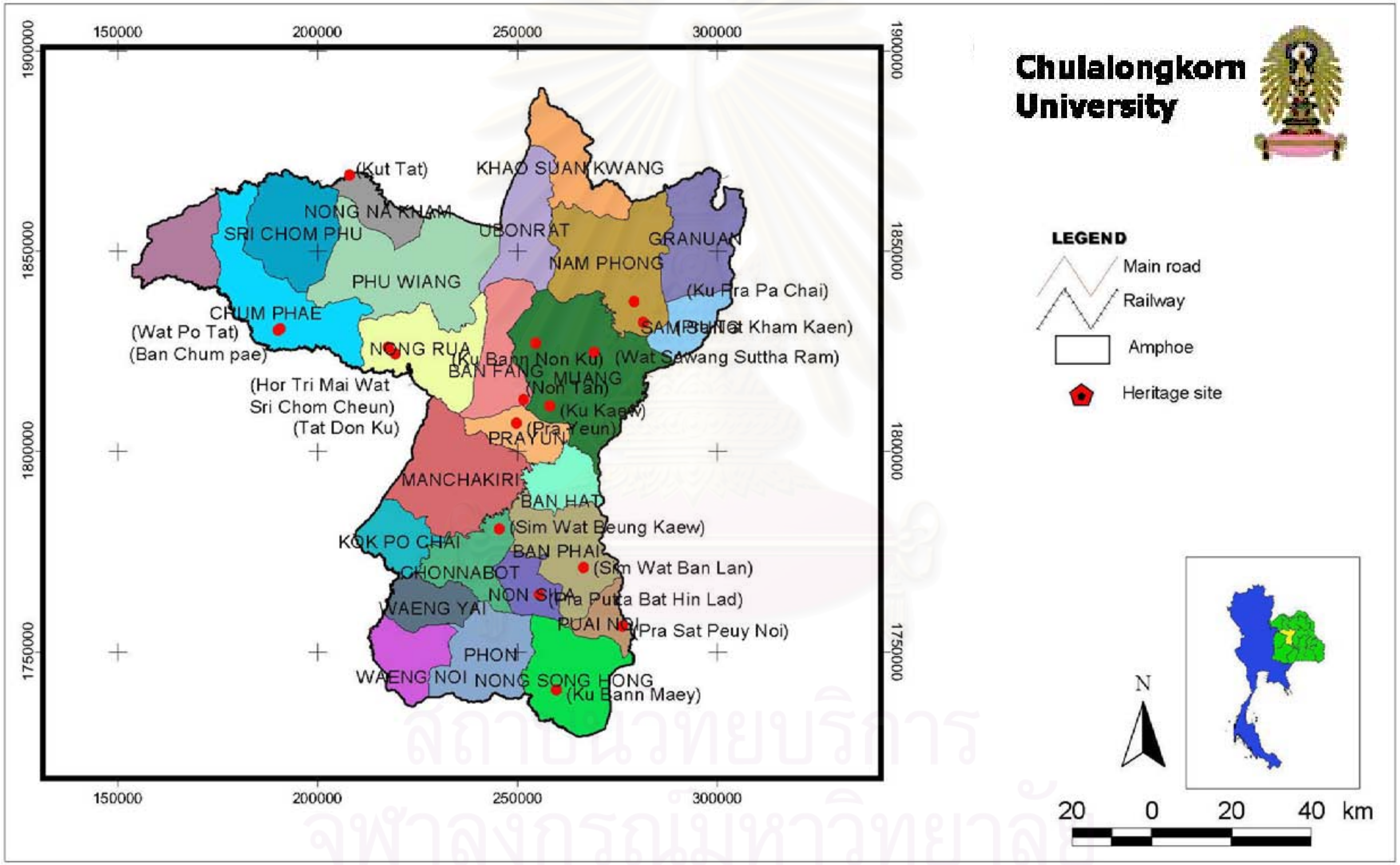


Figure A-3 Heritage Sites

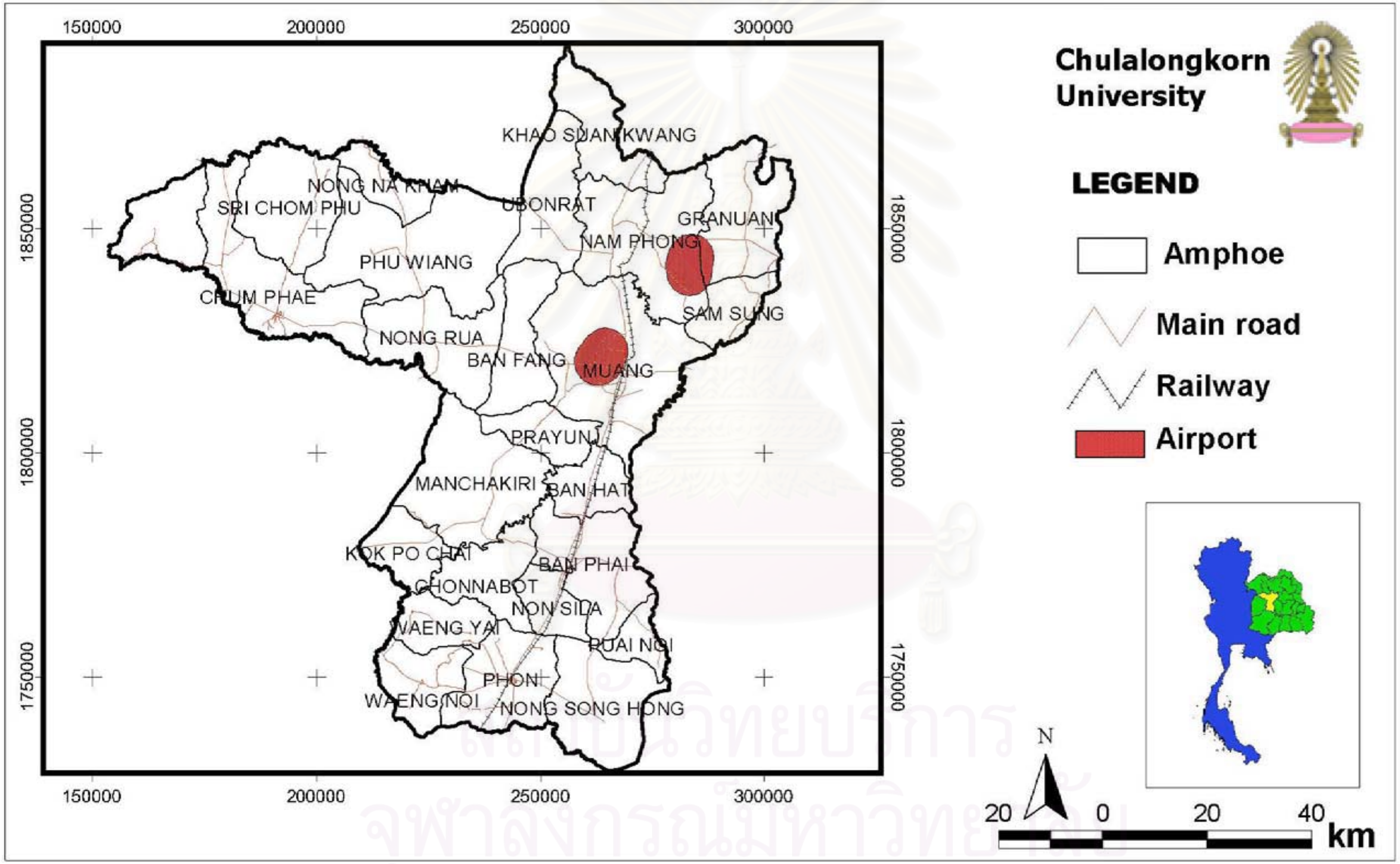


Figure A-4 Airport + Buffer

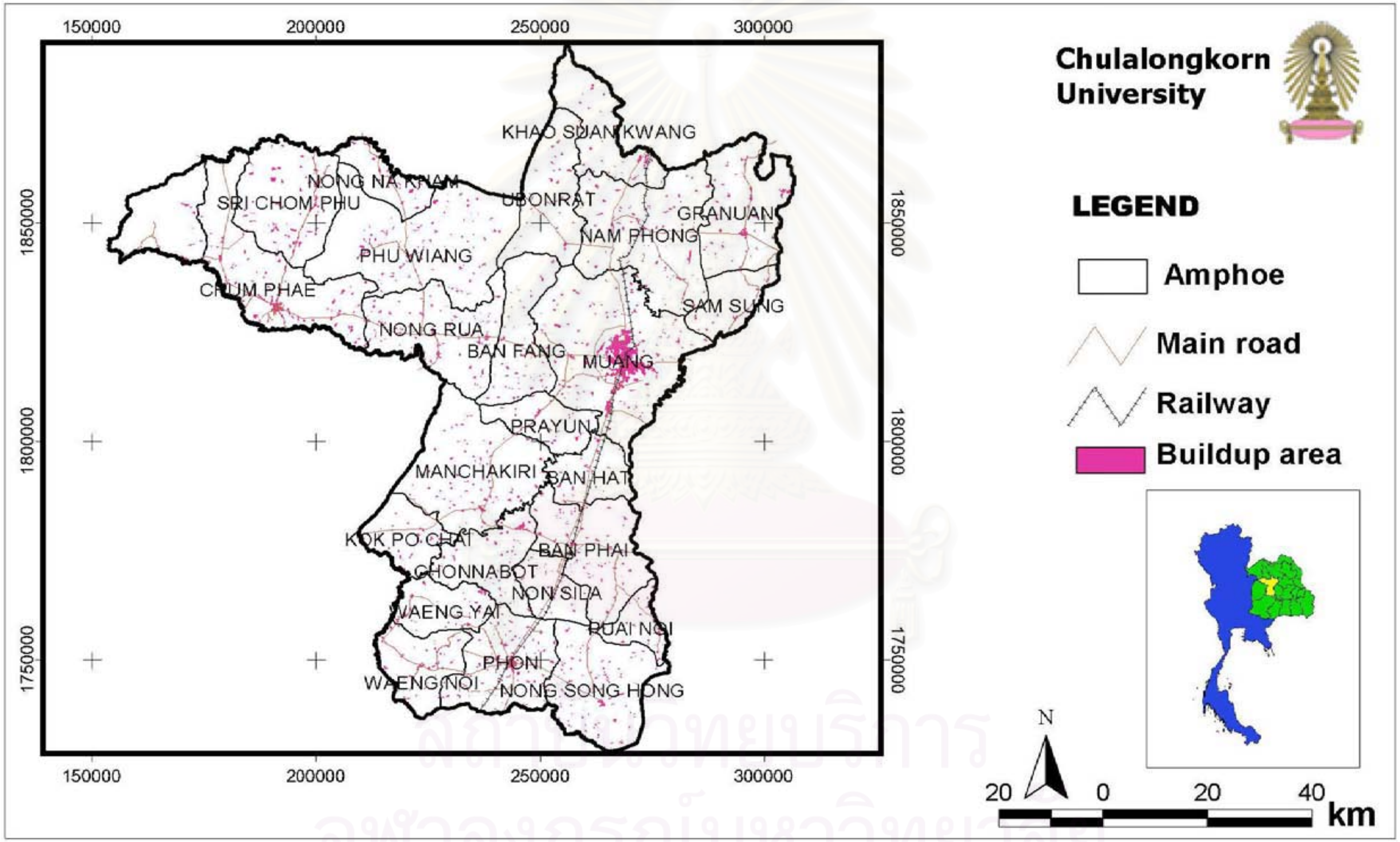


Figure A-5 Buildup Area

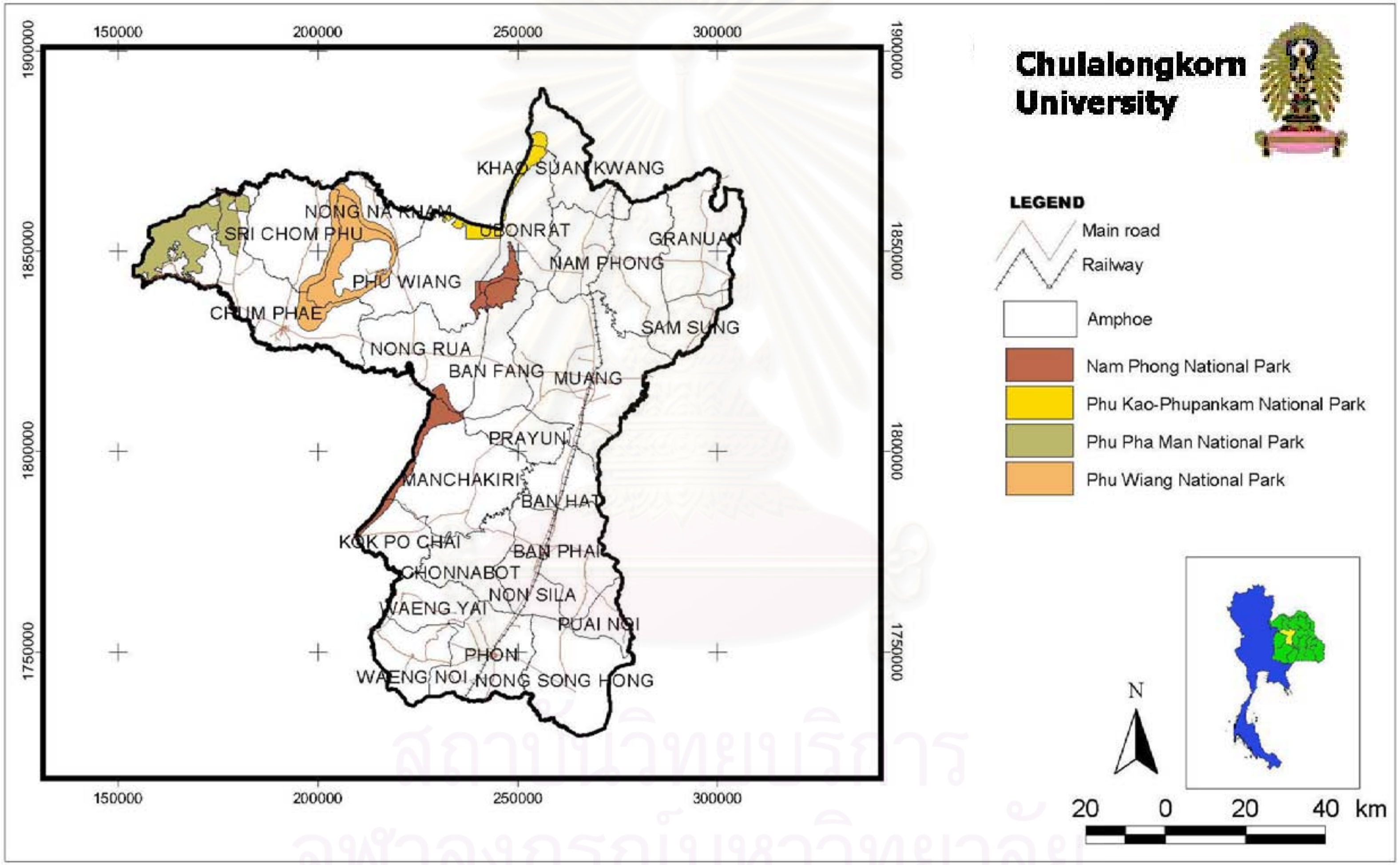


Figure A-6 National Park

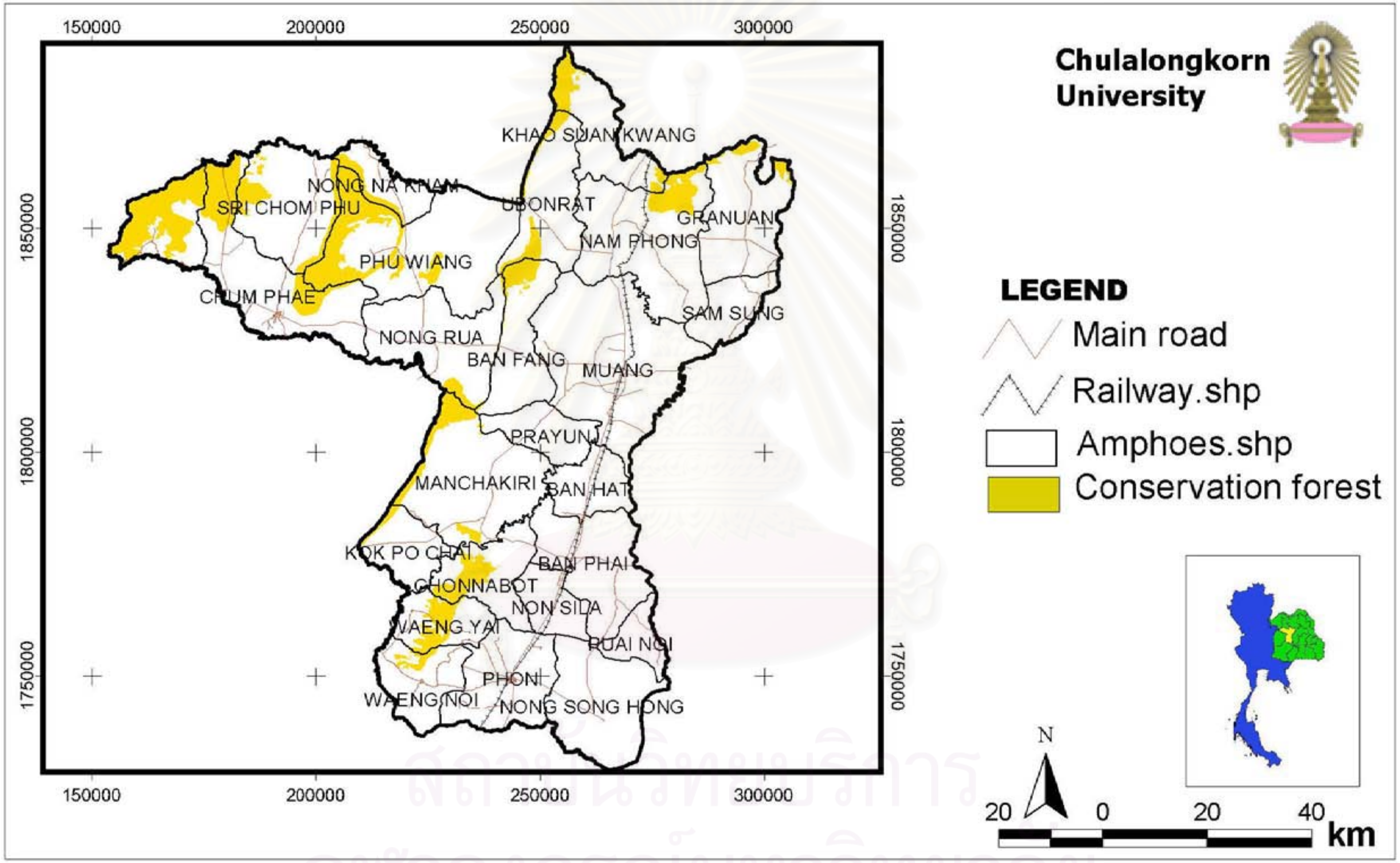


Figure A-7 Conservation Forest

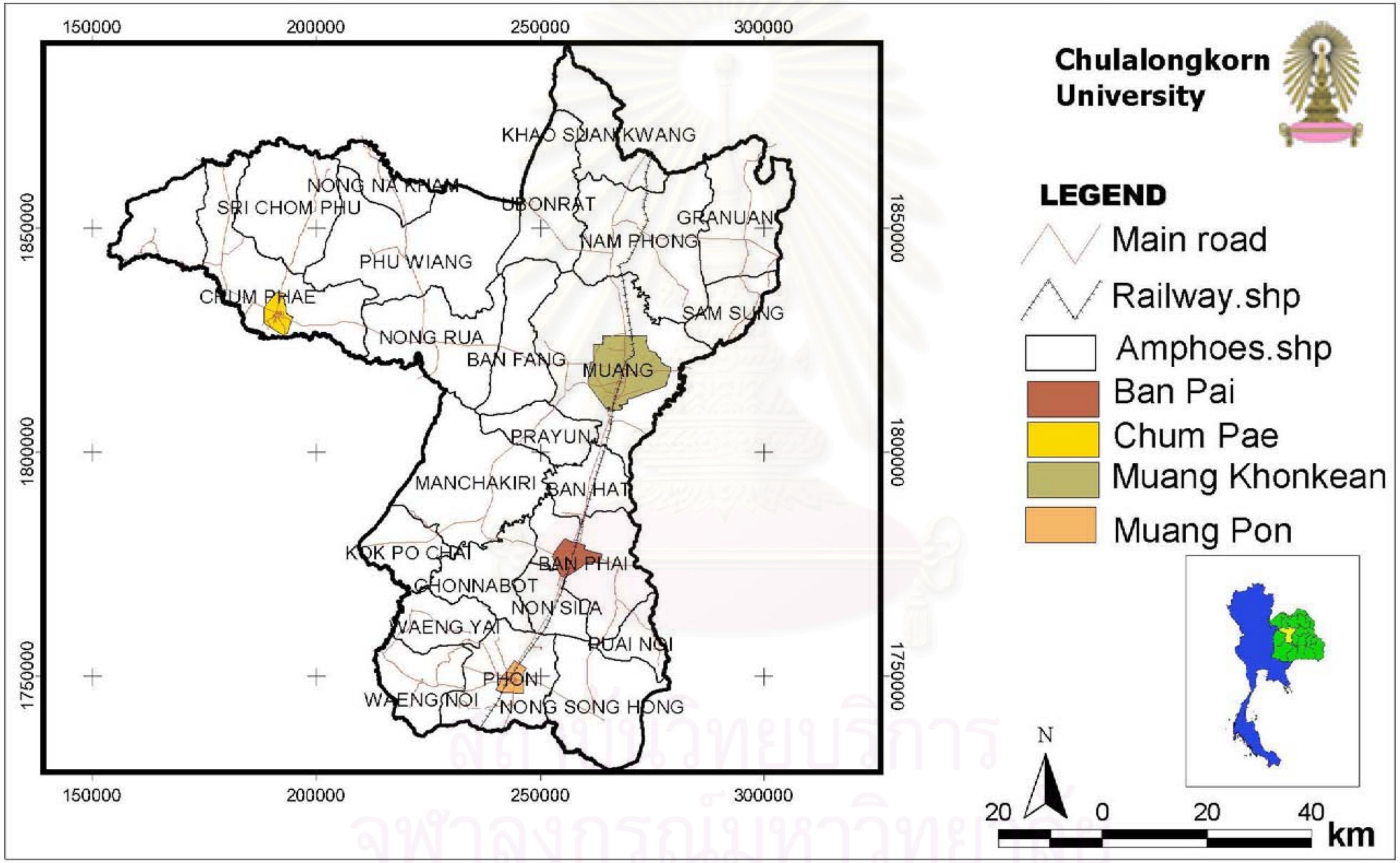


Figure A-8 4 Municipalities Area

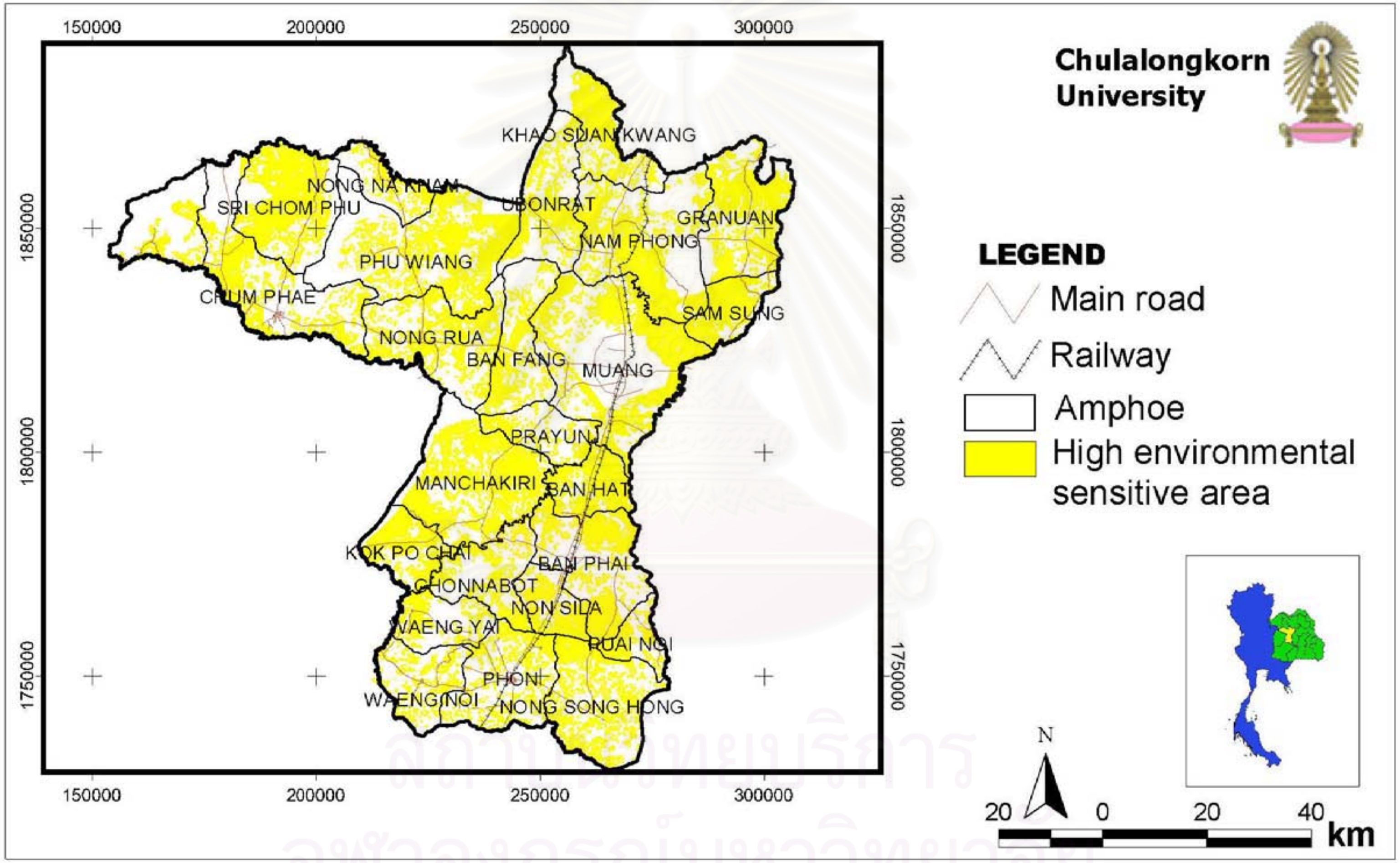


Figure A-9 High Environmental Sensitive Area

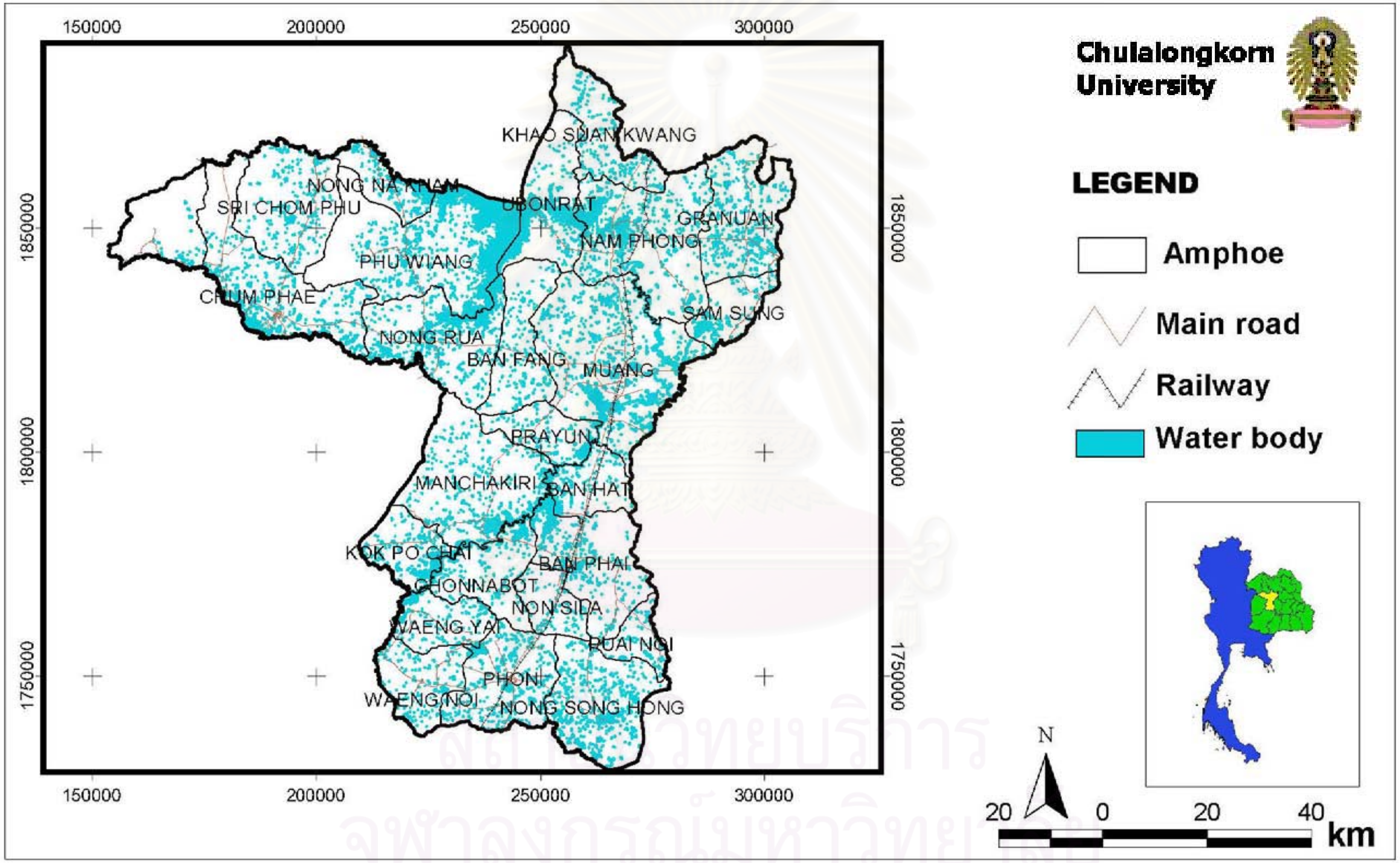


Figure A-10 Water Bodies

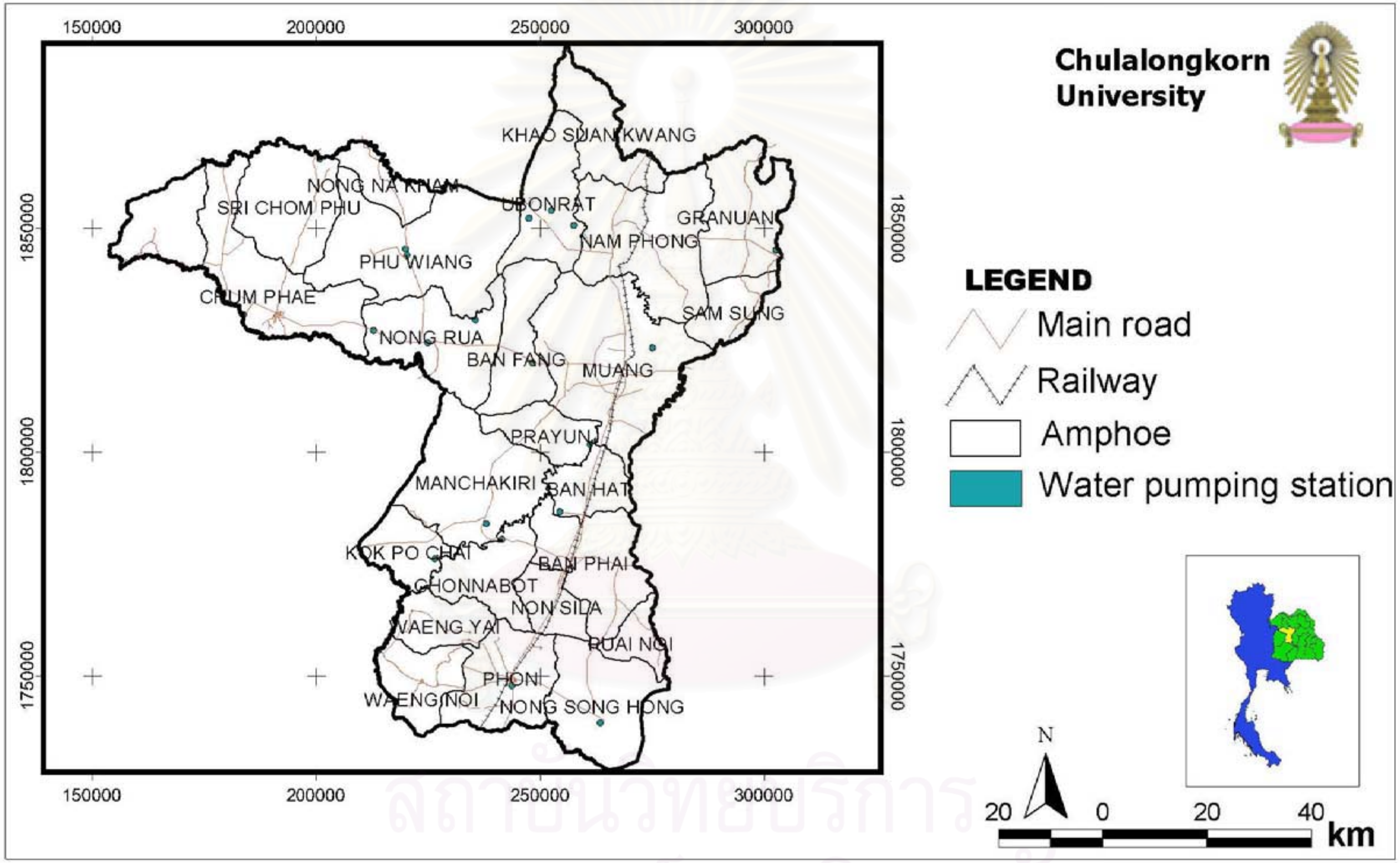


Figure A-11 Water Pumping Station

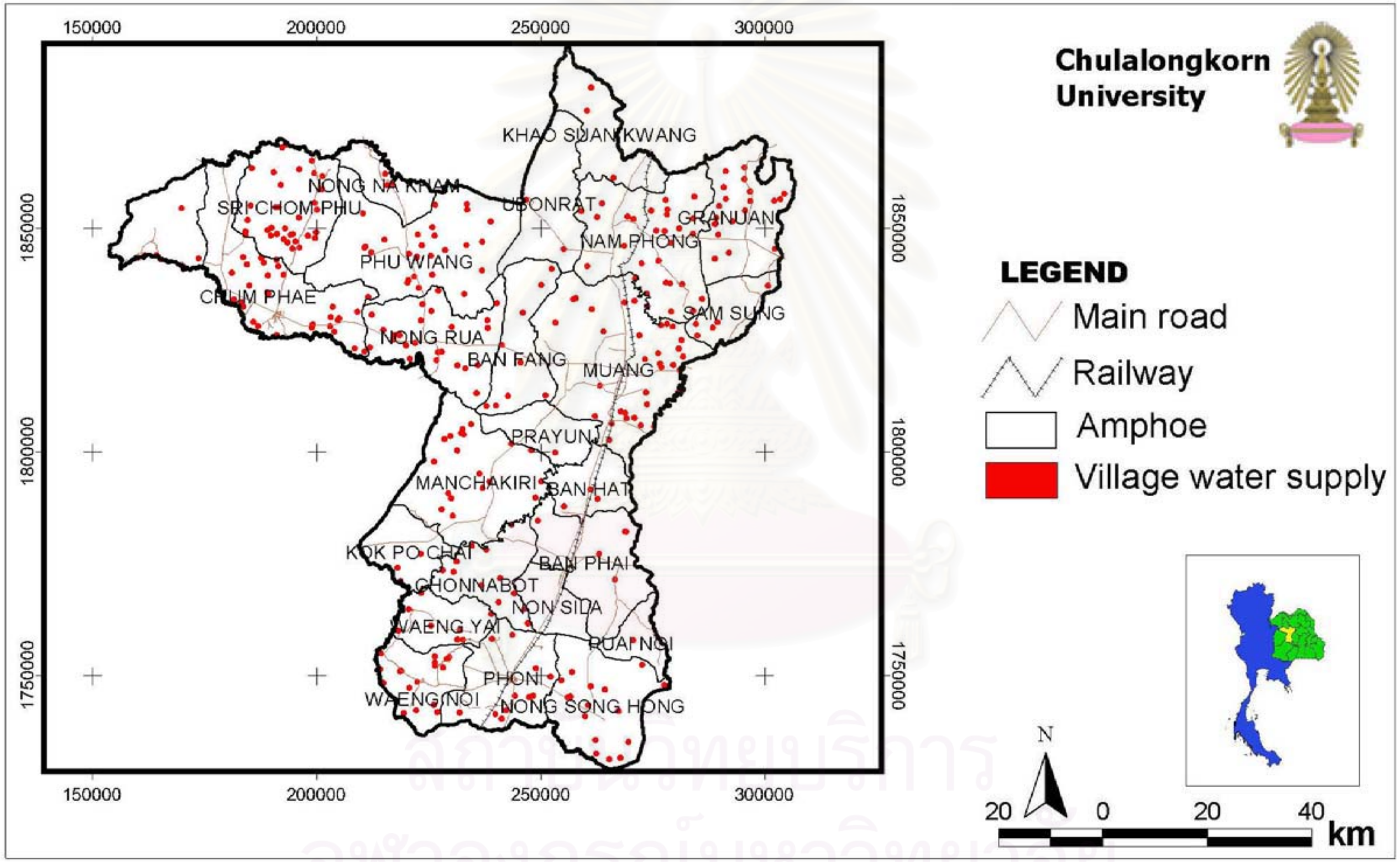


Figure A-12 Village water supply

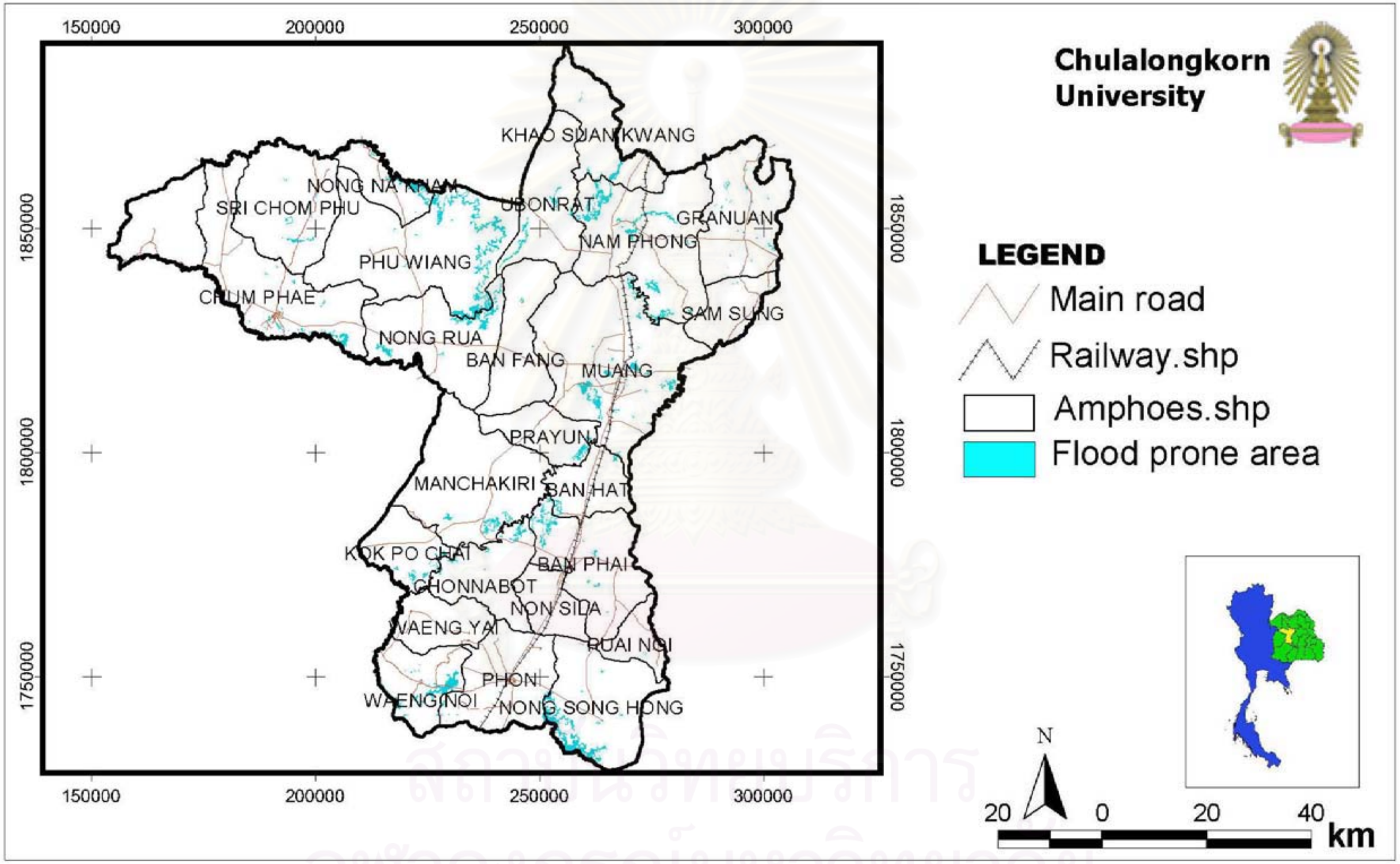


Figure A-13 Flood Prone Area

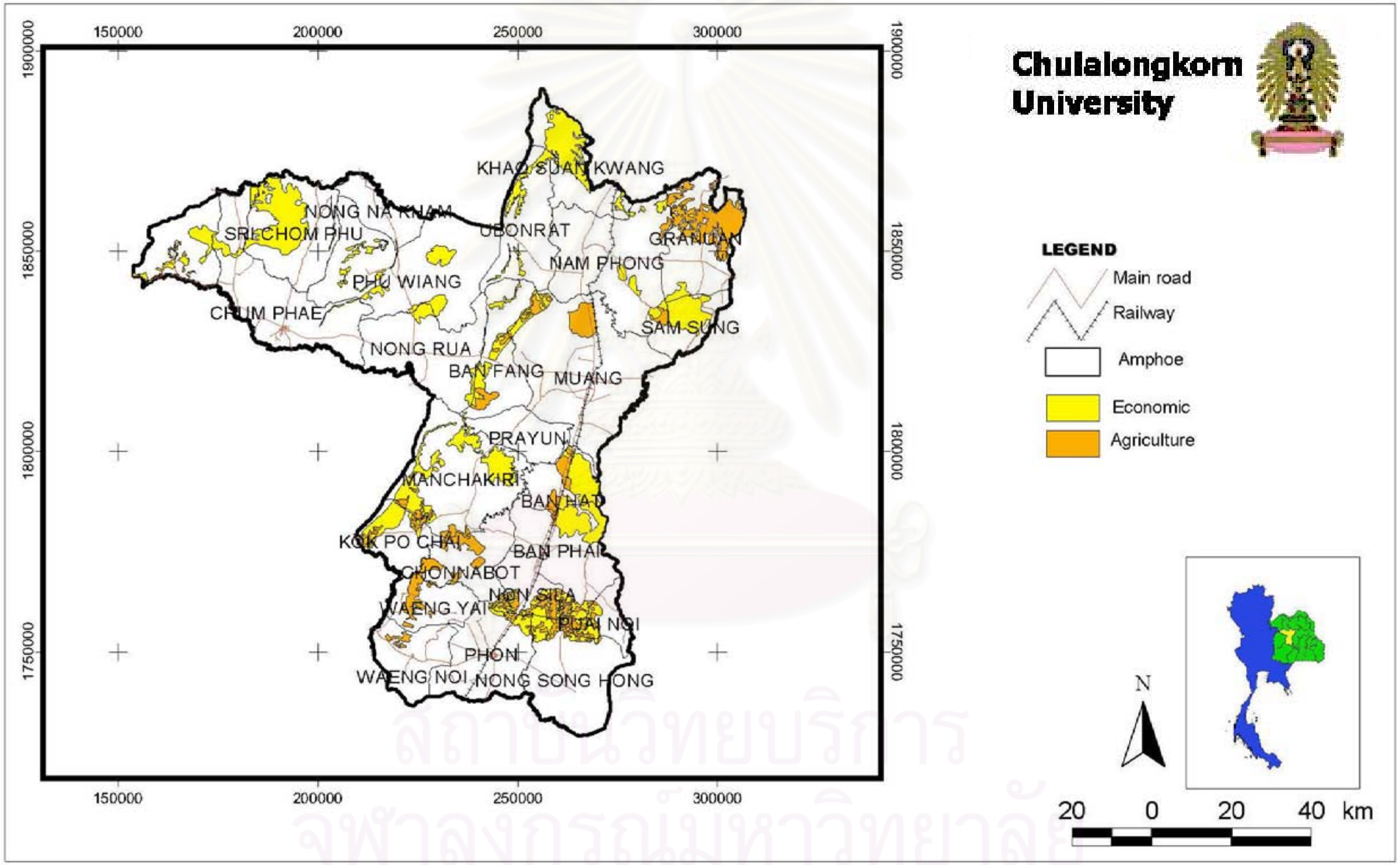


Figure A-14 National reserve forest (Zone A and E).

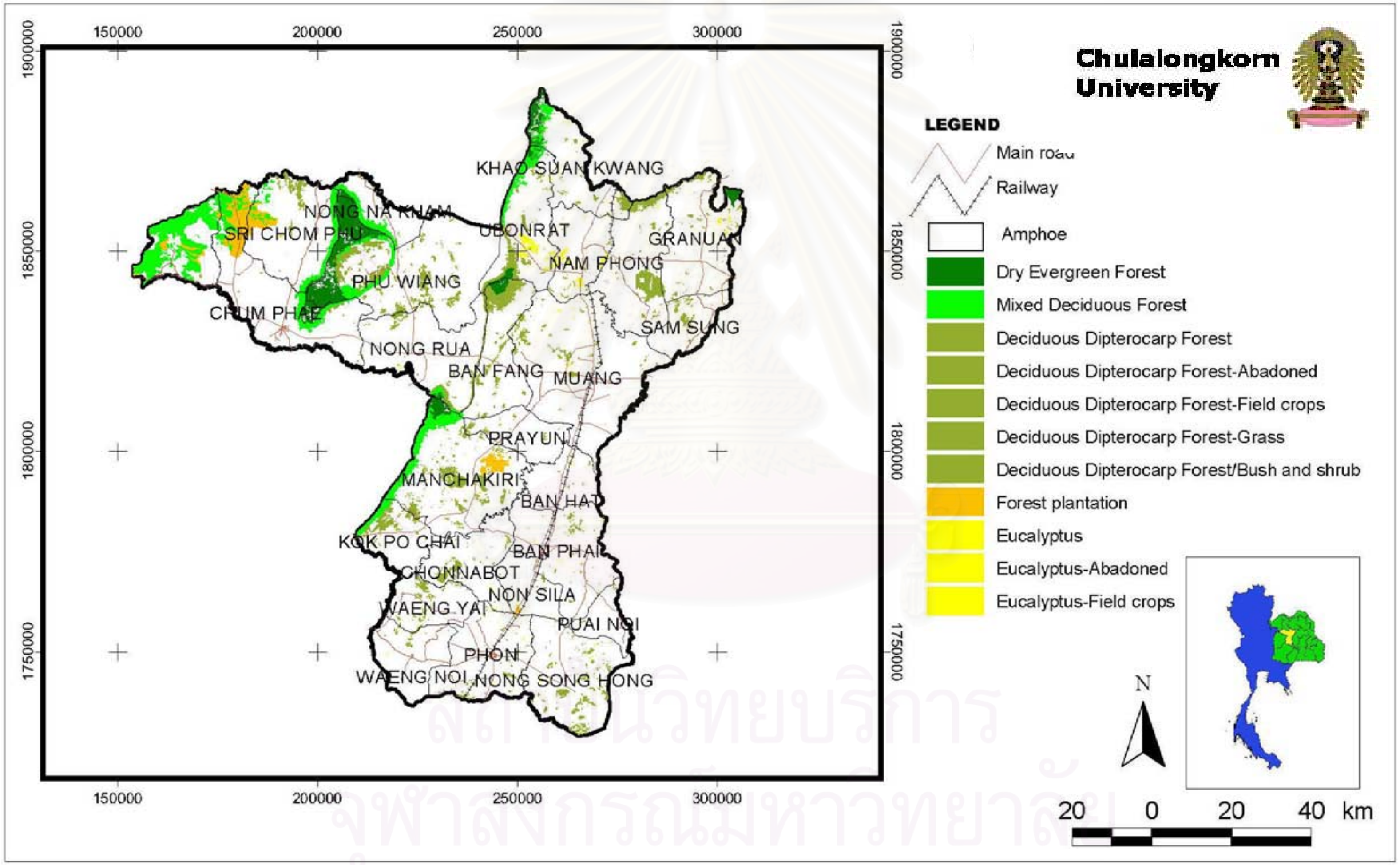


Figure A-15 Existing Forest

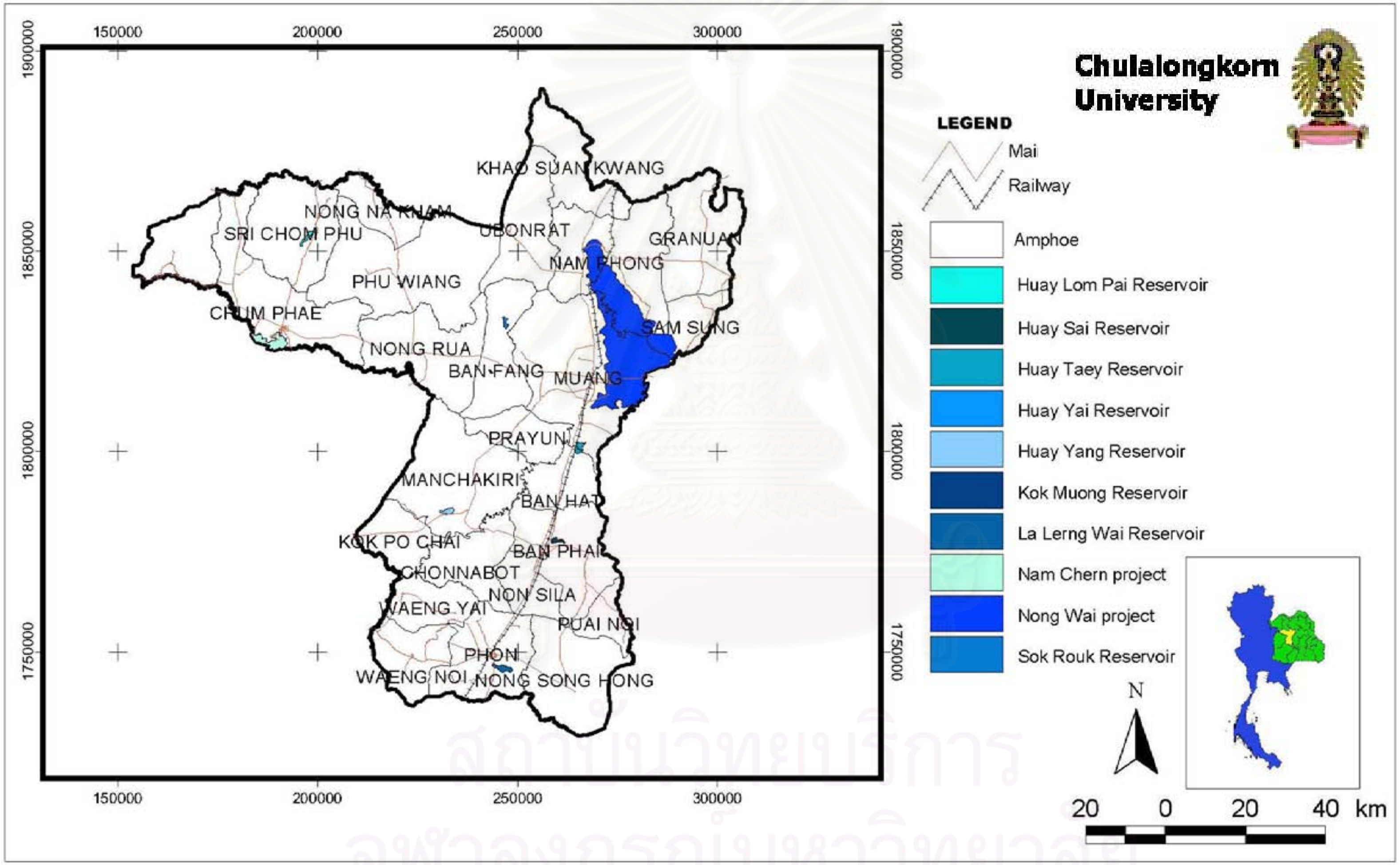


Figure A-16 Irrigation Area

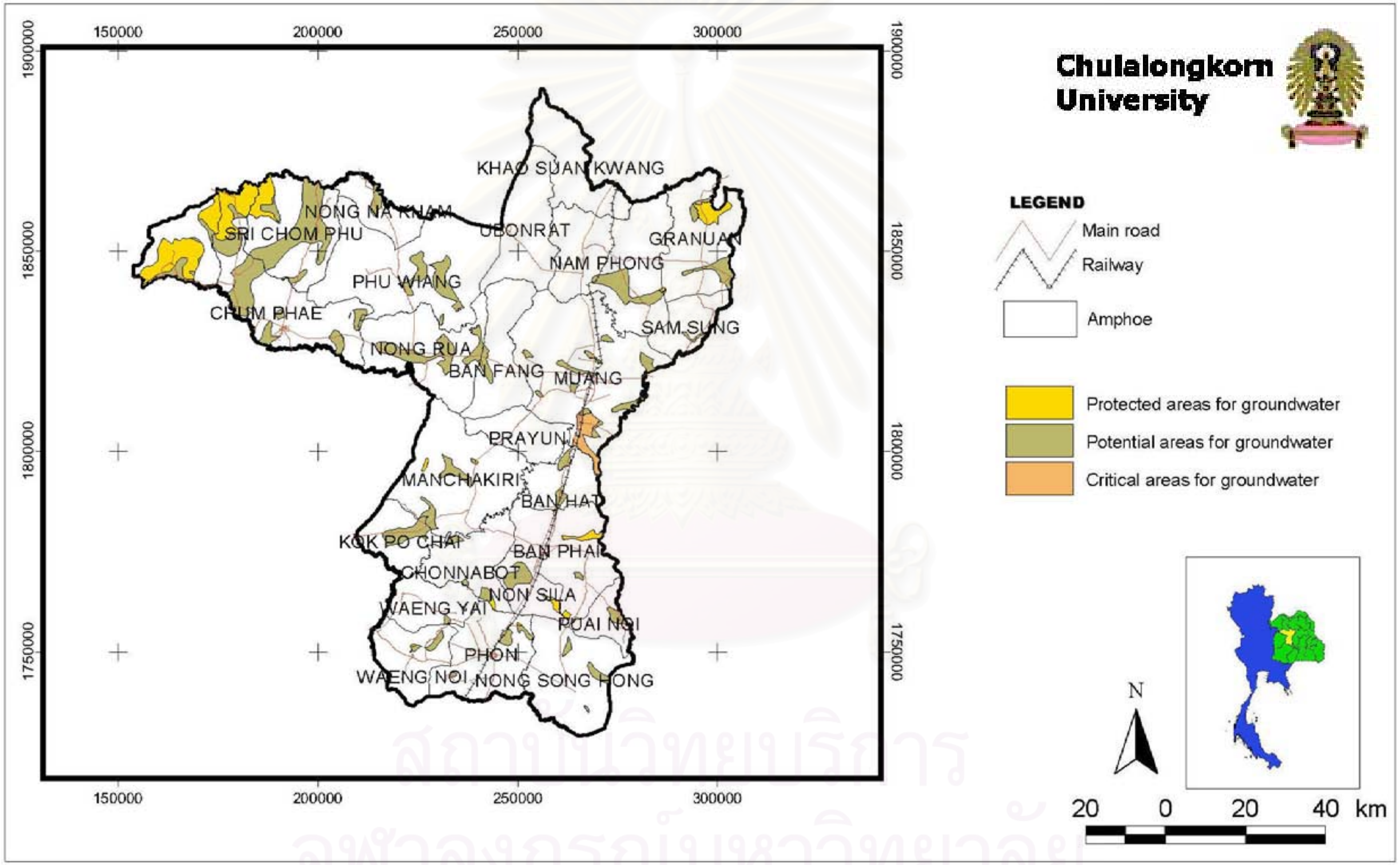


Figure A-17 Potential , protected, and critical; areas for groundwater

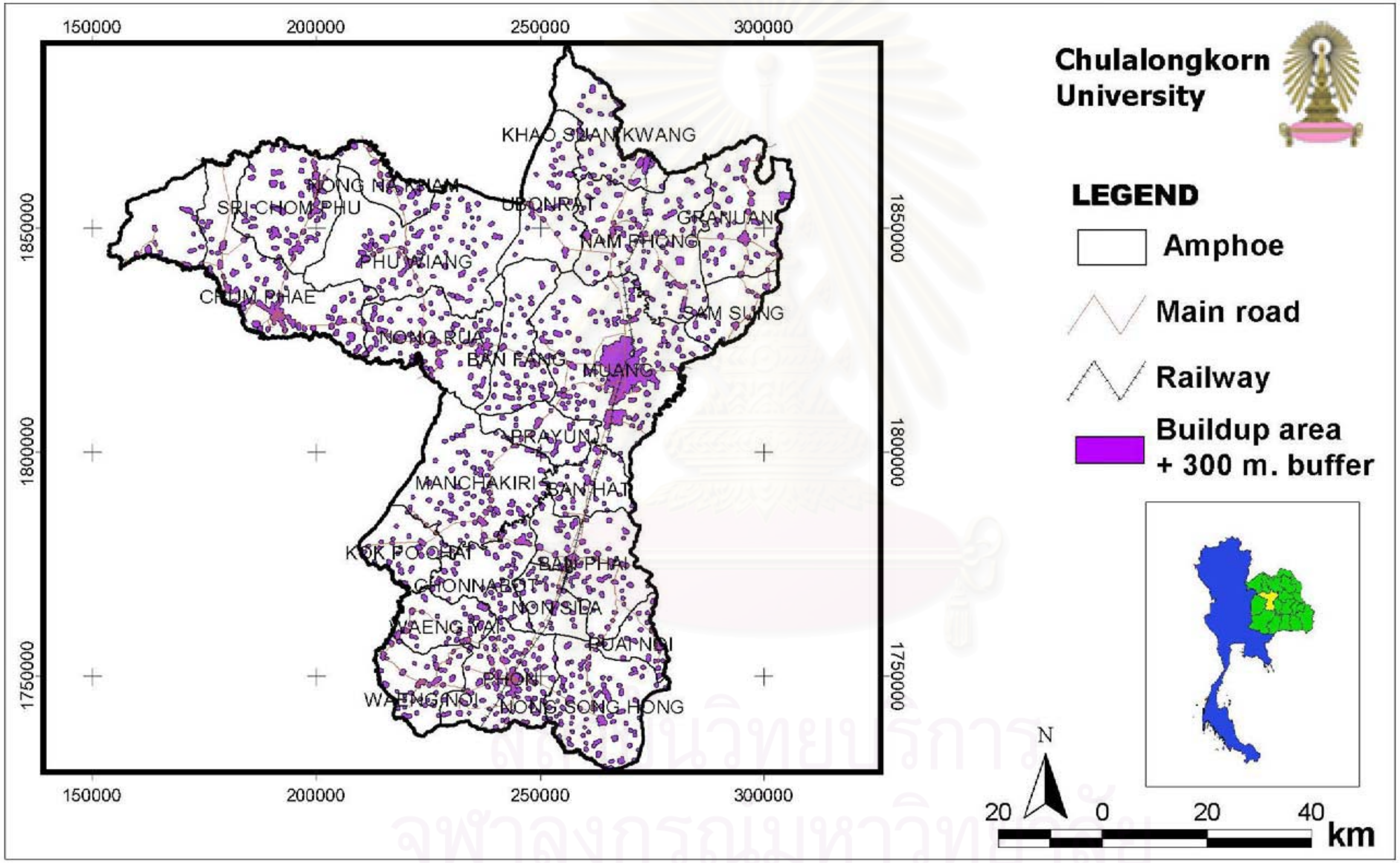


Figure A-18 Buildup Area+ 300m. buffer

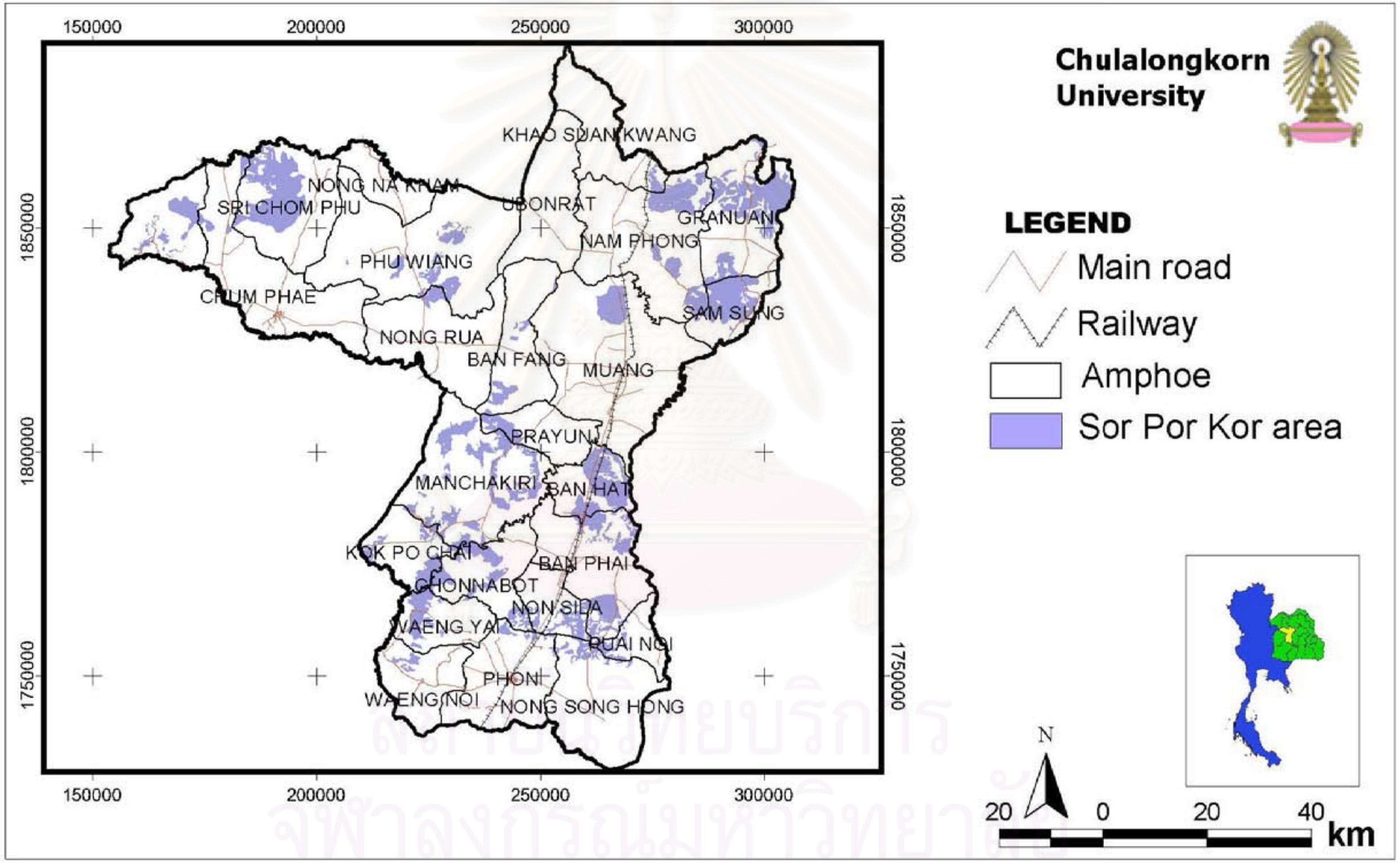


Figure A-19 Sor Por Kor Area

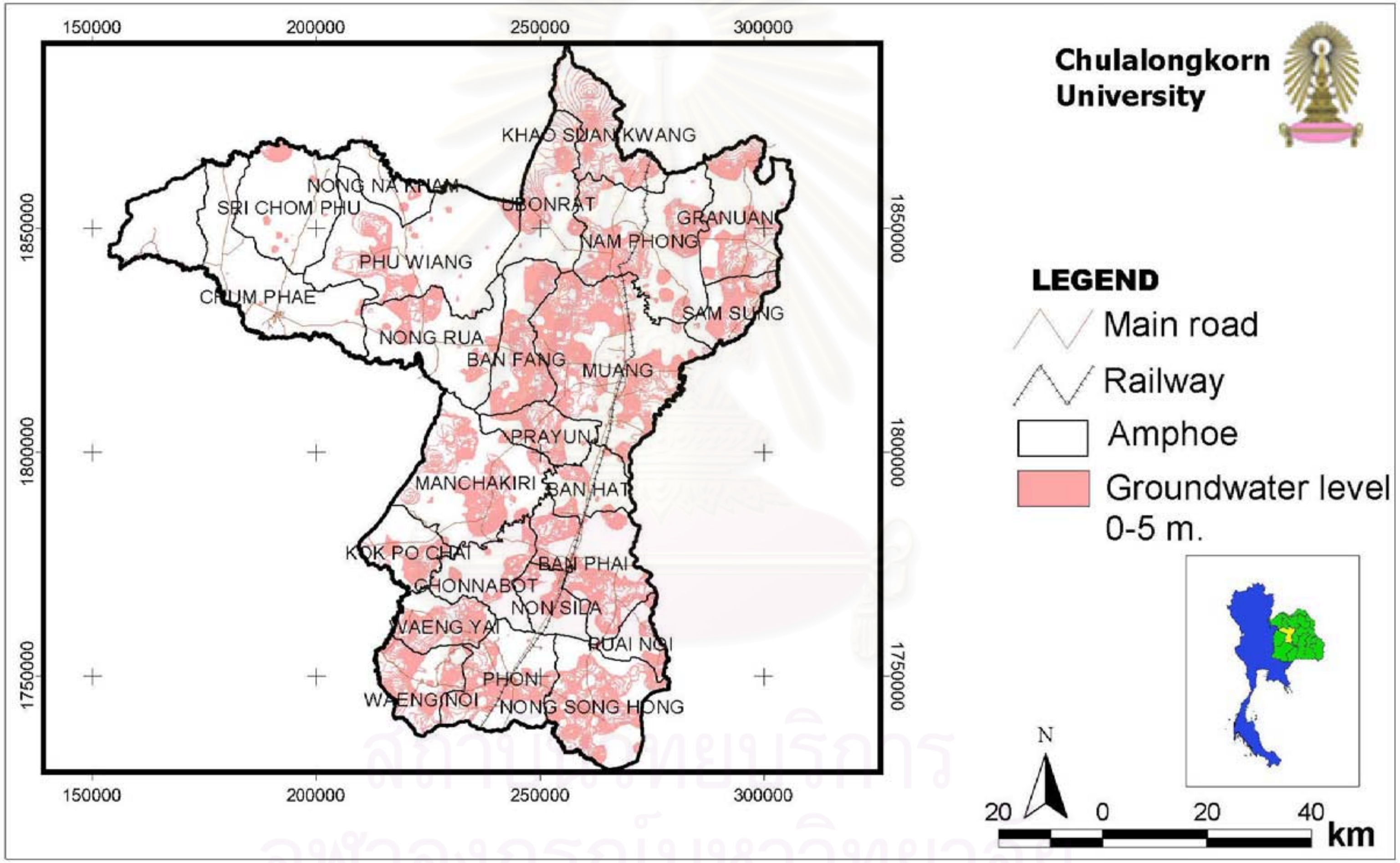


Figure A-20 Groundwater level at 0-5 m.

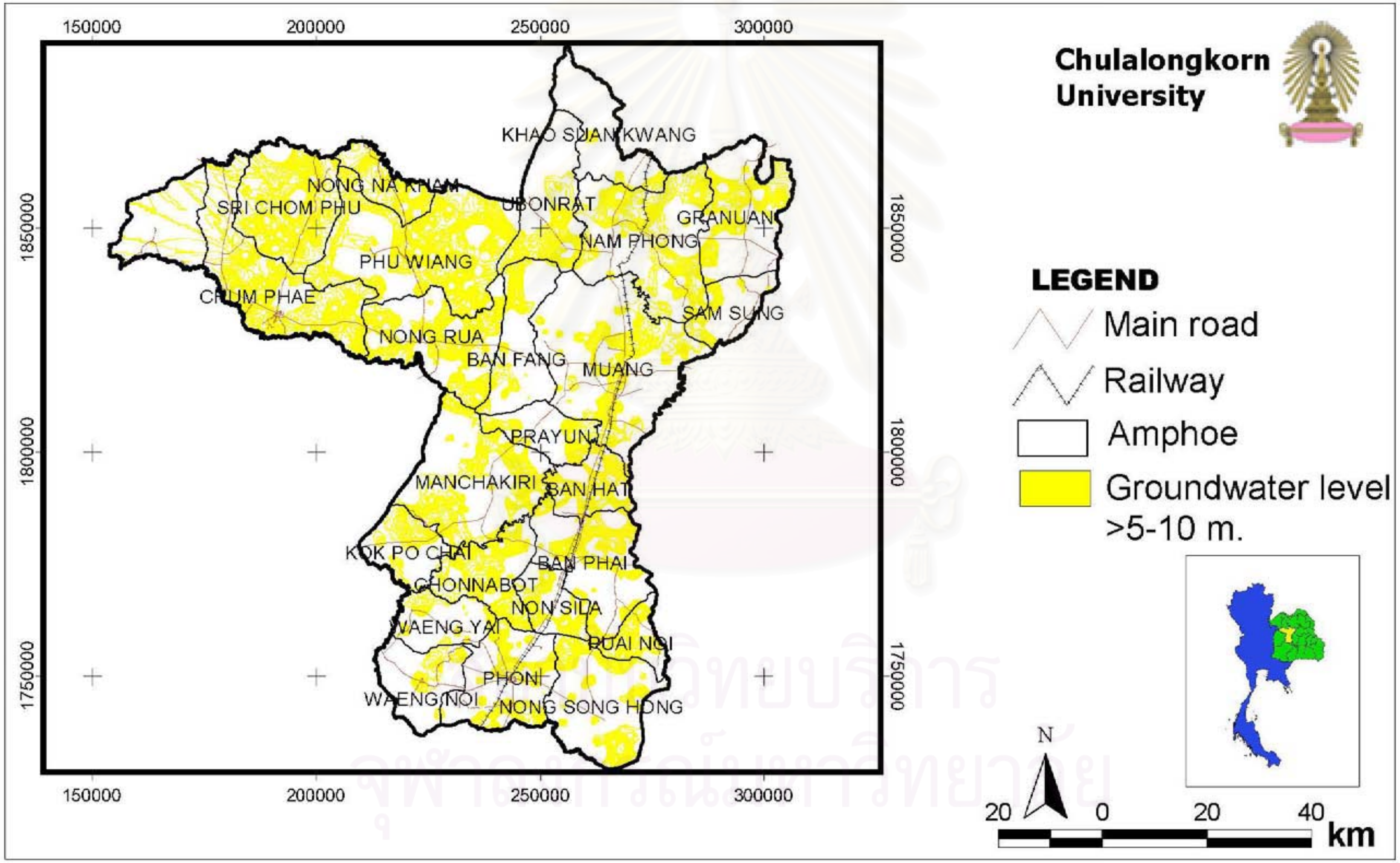


Figure A-21 Groundwater level at 5-10 m.

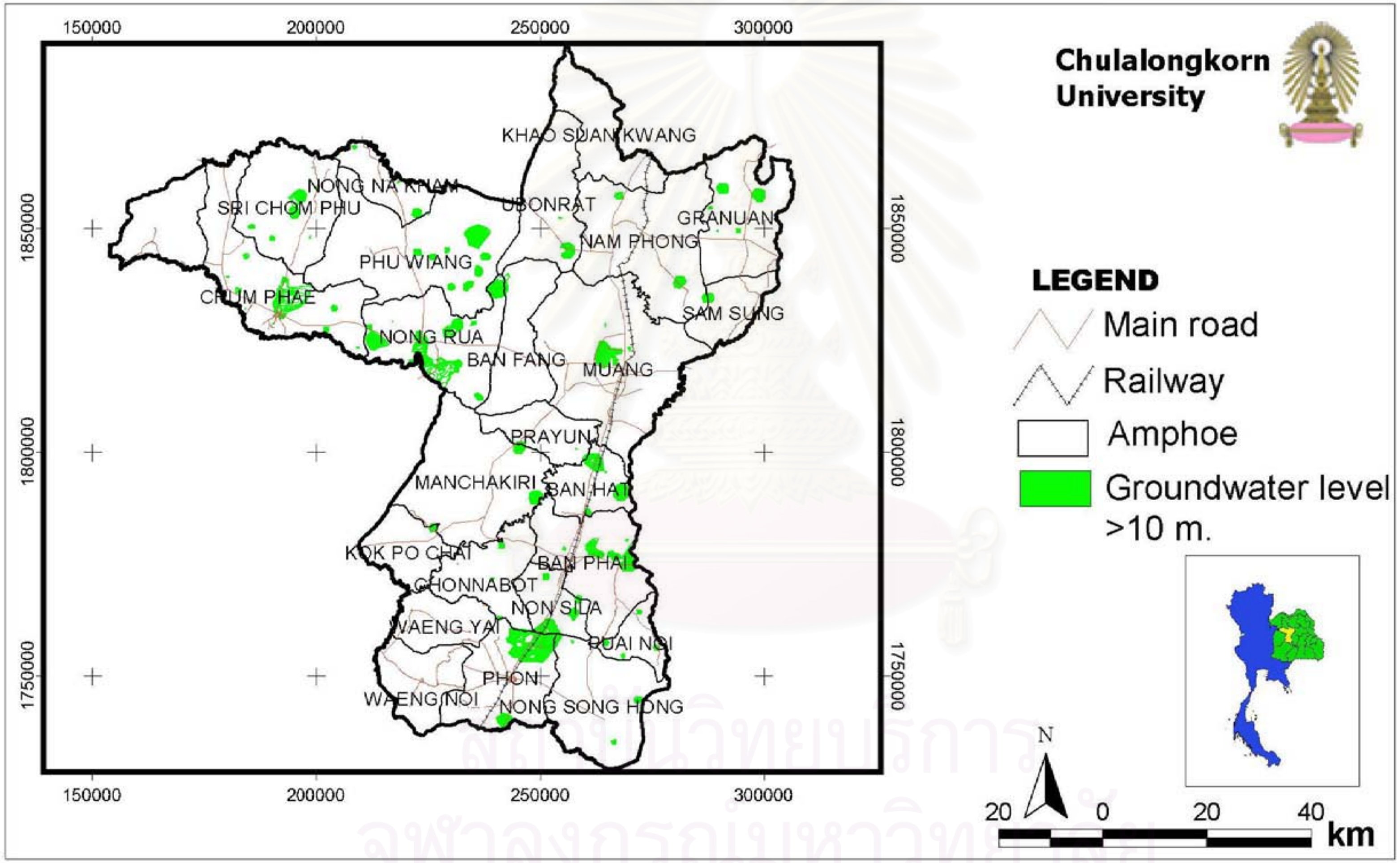


Figure A-22 Groundwater level at >10 m**.**

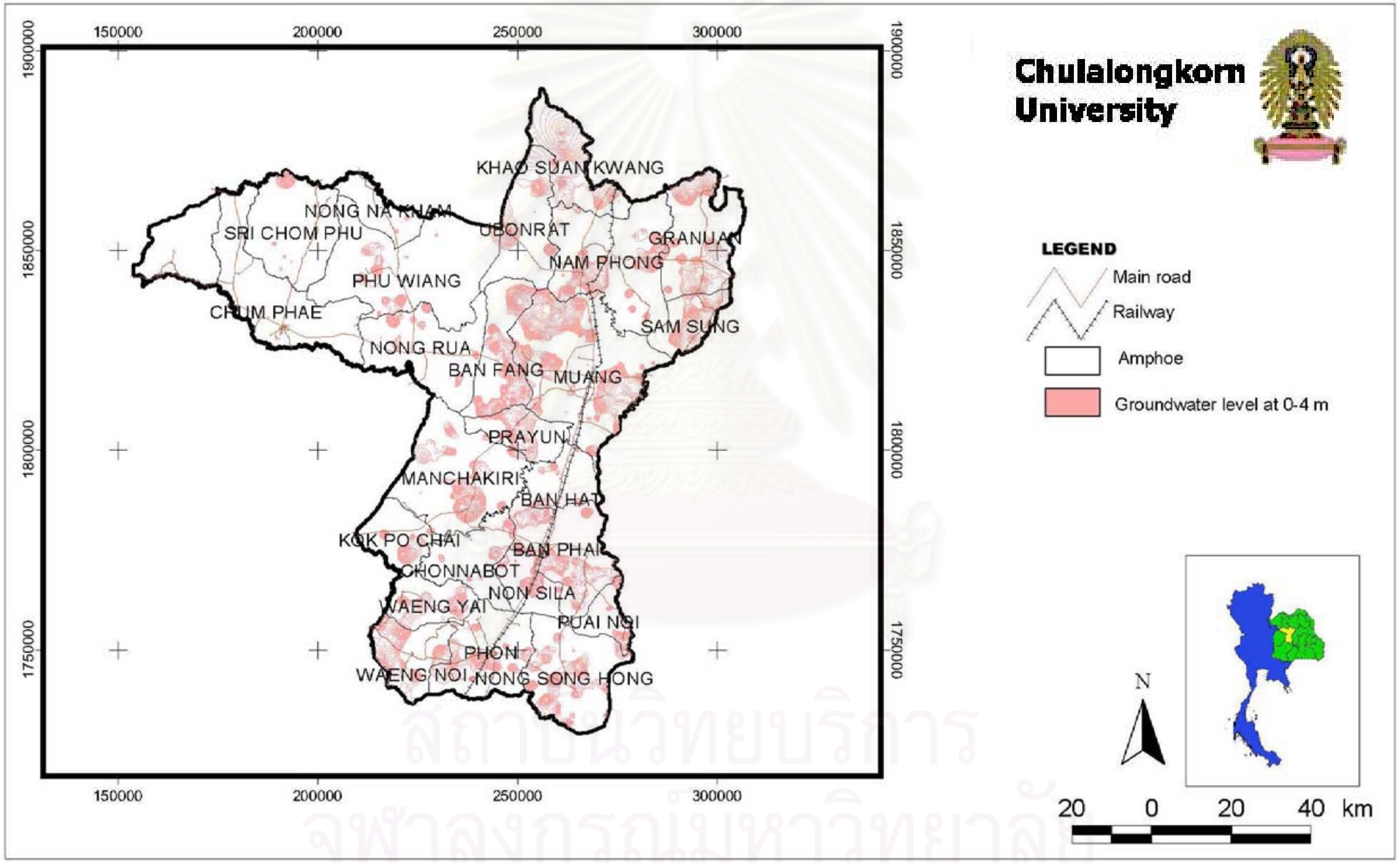


Figure A-23 Groundwater level at 0-4 m.

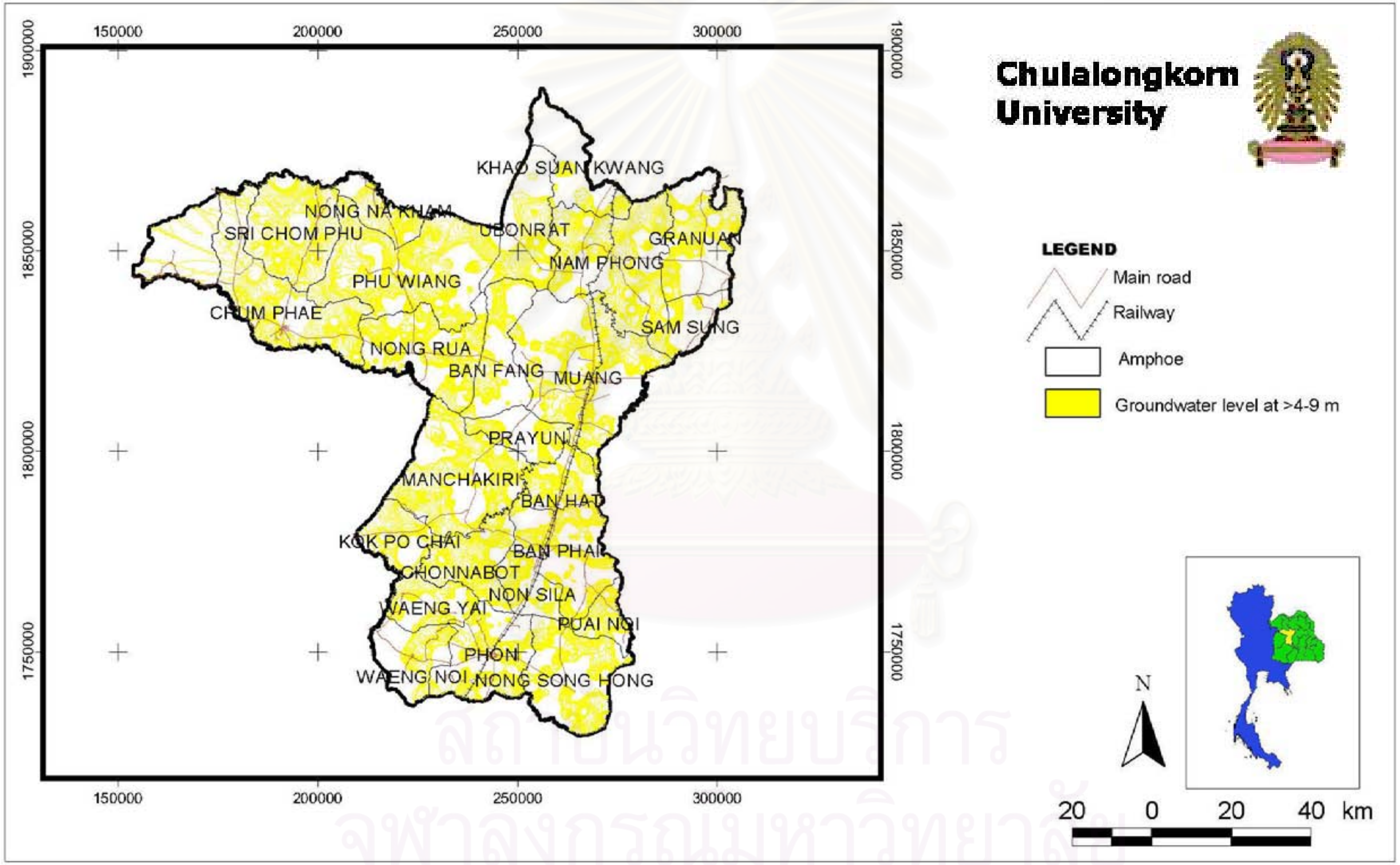


Figure A-24 Groundwater level at >4-9 m.

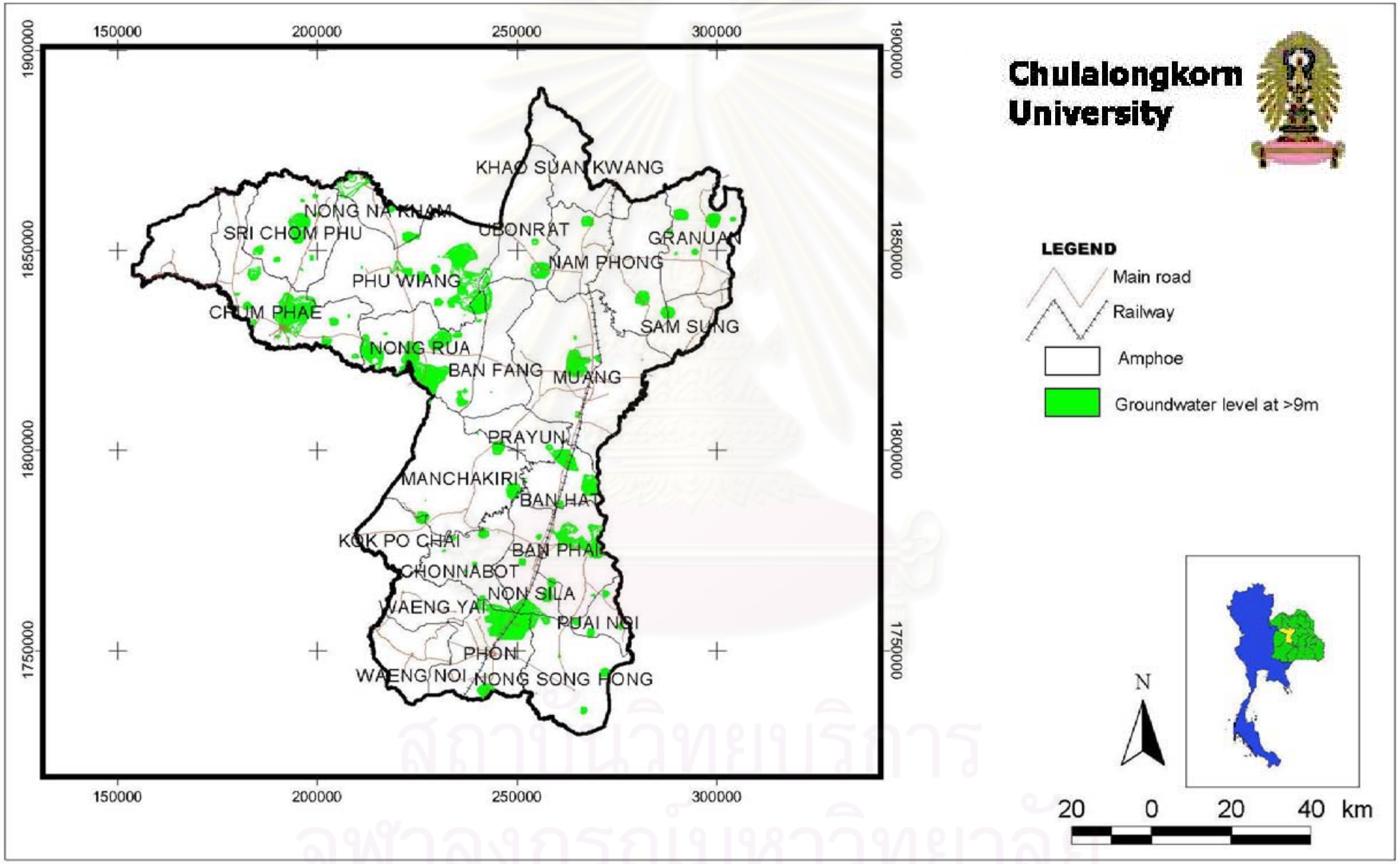


Figure A-25 Groundwater level at > 9 m.

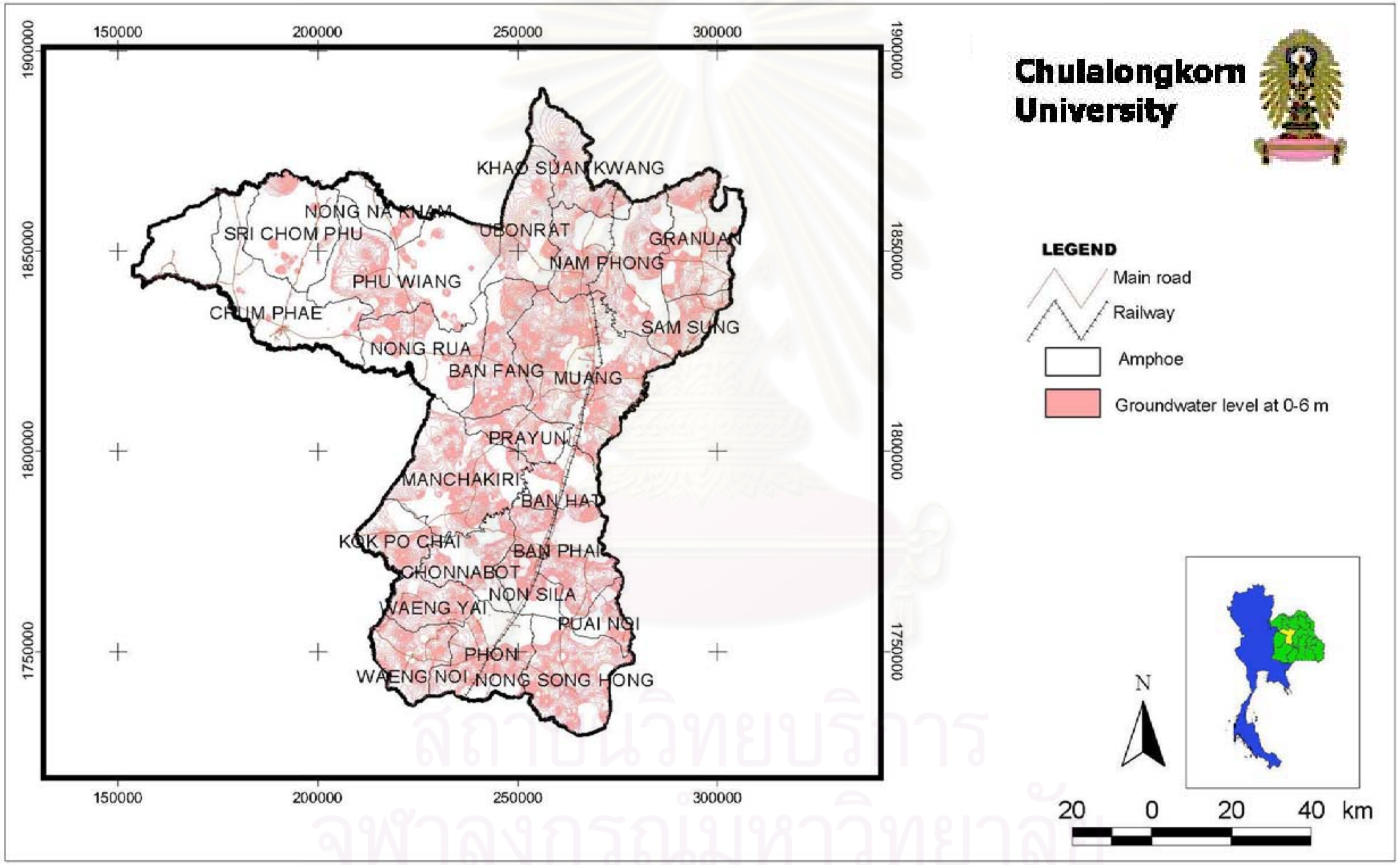


Figure A-26 Groundwater level at 0-6 m.

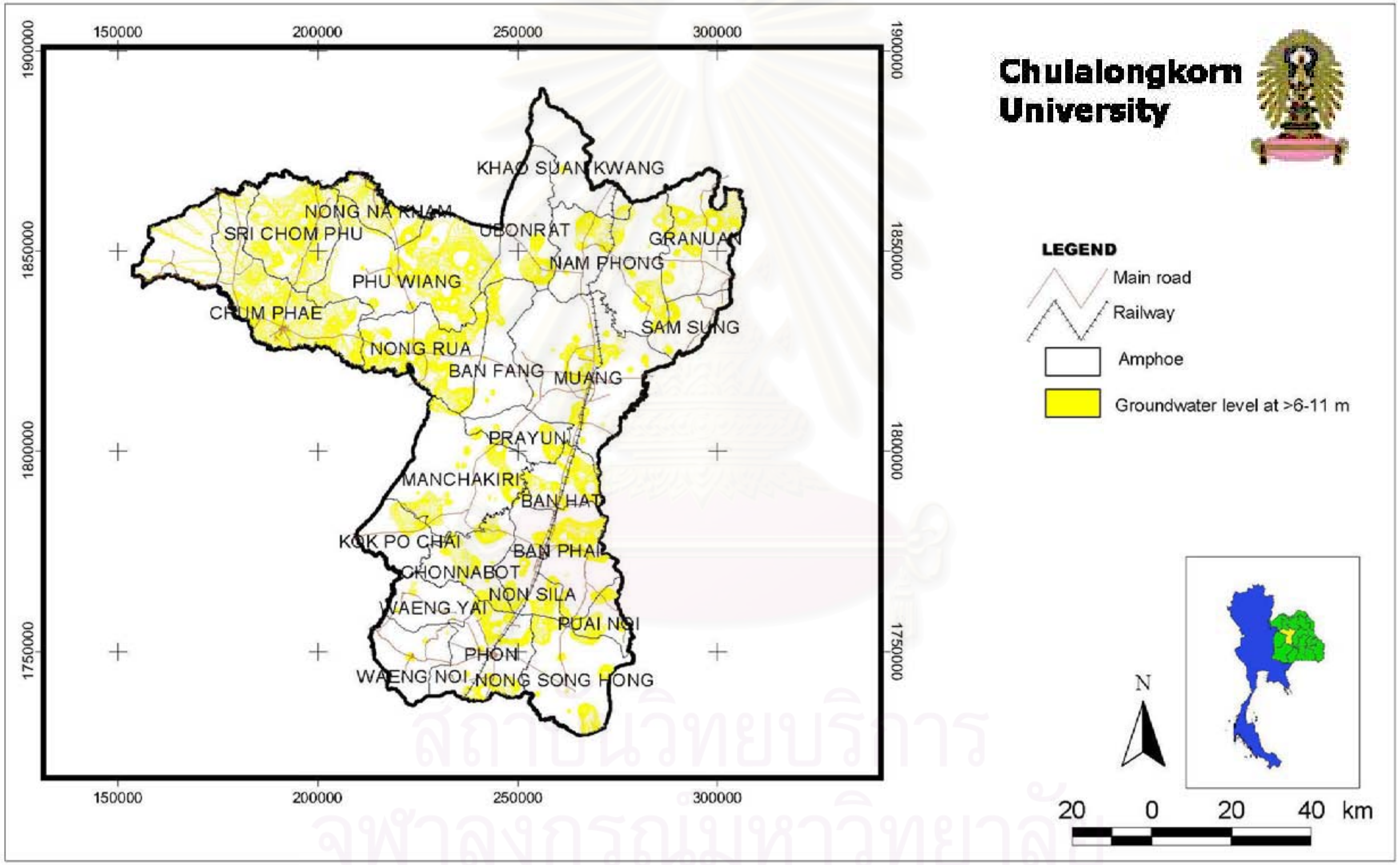


Figure A-27 Groundwater level at >6-11 m.

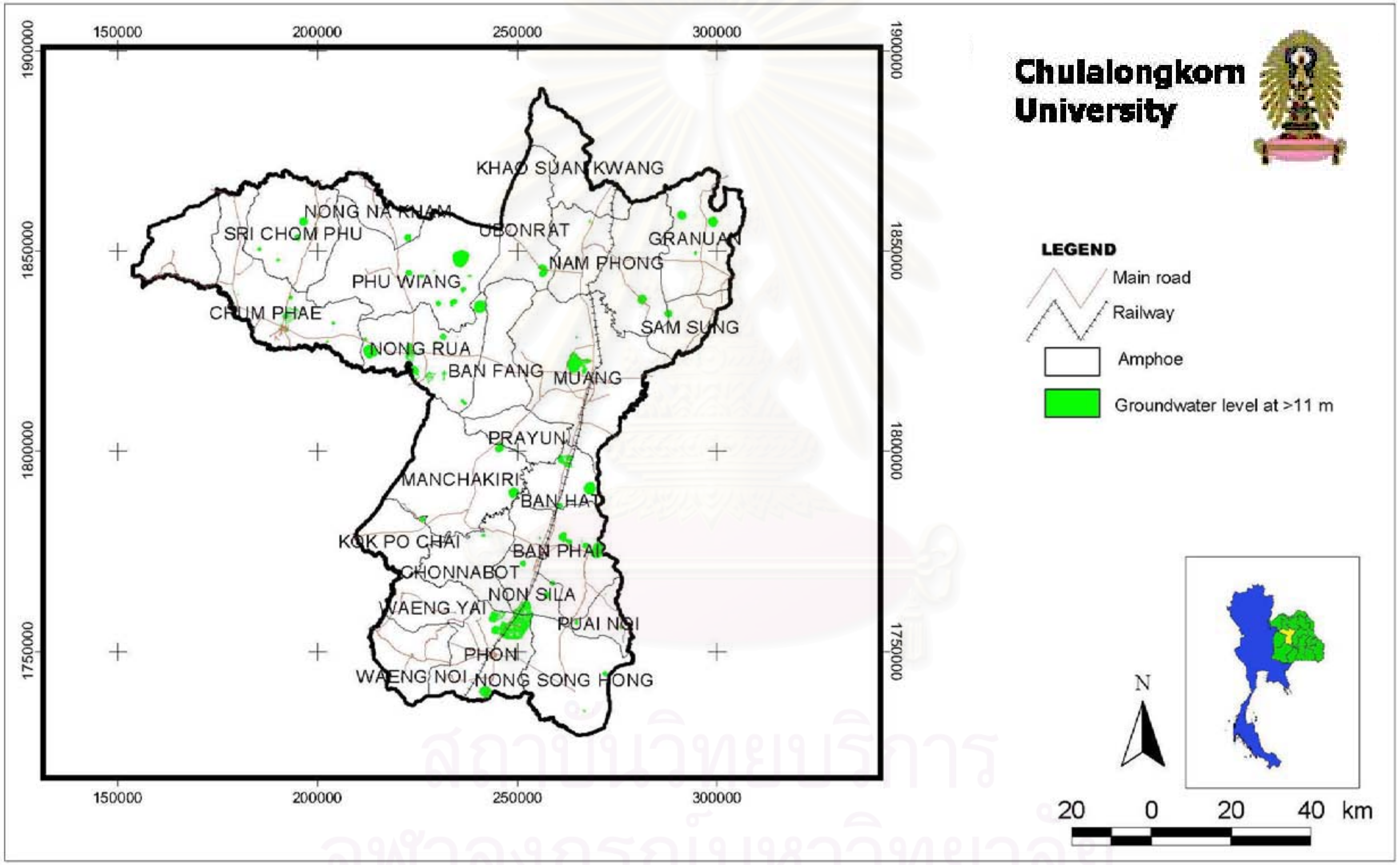


Figure A-28 Groundwater level at >11 m.

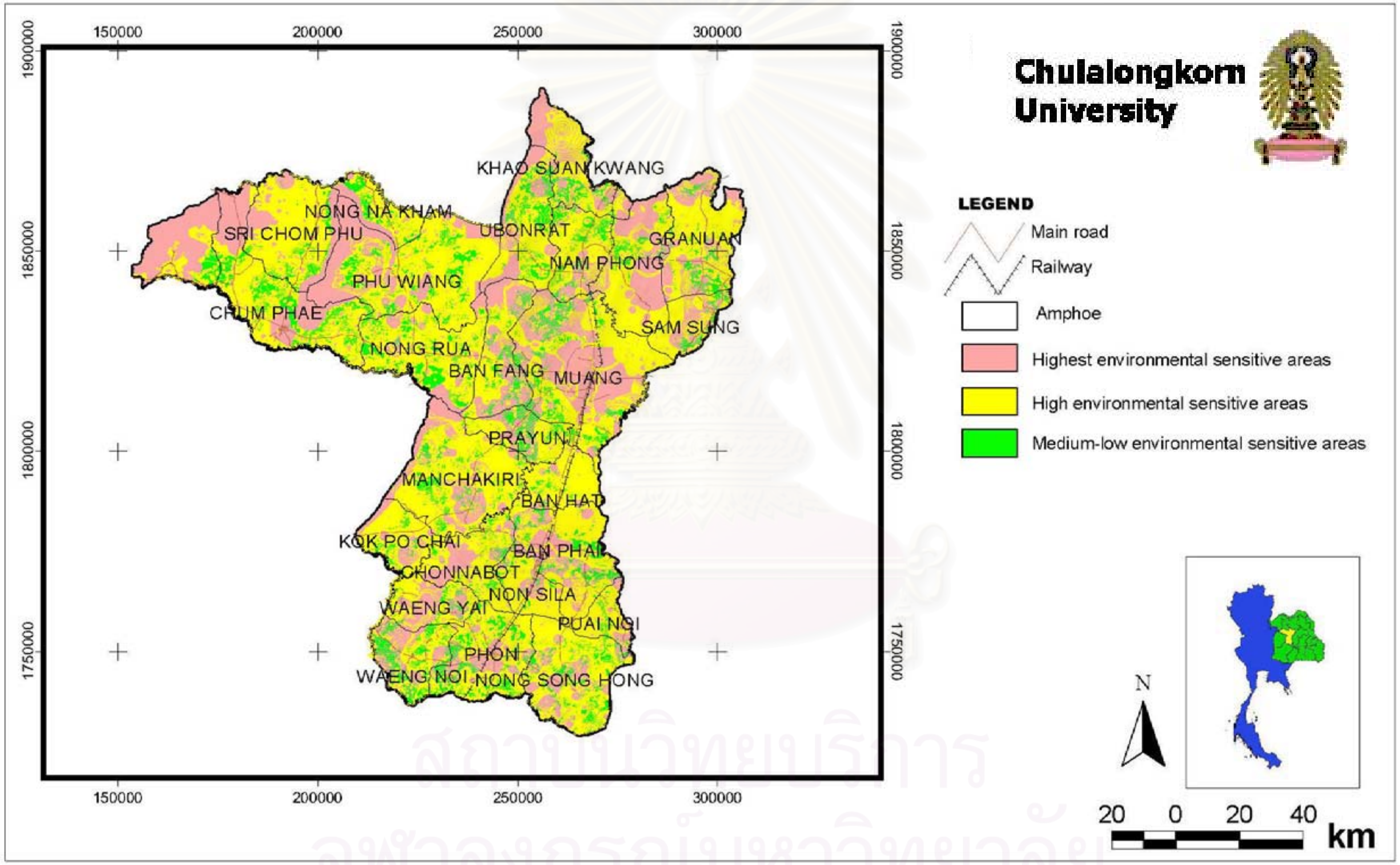


Figure A-29 Map of environmental sensitive areas without groundwater contour factor (0-4, >4-9, and > 9 m).

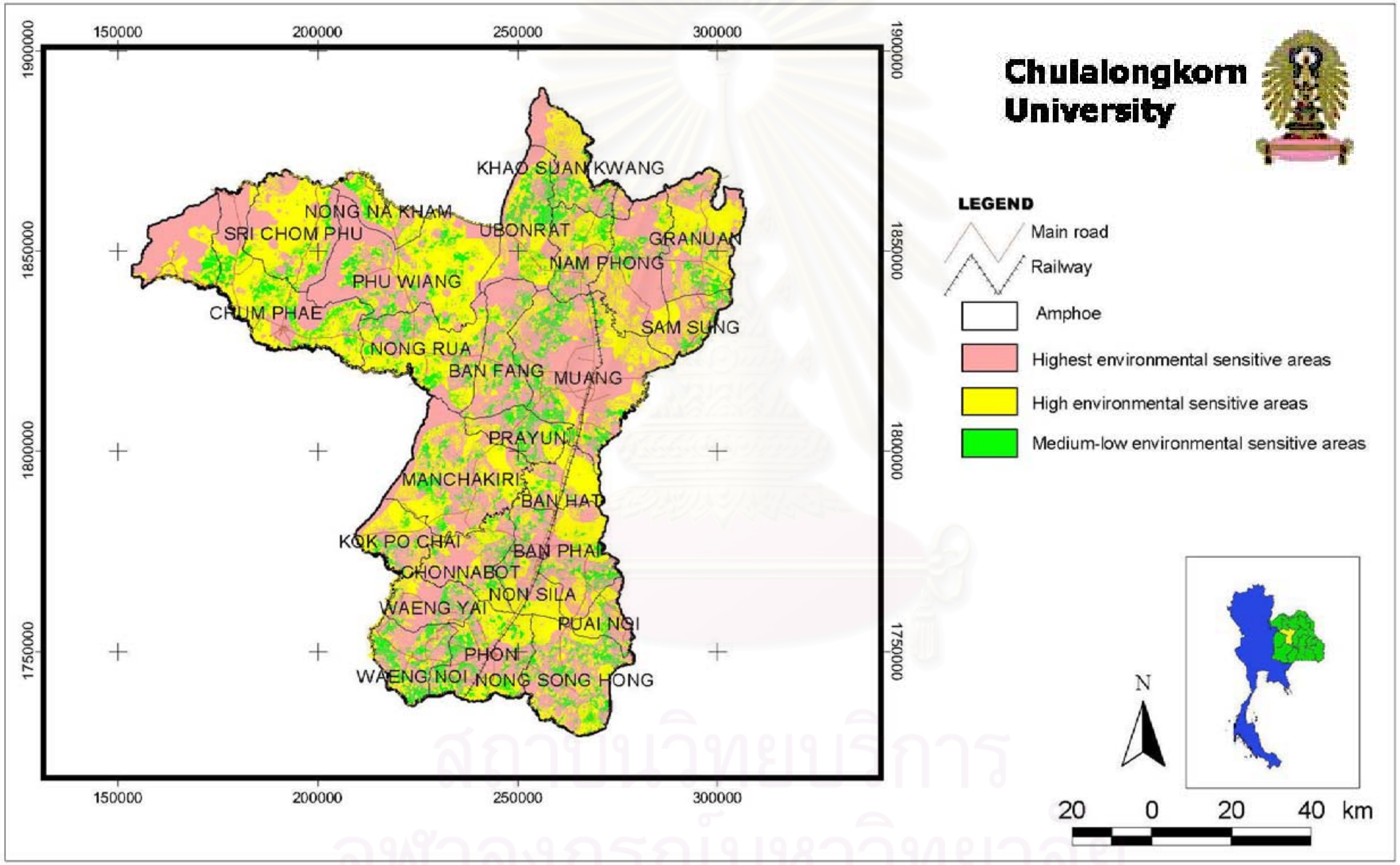


Figure A-30 Map of environmental sensitive areas without groundwater contour factor (0-6, >6-11, and > 11 m).

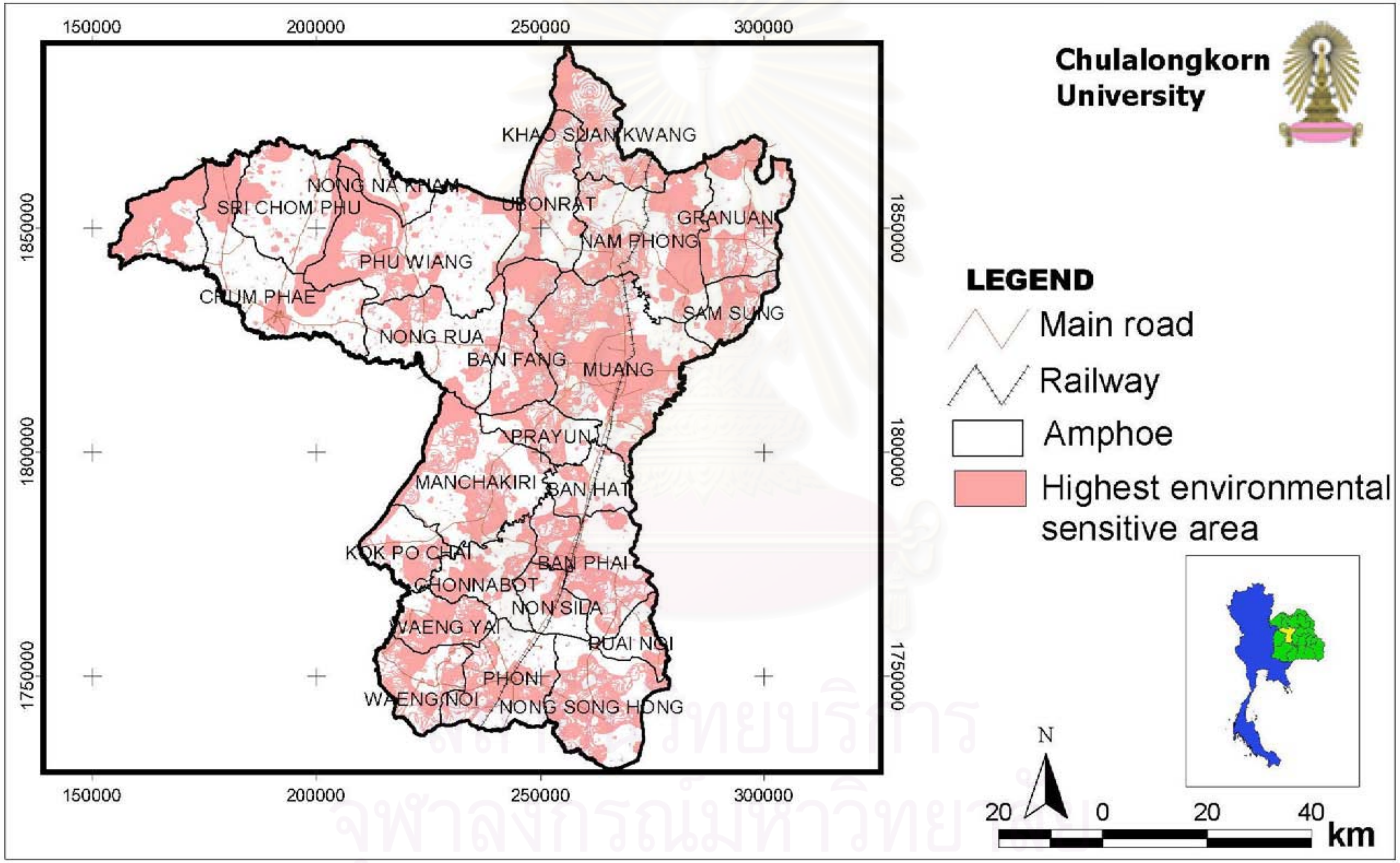


Figure A-31 New highest environmental sensitive areas for landfill proposed in this study.

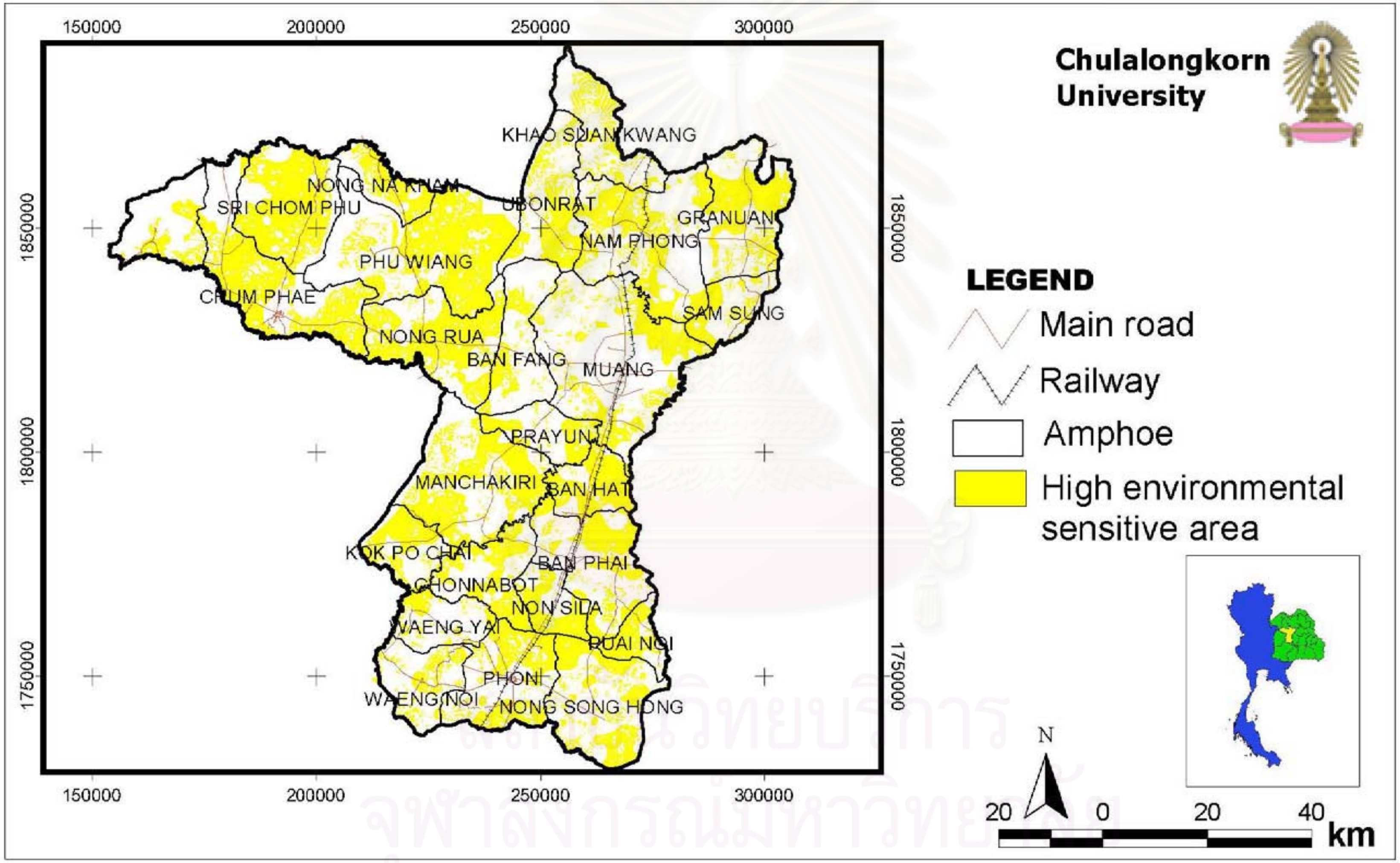


Figure A-32 New high environmental sensitive areas for landfill proposed in this study.

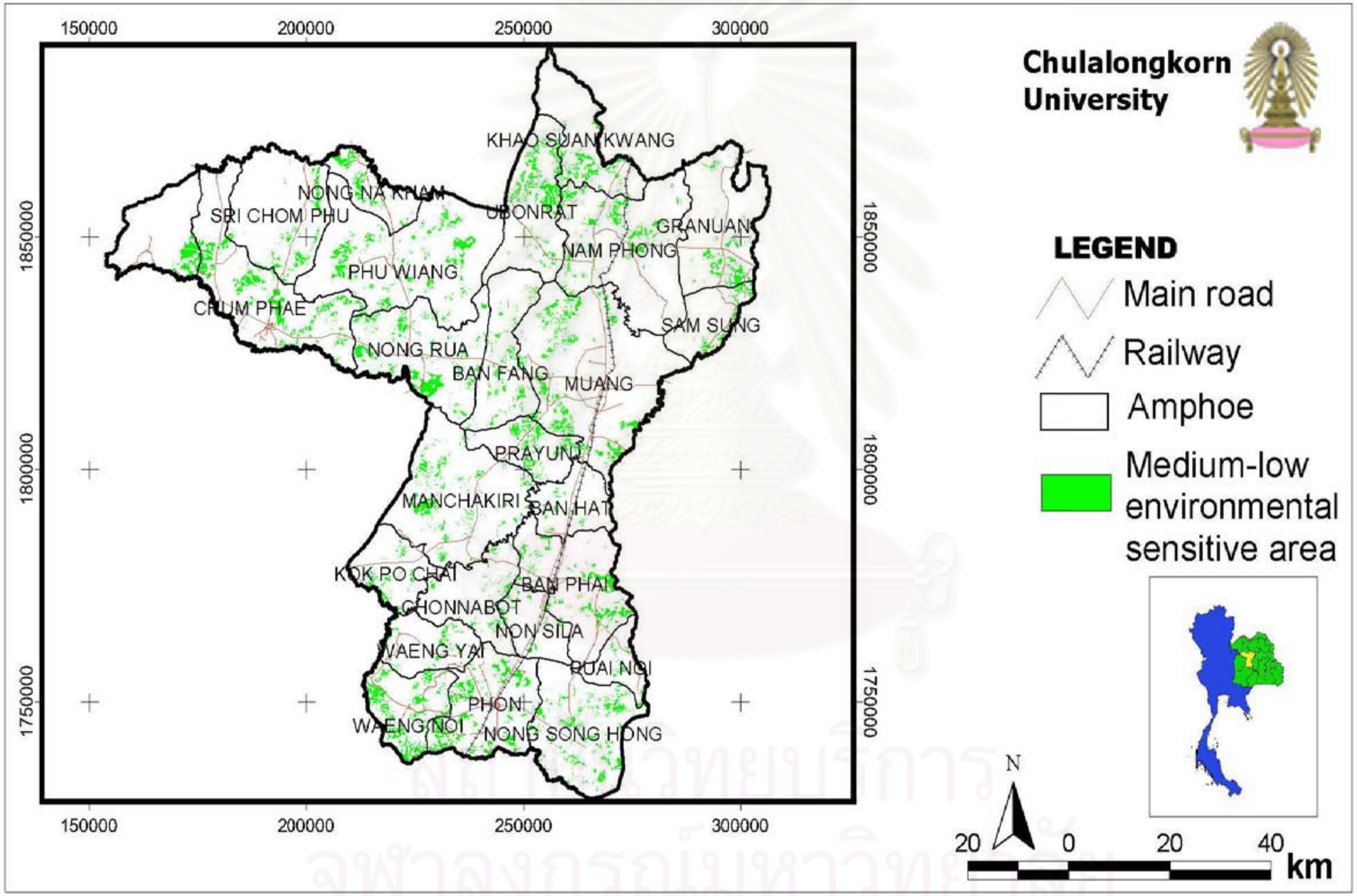


Figure A-33 New medium-low environmental sensitive areas for landfil proposed in this study.

APPENDIX B
VISUAL HELP RESULTS

Project : Thesis

Model : HELP
An US EPA model for predicting landfill hydrologic processes and testing of effectiveness of landfill designs

Author : Hareuthai Thaiyatham

Location : KHON KAEN

1. Profile Site 1A and 1B

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9995	-89.9995	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9990	-289.9990	200.0000
Loam2	-289.9985	-319.9985	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9980	-519.9980	200.0000
Loam3	-519.9975	-549.9975	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9970	-749.9970	200.0000
Loam4	-749.9965	-779.9965	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9960	-979.9960	200.0000
Silty Clay	-979.9955	-1179.9955	200.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	-7.7266E+02	2.4875E+04	-8.4047E+04	1.8231E+04
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	3.7774E+06	3.8023E+06	3.7182E+06	3.7365E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.6012E+05	3.3476E+05	5.7521E+05	4.1196E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.2209E+04	-5.5245E+04	8.9379E+04	-3.8452E+03
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	3.7487E+06	3.6934E+06	3.7828E+06	3.7790E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.5713E+05	4.1206E+05	2.4859E+05	4.5167E+05

(continued)

	Year-9 (m3)	Year-10 (m3)	Year-11 (m3)	Year-12 (m3)
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	7.1849E+04	-1.3618E+04	2.7981E+04	-5.9237E+04
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	3.8508E+06	3.8372E+06	3.8652E+06	3.8059E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.9113E+05	5.2700E+05	6.4475E+05	2.2812E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-4.2876E+04	2.6346E+04	1.9127E+04	6.6369E+04
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	3.7631E+06	3.7894E+06	3.8085E+06	3.8749E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.9980E+05	4.4035E+05	5.7611E+05	4.8315E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.4116E+05	1.6236E+04	-3.0718E+04	2.2471E+04
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	3.7338E+06	3.7500E+06	3.7193E+06	3.7417E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.4681E+05	4.0120E+05	4.3486E+05	7.9336E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	1.4135E+05	-4.5218E+04	-9.0873E+04	-3.1179E+04
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	3.8831E+06	3.8379E+06	3.7470E+06	8.7046E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.7232E+05	5.8521E+05	6.8034E+05	1.0256E+07

2. Profile 1A and 1B with geomembrane

Model Settings
[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9995	-89.9995	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9990	-289.9990	200.0000
Loam2	-289.9985	-319.9985	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9980	-519.9980	200.0000
Loam3	-519.9975	-549.9975	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9970	-749.9970	200.0000
Loam4	-749.9965	-779.9965	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9960	-979.9960	200.0000
High Density Polyethylene (HDPE)	-979.9955	-980.0955	0.1000
Silty Clay	-980.0950	-1180.0950	200.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	2.9897E+05	2.5460E+05	3.3121E+05	2.2443E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	4.3203E+06	4.5749E+06	4.9061E+06	5.1305E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	6.0382E+04	1.0503E+05	1.5996E+05	2.0576E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	3.6495E+04	1.0557E+05	8.0047E+04	1.6324E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	5.1670E+06	5.2726E+06	5.3527E+06	5.5159E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.3284E+05	2.5125E+05	2.5792E+05	2.8458E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.5455E+05	1.7443E+05	3.0001E+05	-2.1703E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	5.6704E+06	5.8449E+06	6.1449E+06	5.9279E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.0843E+05	3.3895E+05	3.7272E+05	3.8591E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-1.0190E+05	1.0883E+05	2.0949E+05	1.3400E+05
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	5.8260E+06	5.9348E+06	6.1443E+06	6.2783E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.5882E+05	3.5786E+05	3.8575E+05	4.1551E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-2.1604E+05	1.9120E+04	-3.9563E+03	3.7529E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	6.0622E+06	6.0814E+06	6.0774E+06	6.4527E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.2170E+05	3.9832E+05	4.0810E+05	4.4055E+05

	Year-21 (m3)	Year-22 (m3)	Year-23 (m3)	Total (m3)
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	4.1955E+04	5.7970E+04	9.3526E+04	2.6248E+06
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	6.4946E+06	6.5526E+06	6.6461E+06	1.3238E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.7172E+05	4.8203E+05	4.9594E+05	7.6000E+06

1. Profile 2A

Model Settings
[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
Silty Clay	-979.9460	-1629.9460	650.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	-7.7266E+02	2.4875E+04	-8.4047E+04	1.8231E+04
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	5.9157E+06	5.9405E+06	5.8565E+06	5.8747E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.6012E+05	3.3476E+05	5.7521E+05	4.1196E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.2209E+04	-5.5245E+04	8.9379E+04	-3.8452E+03
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	5.8869E+06	5.8317E+06	5.9211E+06	5.9172E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.5713E+05	4.1206E+05	2.4859E+05	4.5167E+05

	Year-9 (m3)	Year-10 (m3)	Year-11 (m3)	Year-12 (m3)
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	7.1849E+04	-1.3618E+04	2.7981E+04	-5.9237E+04
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	5.9891E+06	5.9755E+06	6.0034E+06	5.9442E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.9113E+05	5.2700E+05	6.4475E+05	2.2812E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-4.2876E+04	2.6346E+04	1.9127E+04	6.6369E+04
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	5.9013E+06	5.9277E+06	5.9468E+06	6.0132E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.9980E+05	4.4035E+05	5.7611E+05	4.8315E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.4116E+05	1.6236E+04	-3.0718E+04	2.2471E+04
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	5.8720E+06	5.8882E+06	5.8575E+06	5.8800E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.4681E+05	4.0120E+05	4.3486E+05	7.9336E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	1.4135E+05	-4.5218E+04	-9.0873E+04	-3.1179E+04
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	6.0213E+06	5.9761E+06	5.8853E+06	1.3623E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.7232E+05	5.8521E+05	6.8034E+05	1.0256E+07

2. Profile 2B and 2C

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
Silty Clay	-979.9460	-1829.9460	850.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	-1.4598E+03	2.5562E+04	-8.3360E+04	1.8612E+04
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	6.8653E+06	6.8909E+06	6.8075E+06	6.8261E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.6081E+05	3.3407E+05	5.7453E+05	4.1158E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.1141E+04	-5.5245E+04	8.9379E+04	-3.8452E+03
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	6.8373E+06	6.7820E+06	6.8714E+06	6.8676E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.5819E+05	4.1206E+05	2.4859E+05	4.5167E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	7.1849E+04	-1.3618E+04	2.7981E+04	-5.9237E+04
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	6.9394E+06	6.9258E+06	6.9538E+06	6.8945E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.9113E+05	5.2700E+05	6.4475E+05	2.2812E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-4.2876E+04	2.6346E+04	1.9127E+04	6.6369E+04
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	6.8517E+06	6.8780E+06	6.8971E+06	6.9635E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.9980E+05	4.4035E+05	5.7611E+05	4.8315E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.4116E+05	1.6236E+04	-3.0718E+04	2.2471E+04
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	6.8223E+06	6.8386E+06	6.8079E+06	6.8303E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.4681E+05	4.0120E+05	4.3486E+05	7.9336E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	1.4135E+05	-4.5218E+04	-9.0873E+04	-3.1179E+04
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	6.9717E+06	6.9265E+06	6.8356E+06	1.5808E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.7232E+05	5.8521E+05	6.8034E+05	1.0256E+07

3. Profile 2A with geomembrane

Model Settings
[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
High Density Polyethylene (HDPE)	-979.9460	-980.0460	0.1000
Silty Clay	-980.0455	-1630.0455	650.0000

Annual Totals volume (m3)

	Year-1 (m3)	**Year-2 (m3)**	**Year-3 (m3)**	**Year-4 (m3)**
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	3.0031E+05	2.5825E+05	3.3911E+05	2.3646E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	6.4600E+06	6.7182E+06	7.0573E+06	7.2938E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	5.9037E+04	1.0138E+05	1.5206E+05	1.9374E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	5.0334E+04	1.1853E+05	9.2390E+04	1.7735E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	7.3441E+06	7.4627E+06	7.5551E+06	7.7324E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.1900E+05	2.3829E+05	2.4558E+05	2.7047E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.7280E+05	1.9573E+05	3.2299E+05	-1.9622E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	7.9052E+06	8.1009E+06	8.4239E+06	8.2277E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.9019E+05	3.1765E+05	3.4974E+05	3.6510E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-8.5602E+04	1.2110E+05	2.2472E+05	1.4959E+05
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	8.1421E+06	8.2632E+06	8.4879E+06	8.6375E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.4252E+05	3.4559E+05	3.7052E+05	3.9993E+05

	Year-17 (m3)	Year-18 (m3)	Year-19 (m3)	Year-20 (m3)
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.9890E+05	2.6129E+04	5.2774E+03	3.9100E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	8.4386E+06	8.4647E+06	8.4700E+06	8.8610E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.0455E+05	3.9131E+05	3.9887E+05	4.2483E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	9.1024E+05	1.8100E+07
Change in water storage (m3)	6.6528E+04	8.1387E+04	7.0453E+04	2.9197E+06
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	8.9276E+06	9.0089E+06	9.0794E+06	1.8506E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.4714E+05	4.5861E+05	4.7497E+05	7.2611E+06

4. Profile 2B and 2C with geomembrane

Model Settings
[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
High Density Polyethylene (HDPE)	-979.9460	-980.0460	0.1000
Silty Clay	-980.0455	-1830.0455	850.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	3.0045E+05	2.5864E+05	3.3997E+05	2.3775E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	7.4105E+06	7.6691E+06	8.0091E+06	8.2468E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	5.8895E+04	1.0099E+05	1.5120E+05	1.9245E+05

	Year-5 (m3)	Year-6 (m3)	Year-7 (m3)	Year-8 (m3)
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	5.1858E+04	1.2014E+05	9.3158E+04	1.7926E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	8.2987E+06	8.4188E+06	8.5120E+06	8.6912E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.1748E+05	2.3668E+05	2.4481E+05	2.6857E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.7498E+05	1.9824E+05	3.2581E+05	-1.9386E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	8.8662E+06	9.0645E+06	9.3903E+06	9.1964E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.8801E+05	3.1514E+05	3.4692E+05	3.6274E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-8.3497E+04	1.2290E+05	2.2664E+05	1.5238E+05
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	9.1129E+06	9.2358E+06	9.4625E+06	9.6148E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.4042E+05	3.4379E+05	3.6860E+05	3.9714E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.9622E+05	2.8011E+04	7.0684E+03	3.9338E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	9.4186E+06	9.4466E+06	9.4537E+06	9.8471E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.0187E+05	3.8943E+05	3.9708E+05	4.2245E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	9.3954E+05	1.8130E+07
Change in water storage (m3)	6.9448E+04	8.2938E+04	4.4745E+04	2.9342E+06
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	9.9165E+06	9.9995E+06	1.0044E+07	2.0733E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.4422E+05	4.5706E+05	4.7137E+05	7.2173E+06

1. Profile 2A

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
Silty Clay	-979.9460	-1629.9460	650.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	-7.7266E+02	2.4875E+04	-8.4047E+04	1.8231E+04
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	5.9157E+06	5.9405E+06	5.8565E+06	5.8747E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.6012E+05	3.3476E+05	5.7521E+05	4.1196E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.2209E+04	-5.5245E+04	8.9379E+04	-3.8452E+03
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	5.8869E+06	5.8317E+06	5.9211E+06	5.9172E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.5713E+05	4.1206E+05	2.4859E+05	4.5167E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	7.1849E+04	-1.3618E+04	2.7981E+04	-5.9237E+04
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	5.9891E+06	5.9755E+06	6.0034E+06	5.9442E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.9113E+05	5.2700E+05	6.4475E+05	2.2812E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-4.2876E+04	2.6346E+04	1.9127E+04	6.6369E+04
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	5.9013E+06	5.9277E+06	5.9468E+06	6.0132E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.9980E+05	4.4035E+05	5.7611E+05	4.8315E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.4116E+05	1.6236E+04	-3.0718E+04	2.2471E+04
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	5.8720E+06	5.8882E+06	5.8575E+06	5.8800E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.4681E+05	4.0120E+05	4.3486E+05	7.9336E+05

	Year-21 (m3)	Year-22 (m3)	Year-23 (m3)	Total (m3)
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	1.4135E+05	-4.5218E+04	-9.0873E+04	-3.1179E+04
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	6.0213E+06	5.9761E+06	5.8853E+06	1.3623E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.7232E+05	5.8521E+05	6.8034E+05	1.0256E+07

2. Profile 2B and 2C

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
Silty Clay	-979.9460	-1829.9460	850.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	-1.4598E+03	2.5562E+04	-8.3360E+04	1.8612E+04
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	6.8653E+06	6.8909E+06	6.8075E+06	6.8261E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.6081E+05	3.3407E+05	5.7453E+05	4.1158E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.1141E+04	-5.5245E+04	8.9379E+04	-3.8452E+03
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	6.8373E+06	6.7820E+06	6.8714E+06	6.8676E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.5819E+05	4.1206E+05	2.4859E+05	4.5167E+05

	Year-9 (m3)	Year-10 (m3)	Year-11 (m3)	Year-12 (m3)
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	7.1849E+04	-1.3618E+04	2.7981E+04	-5.9237E+04
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	6.9394E+06	6.9258E+06	6.9538E+06	6.8945E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.9113E+05	5.2700E+05	6.4475E+05	2.2812E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-4.2876E+04	2.6346E+04	1.9127E+04	6.6369E+04
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	6.8517E+06	6.8780E+06	6.8971E+06	6.9635E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.9980E+05	4.4035E+05	5.7611E+05	4.8315E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.4116E+05	1.6236E+04	-3.0718E+04	2.2471E+04
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	6.8223E+06	6.8386E+06	6.8079E+06	6.8303E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.4681E+05	4.0120E+05	4.3486E+05	7.9336E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	1.4135E+05	-4.5218E+04	-9.0873E+04	-3.1179E+04
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	6.9717E+06	6.9265E+06	6.8356E+06	1.5808E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.7232E+05	5.8521E+05	6.8034E+05	1.0256E+07

3. Profile 2A with geomembrane

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
High Density Polyethylene (HDPE)	-979.9460	-980.0460	0.1000
Silty Clay	-980.0455	-1630.0455	650.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	3.0031E+05	2.5825E+05	3.3911E+05	2.3646E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	6.4600E+06	6.7182E+06	7.0573E+06	7.2938E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	5.9037E+04	1.0138E+05	1.5206E+05	1.9374E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	5.0334E+04	1.1853E+05	9.2390E+04	1.7735E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	7.3441E+06	7.4627E+06	7.5551E+06	7.7324E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.1900E+05	2.3829E+05	2.4558E+05	2.7047E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.7280E+05	1.9573E+05	3.2299E+05	-1.9622E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	7.9052E+06	8.1009E+06	8.4239E+06	8.2277E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.9019E+05	3.1765E+05	3.4974E+05	3.6510E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-8.5602E+04	1.2110E+05	2.2472E+05	1.4959E+05
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	8.1421E+06	8.2632E+06	8.4879E+06	8.6375E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.4252E+05	3.4559E+05	3.7052E+05	3.9993E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.9890E+05	2.6129E+04	5.2774E+03	3.9100E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	8.4386E+06	8.4647E+06	8.4700E+06	8.8610E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.0455E+05	3.9131E+05	3.9887E+05	4.2483E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	9.1024E+05	1.8100E+07
Change in water storage (m3)	6.6528E+04	8.1387E+04	7.0453E+04	2.9197E+06
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	8.9276E+06	9.0089E+06	9.0794E+06	1.8506E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.4714E+05	4.5861E+05	4.7497E+05	7.2611E+06

4. Profile 2B and 2C with geomembrane

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
High Density Polyethylene (HDPE)	-979.9460	-980.0460	0.1000
Silty Clay	-980.0455	-1830.0455	850.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	3.0045E+05	2.5864E+05	3.3997E+05	2.3775E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	7.4105E+06	7.6691E+06	8.0091E+06	8.2468E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	5.8895E+04	1.0099E+05	1.5120E+05	1.9245E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	5.1858E+04	1.2014E+05	9.3158E+04	1.7926E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	8.2987E+06	8.4188E+06	8.5120E+06	8.6912E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.1748E+05	2.3668E+05	2.4481E+05	2.6857E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.7498E+05	1.9824E+05	3.2581E+05	-1.9386E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	8.8662E+06	9.0645E+06	9.3903E+06	9.1964E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.8801E+05	3.1514E+05	3.4692E+05	3.6274E+05

	Year-13 (m3)	Year-14 (m3)	Year-15 (m3)	Year-16 (m3)
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-8.3497E+04	1.2290E+05	2.2664E+05	1.5238E+05
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	9.1129E+06	9.2358E+06	9.4625E+06	9.6148E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.4042E+05	3.4379E+05	3.6860E+05	3.9714E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.9622E+05	2.8011E+04	7.0684E+03	3.9338E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	9.4186E+06	9.4466E+06	9.4537E+06	9.8471E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.0187E+05	3.8943E+05	3.9708E+05	4.2245E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	9.3954E+05	1.8130E+07
Change in water storage (m3)	6.9448E+04	8.2938E+04	4.4745E+04	2.9342E+06
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	9.9165E+06	9.9995E+06	1.0044E+07	2.0733E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.4422E+05	4.5706E+05	4.7137E+05	7.2173E+06

1. Profile 3A and 3B

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9995	-89.9995	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9990	-289.9990	200.0000
Loam2	-289.9985	-319.9985	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9980	-519.9980	200.0000
Loam3	-519.9975	-549.9975	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9970	-749.9970	200.0000
Loam4	-749.9965	-779.9965	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9960	-979.9960	200.0000
Clay	-979.9955	-1479.9955	500.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	-7.7266E+02	2.4875E+04	-8.4047E+04	1.8231E+04
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	5.1831E+06	5.2079E+06	5.1239E+06	5.1421E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.6012E+05	3.3476E+05	5.7521E+05	4.1196E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.2209E+04	-5.5245E+04	8.9379E+04	-3.8452E+03
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	5.1543E+06	5.0991E+06	5.1885E+06	5.1846E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.5713E+05	4.1206E+05	2.4859E+05	4.5167E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	7.1849E+04	-1.3618E+04	2.7981E+04	-5.9237E+04
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	5.2565E+06	5.2429E+06	5.2708E+06	5.2116E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.9113E+05	5.2700E+05	6.4475E+05	2.2812E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-4.2876E+04	2.6346E+04	1.9127E+04	6.6369E+04
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	5.1687E+06	5.1951E+06	5.2142E+06	5.2806E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.9980E+05	4.4035E+05	5.7611E+05	4.8315E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.4116E+05	1.6236E+04	-3.0718E+04	2.2471E+04
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	5.1394E+06	5.1557E+06	5.1249E+06	5.1474E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.4681E+05	4.0120E+05	4.3486E+05	7.9336E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	1.4135E+05	-4.5218E+04	-9.0873E+04	-3.1179E+04
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	5.2888E+06	5.2435E+06	5.1527E+06	1.1938E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.7232E+05	5.8521E+05	6.8034E+05	1.0256E+07

2. Profile 3A and 3B with geomembrane

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9995	-89.9995	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9990	-289.9990	200.0000
Loam2	-289.9985	-319.9985	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9980	-519.9980	200.0000
Loam3	-519.9975	-549.9975	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9970	-749.9970	200.0000
Loam4	-749.9965	-779.9965	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9960	-979.9960	200.0000
High Density Polyethylene (HDPE)	-979.9955	-980.0955	0.1000
Clay	-980.0950	-1480.0950	500.0000

Annual Totals volume (m3)

	Year-1 (m3)	**Year-2 (m3)**	**Year-3 (m3)**	**Year-4 (m3)**
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	3.1390E+05	2.7988E+05	3.7016E+05	2.7358E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	5.7428E+06	6.0226E+06	6.3928E+06	6.6664E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.5450E+04	7.9755E+04	1.2101E+05	1.5661E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	8.7558E+04	1.5509E+05	1.2583E+05	2.1601E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	6.7539E+06	6.9090E+06	7.0349E+06	7.2509E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	1.8178E+05	2.0173E+05	2.1214E+05	2.3181E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	2.1255E+05	2.3360E+05	3.6164E+05	-1.5640E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	7.4634E+06	7.6970E+06	8.0587E+06	7.9023E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.5043E+05	2.7979E+05	3.1109E+05	3.2528E+05

	Year-13 (m3)	Year-14 (m3)	Year-15 (m3)	Year-16 (m3)
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.7165E+05
Change in water storage (m3)	-5.6898E+04	1.4775E+05	2.5517E+05	1.5637E+05
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	7.8454E+06	7.9931E+06	8.2483E+06	8.4046E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.1382E+05	3.1894E+05	3.4007E+05	3.6595E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8610E+05	7.9061E+05	8.5270E+05	1.2114E+06
Change in water storage (m3)	-1.6356E+05	5.5878E+04	1.1119E+04	1.1773E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	8.2411E+06	8.2970E+06	8.3081E+06	8.4258E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.6828E+05	3.6166E+05	3.7222E+05	3.8804E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	9.6224E+05	9.6219E+05	1.0984E+06	1.8896E+07
Change in water storage (m3)	-7.8654E+03	4.0620E+04	-3.2857E+04	2.9968E+06
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	8.4179E+06	8.4586E+06	8.4257E+06	1.7496E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.8443E+05	3.8777E+05	3.9010E+05	6.3882E+06

1. Profile 4A

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
Silty Clay	-979.9460	-2479.9460	1500.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	-1.4598E+03	2.5562E+04	-8.3360E+04	1.8612E+04
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	9.9539E+06	9.9795E+06	9.8961E+06	9.9147E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.6081E+05	3.3407E+05	5.7453E+05	4.1158E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.1141E+04	-5.5245E+04	8.9379E+04	-3.8452E+03
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	9.9259E+06	9.8706E+06	9.9600E+06	9.9561E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.5819E+05	4.1206E+05	2.4859E+05	4.5167E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	7.1849E+04	-1.3618E+04	2.7981E+04	-5.9237E+04
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	1.0028E+07	1.0014E+07	1.0042E+07	9.9831E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.9113E+05	5.2700E+05	6.4475E+05	2.2812E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-4.2876E+04	2.6346E+04	1.9127E+04	6.6369E+04
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	9.9402E+06	9.9666E+06	9.9857E+06	1.0052E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.9980E+05	4.4035E+05	5.7611E+05	4.8315E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.4116E+05	1.6236E+04	-3.0718E+04	2.2471E+04
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	9.9109E+06	9.9272E+06	9.8965E+06	9.9189E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.4681E+05	4.0120E+05	4.3486E+05	7.9336E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	1.4135E+05	-4.5218E+04	-9.0873E+04	-3.1179E+04
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	1.0060E+07	1.0015E+07	9.9242E+06	2.2912E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.7232E+05	5.8521E+05	6.8034E+05	1.0256E+07

2. Profile 4B

Model Settings
[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
Silty Clay	-979.9460	-2379.9460	1400.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	-1.4598E+03	2.5562E+04	-8.3360E+04	1.8612E+04
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	9.4787E+06	9.5043E+06	9.4209E+06	9.4396E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.6081E+05	3.3407E+05	5.7453E+05	4.1158E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.1141E+04	-5.5245E+04	8.9379E+04	-3.8452E+03
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	9.4507E+06	9.3954E+06	9.4848E+06	9.4810E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.5819E+05	4.1206E+05	2.4859E+05	4.5167E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	7.1849E+04	-1.3618E+04	2.7981E+04	-5.9237E+04
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	9.5528E+06	9.5392E+06	9.5672E+06	9.5080E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.9113E+05	5.2700E+05	6.4475E+05	2.2812E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-4.2876E+04	2.6346E+04	1.9127E+04	6.6369E+04
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	9.4651E+06	9.4914E+06	9.5106E+06	9.5769E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.9980E+05	4.4035E+05	5.7611E+05	4.8315E+05

	Year-17 (m3)	Year-18 (m3)	Year-19 (m3)	Year-20 (m3)
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.4116E+05	1.6236E+04	-3.0718E+04	2.2471E+04
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	9.4358E+06	9.4520E+06	9.4213E+06	9.4438E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.4681E+05	4.0120E+05	4.3486E+05	7.9336E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	1.4135E+05	-4.5218E+04	-9.0873E+04	-3.1179E+04
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	9.5851E+06	9.5399E+06	9.4490E+06	2.1819E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.7232E+05	5.8521E+05	6.8034E+05	1.0256E+07

3. Profile 4A with geomembrane

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
High Density Polyethylene (HDPE)	-979.9460	-980.0460	0.1000
Silty Clay	-980.0455	-2480.0455	1500.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	3.0065E+05	2.5919E+05	3.4118E+05	2.3959E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	1.0499E+07	1.0758E+07	1.1100E+07	1.1339E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	5.8696E+04	1.0045E+05	1.4999E+05	1.9061E+05

	Year-5 (m3)	Year-6 (m3)	Year-7 (m3)	Year-8 (m3)
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	5.4026E+04	1.2246E+05	9.4708E+04	1.8201E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	1.1393E+07	1.1516E+07	1.1610E+07	1.1792E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.1531E+05	2.3436E+05	2.4326E+05	2.6582E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.7807E+05	2.0184E+05	3.2990E+05	-1.9029E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	1.1971E+07	1.2172E+07	1.2502E+07	1.2312E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.8491E+05	3.1154E+05	3.4283E+05	3.5917E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-8.0932E+04	1.2567E+05	2.2952E+05	1.5660E+05
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	1.2231E+07	1.2357E+07	1.2586E+07	1.2743E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.3785E+05	3.4102E+05	3.6572E+05	3.9291E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.9210E+05	3.0914E+04	9.9835E+03	3.9704E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	1.2551E+07	1.2582E+07	1.2592E+07	1.2989E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.9776E+05	3.8653E+05	3.9416E+05	4.1879E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	9.8196E+05	1.8172E+07
Change in water storage (m3)	7.3180E+04	8.5274E+04	6.9256E+03	2.9554E+06
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	1.3062E+07	1.3147E+07	1.3154E+07	2.7896E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.4049E+05	4.5472E+05	4.6677E+05	7.1537E+06

4. Profile 4B with geomembrane

Model Settings
[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
High Density Polyethylene (HDPE)	-979.9460	-980.0460	0.1000
Silty Clay	-980.0455	-2380.0455	1400.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	3.0063E+05	2.5913E+05	3.4107E+05	2.3941E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	1.0024E+07	1.0283E+07	1.0624E+07	1.0864E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	5.8715E+04	1.0050E+05	1.5010E+05	1.9078E+05

	Year-5 (m3)	Year-6 (m3)	Year-7 (m3)	Year-8 (m3)
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	5.3821E+04	1.2224E+05	9.4543E+04	1.8175E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	1.0918E+07	1.1040E+07	1.1134E+07	1.1316E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.1551E+05	2.3458E+05	2.4342E+05	2.6608E+05

	Year-9 (m3)	Year-10 (m3)	Year-11 (m3)	Year-12 (m3)
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.7778E+05	2.0150E+05	3.2952E+05	-1.9064E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	1.1494E+07	1.1695E+07	1.2025E+07	1.1834E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.8520E+05	3.1188E+05	3.4322E+05	3.5952E+05

	Year-13 (m3)	Year-14 (m3)	Year-15 (m3)	Year-16 (m3)
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-8.1145E+04	1.2539E+05	2.2924E+05	1.5619E+05
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	1.1753E+07	1.1878E+07	1.2108E+07	1.2264E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.3807E+05	3.4130E+05	3.6600E+05	3.9332E+05

	Year-17 (m3)	Year-18 (m3)	Year-19 (m3)	Year-20 (m3)
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.9250E+05	3.0625E+04	9.7046E+03	3.9682E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	1.2071E+07	1.2102E+07	1.2112E+07	1.2509E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.9815E+05	3.8682E+05	3.9444E+05	4.1901E+05

	Year-21 (m3)	Year-22 (m3)	Year-23 (m3)	Total (m3)
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	9.7735E+05	1.8167E+07
Change in water storage (m3)	7.2821E+04	8.4988E+04	1.1060E+04	2.9540E+06
Water budget balance (m3)	-2.0107E-02	-2.0885E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	1.2581E+07	1.2666E+07	1.2677E+07	2.6797E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.4085E+05	4.5501E+05	4.6725E+05	7.1597E+06

1. Profile 5A and 5B

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
Loamy Sand1	-979.9460	-1479.9460	500.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	3.1944E+05	-1.3961E+04	1.6846E+04	3.1726E+04
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	3.9186E+06	3.9046E+06	3.9215E+06	3.9532E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.9910E+04	3.7360E+05	4.7432E+05	3.9847E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	-1.5545E+05	-2.8164E+04	1.1852E+05	-4.5028E+04
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	3.7977E+06	3.7696E+06	3.8881E+06	3.8431E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	4.2478E+05	3.8498E+05	2.1944E+05	4.9285E+05

	Year-9 (m3)	Year-10 (m3)	Year-11 (m3)	Year-12 (m3)
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.2667E+05	7.4475E+01	1.2108E+05	-3.2041E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	3.9697E+06	3.9698E+06	4.0909E+06	3.7705E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.3631E+05	5.1331E+05	5.5165E+05	4.8929E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	5.7569E+04	1.7508E+05	-2.1746E+04	8.3537E+04
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	3.8281E+06	4.0031E+06	3.9814E+06	4.0649E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	1.9935E+05	2.9161E+05	6.1699E+05	4.6598E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-3.0379E+05	1.7243E+05	-1.6976E+05	2.1801E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	3.7611E+06	3.9336E+06	3.7638E+06	3.9818E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	5.0944E+05	2.4501E+05	5.7390E+05	5.9782E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	5.1283E+04	1.2622E+04	-6.1255E+04	3.8534E+05
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	4.0331E+06	4.0457E+06	3.9845E+06	9.0178E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	4.6239E+05	5.2737E+05	6.5072E+05	9.8395E+06

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

2. Profile 5A and 5B with geomembrane

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
High Density Polyethylene (HDPE)	-979.9460	-980.0460	0.1000
Loamy Sand1	-980.0455	-1480.0455	500.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	3.5935E+05	3.5963E+05	4.9117E+05	2.3462E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	4.0469E+06	4.4065E+06	4.8977E+06	5.1323E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	6.9587E+04	1.2551E+05	2.0025E+05	2.6512E+05
Percolation or leakance through Layer 11 (m3)	0.0000E+00	0.0000E+00	2.2059E-01	1.9558E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	-2.4740E+04	5.9271E+04	3.0707E+04	1.3223E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	5.1075E+06	5.1668E+06	5.1975E+06	5.3298E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.9472E+05	3.0671E+05	3.0349E+05	3.2725E+05
Percolation or leakance through Layer 11 (m3)	2.9407E+05	2.9755E+05	3.0726E+05	3.1559E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.1861E+05	1.3363E+05	2.4431E+05	-3.0491E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	5.4484E+06	5.5820E+06	5.8263E+06	5.5214E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.5148E+05	3.9541E+05	4.4603E+05	4.5368E+05
Percolation or leakance through Layer 11 (m3)	3.4438E+05	3.7975E+05	4.2842E+05	4.7379E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-1.3383E+05	1.0687E+05	1.9800E+05	8.8234E+04
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	5.3876E+06	5.4944E+06	5.6924E+06	5.7807E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.7691E+05	3.6937E+05	4.1468E+05	4.6473E+05
Percolation or leakance through Layer 11 (m3)	3.9075E+05	3.5982E+05	3.9724E+05	4.6128E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-2.7128E+05	1.3274E+04	-1.5621E+04	3.7617E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	5.5094E+06	5.5227E+06	5.5070E+06	5.8832E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	4.6258E+05	4.0360E+05	4.2070E+05	4.6522E+05
Percolation or leakance through Layer 11 (m3)	4.7694E+05	4.0417E+05	4.1976E+05	4.3967E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	-5.2340E+03	2.0050E+04	6.1228E+04	2.2717E+06
Water budget balance (m3)	-2.0107E-02	-2.0885E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	5.8780E+06	5.8980E+06	5.9593E+06	1.2418E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	5.1587E+05	5.2116E+05	5.3519E+05	8.4892E+06
Percolation or leakance through Layer 11 (m3)	5.1891E+05	5.1995E+05	5.2824E+05	7.9531E+06

1. Profile 6A, 6B, and 6C

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
Silty Clay	-979.9460	-1079.9460	100.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	-1.4598E+03	2.5562E+04	-8.3360E+04	1.8612E+04
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	3.3016E+06	3.3271E+06	3.2438E+06	3.2624E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.6081E+05	3.3407E+05	5.7453E+05	4.1158E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.1141E+04	-5.5245E+04	8.9379E+04	-3.8452E+03
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	3.2735E+06	3.2183E+06	3.3076E+06	3.3038E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.5819E+05	4.1206E+05	2.4859E+05	4.5167E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	7.1849E+04	-1.3618E+04	2.7981E+04	-5.9237E+04
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	3.3756E+06	3.3620E+06	3.3900E+06	3.3308E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.9113E+05	5.2700E+05	6.4475E+05	2.2812E+05

	Year-13 (m3)	Year-14 (m3)	Year-15 (m3)	Year-16 (m3)
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-4.2876E+04	2.6346E+04	1.9127E+04	6.6369E+04
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	3.2879E+06	3.3142E+06	3.3334E+06	3.3997E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.9980E+05	4.4035E+05	5.7611E+05	4.8315E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-1.4116E+05	1.6236E+04	-3.0718E+04	2.2471E+04
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	3.2586E+06	3.2748E+06	3.2441E+06	3.2666E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.4681E+05	4.0120E+05	4.3486E+05	7.9336E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	1.4135E+05	-4.5218E+04	-9.0873E+04	-3.1179E+04
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	3.4079E+06	3.3627E+06	3.2718E+06	7.6118E+07
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.7232E+05	5.8521E+05	6.8034E+05	1.0256E+07

2. Profile 6A, 6B, and 6C with liner

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
High Density Polyethylene (HDPE)	-979.9460	-980.0460	0.1000
Silty Clay	-980.0455	-1080.0455	100.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	2.9704E+05	2.4946E+05	3.2032E+05	2.0821E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	3.8431E+06	4.0925E+06	4.4129E+06	4.6211E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	6.2309E+04	1.1017E+05	1.7085E+05	2.2199E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.8490E+04	8.9775E+04	6.5573E+04	1.4806E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	4.6396E+06	4.7293E+06	4.7949E+06	4.9430E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	2.5084E+05	2.6704E+05	2.7239E+05	2.9977E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.3438E+05	1.5013E+05	2.7486E+05	-2.4209E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	5.0773E+06	5.2275E+06	5.5023E+06	5.2602E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.2860E+05	3.6326E+05	3.9787E+05	4.1097E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-1.1611E+05	9.7242E+04	1.9792E+05	1.1957E+05
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	5.1441E+06	5.2414E+06	5.4393E+06	5.5589E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	3.7303E+05	3.6945E+05	3.9732E+05	4.2994E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-2.2827E+05	1.0989E+04	-1.0823E+04	3.6466E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	5.3306E+06	5.3416E+06	5.3308E+06	5.6954E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.3392E+05	4.0645E+05	4.1497E+05	4.5117E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	2.9499E+04	4.3081E+04	7.4949E+04	2.2969E+06
Water budget balance (m3)	-2.0107E-02	-2.0885E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	5.7249E+06	5.7680E+06	5.8430E+06	1.1756E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 11 (m3)	4.8417E+05	4.9692E+05	5.1452E+05	7.9279E+06

1. Profile 7A

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
Silty Loam1	-979.9455	-1579.9455	600.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	9.0052E+04	-2.3616E+04	8.6417E+04	6.0400E+02
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	4.8483E+06	4.8246E+06	4.9111E+06	4.9117E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.6930E+05	3.8325E+05	4.0475E+05	4.2959E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	-1.9450E+05	5.3670E+02	7.3450E+04	2.3405E+04
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	4.7172E+06	4.7177E+06	4.7912E+06	4.8146E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	4.6383E+05	3.5628E+05	2.6452E+05	4.2442E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.0760E+05	-3.3358E+03	1.7570E+05	-4.2301E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	4.9222E+06	4.9188E+06	5.0945E+06	4.6715E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.5539E+05	5.1672E+05	4.9703E+05	5.9189E+05

	Year-13 (m3)	Year-14 (m3)	Year-15 (m3)	Year-16 (m3)
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	5.0793E+04	1.9828E+05	6.1956E+04	2.6315E+03
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	4.7223E+06	4.9206E+06	4.9825E+06	4.9852E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.0613E+05	2.6842E+05	5.3328E+05	5.4688E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-3.1644E+05	2.0715E+05	-1.4193E+05	2.7525E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	4.6687E+06	4.8759E+06	4.7340E+06	5.0092E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	5.2210E+05	2.1029E+05	5.4607E+05	5.4058E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	-4.9408E+04	2.2680E+04	1.8877E+04	2.4314E+05
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	4.9598E+06	4.9825E+06	5.0014E+06	1.1199E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	5.6308E+05	5.1732E+05	5.7059E+05	9.9817E+06

2. Profile 7B

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
Silty Loam1	-979.9455	-1679.9455	700.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	9.0052E+04	-2.3616E+04	8.6417E+04	6.0400E+02
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	4.8483E+06	4.8246E+06	4.9111E+06	4.9117E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.6930E+05	3.8325E+05	4.0475E+05	4.2959E+05
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	-1.9450E+05	5.3670E+02	7.3450E+04	2.3405E+04
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	4.7172E+06	4.7177E+06	4.7912E+06	4.8146E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	4.6383E+05	3.5628E+05	2.6452E+05	4.2442E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	1.0760E+05	-3.3358E+03	1.7570E+05	-4.2301E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	4.9222E+06	4.9188E+06	5.0945E+06	4.6715E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.5539E+05	5.1672E+05	4.9703E+05	5.9189E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	5.0793E+04	1.9828E+05	6.1956E+04	2.6315E+03
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	4.7223E+06	4.9206E+06	4.9825E+06	4.9852E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.0613E+05	2.6842E+05	5.3328E+05	5.4688E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.0132E+05
Change in water storage (m3)	-3.1644E+05	2.0715E+05	-1.4193E+05	2.7525E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	4.6687E+06	4.8759E+06	4.7340E+06	5.0092E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	5.2210E+05	2.1029E+05	5.4607E+05	5.4058E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.2513E+05	8.5059E+05	8.6619E+05	1.8056E+07
Change in water storage (m3)	-4.9408E+04	2.2680E+04	1.8877E+04	2.4314E+05
Water budget balance (m3)	-2.0107E-02	-2.0884E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	4.9598E+06	4.9825E+06	5.0014E+06	1.1199E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	5.6308E+05	5.1732E+05	5.7059E+05	9.9817E+06

3. Profile 7A with geomembrane

Model Settings
[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
High Density Polyethylene (HDPE)	-979.9455	-980.0455	0.1000
Silty Loam1	-980.0450	-1580.0450	600.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	3.2764E+05	3.0286E+05	4.4392E+05	3.4675E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	5.1784E+06	5.4813E+06	5.9252E+06	6.2720E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.1585E+04	6.1214E+04	1.0261E+05	1.4434E+05
Percolation or leakance through Layer 11 (m3)	3.1711E+04	5.6773E+04	4.7249E+04	8.3449E+04
	Year-5 (m3)	**Year-6 (m3)**	**Year-7 (m3)**	**Year-8 (m3)**
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.2645E+05	1.7855E+05	1.3168E+05	2.2732E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	6.3984E+06	6.5770E+06	6.7086E+06	6.9360E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	1.7750E+05	2.0155E+05	2.1427E+05	2.4038E+05
Percolation or leakance through Layer 11 (m3)	1.4288E+05	1.7827E+05	2.0629E+05	2.2051E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	2.1324E+05	2.3067E+05	3.4655E+05	-2.0345E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	7.1492E+06	7.3799E+06	7.7264E+06	7.5230E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.6632E+05	3.0676E+05	3.4950E+05	3.6422E+05
Percolation or leakance through Layer 11 (m3)	2.4974E+05	2.8271E+05	3.2618E+05	3.7233E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-9.0511E+04	1.2940E+05	2.3820E+05	1.5393E+05
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	7.4325E+06	7.5619E+06	7.8001E+06	7.9540E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.4055E+05	3.4458E+05	3.7373E+05	4.0394E+05
Percolation or leakance through Layer 11 (m3)	3.4743E+05	3.3730E+05	3.5704E+05	3.9559E+05

	Year-17 (m3)	Year-18 (m3)	Year-19 (m3)	Year-20 (m3)
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.9462E+05
Change in water storage (m3)	-2.1112E+05	2.6376E+04	4.6992E+03	3.0774E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	7.7429E+06	7.7692E+06	7.7739E+06	8.0817E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	4.0834E+05	3.9153E+05	4.0114E+05	4.3975E+05
Percolation or leakance through Layer 11 (m3)	4.1678E+05	3.9106E+05	3.9944E+05	4.1480E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.5213E+05	8.8344E+05	1.0227E+06	1.8366E+07
Change in water storage (m3)	3.6103E+04	4.6423E+04	-3.7418E+04	3.2760E+06
Water budget balance (m3)	-2.0107E-02	-2.0885E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	8.1178E+06	8.1642E+06	8.1268E+06	1.6578E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	4.5113E+05	4.6502E+05	4.7027E+05	6.9502E+06
Percolation or leakance through Layer 11 (m3)	4.5057E+05	4.6072E+05	4.7035E+05	6.6392E+06

4. Profile 7B with geomembrane

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	0	(%%)
Vegetation Class	Bare soil	(-)

Profile Structure

Layer	Top (cm)	Bottom (cm)	Thickness (cm)
Silty Loam	0.0000	-60.0000	60.0000
Loam1	-59.9500	-89.9500	30.0000
Municipal Waste (312 kg/cub.m)1	-89.9495	-289.9495	200.0000
Loam2	-289.9490	-319.9490	30.0000
Municipal Waste (312 kg/cub.m)2	-319.9485	-519.9485	200.0000
Loam3	-519.9480	-549.9480	30.0000
Municipal Waste (312 kg/cub.m)3	-549.9475	-749.9475	200.0000
Loam4	-749.9470	-779.9470	30.0000
Municipal Waste (312 kg/cub.m)4	-779.9465	-979.9465	200.0000
High Density Polyethylene (HDPE)	-979.9455	-980.0455	0.1000
Silty Loam1	-980.0450	-1680.0450	700.0000

Annual Totals volume (m3)

	Year-1 (m3)	Year-2 (m3)	Year-3 (m3)	Year-4 (m3)
Precipitation (m3)	1.2559E+06	1.1967E+06	1.2586E+06	1.2366E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.9652E+05	8.3711E+05	7.6748E+05	8.0643E+05
Change in water storage (m3)	3.2775E+05	3.0298E+05	4.4647E+05	3.5692E+05
Water budget balance (m3)	-1.8861E-02	-1.7973E-02	-1.8903E-02	-1.8572E-02
Soil water (m3)	5.4602E+06	5.7632E+06	6.2097E+06	6.5666E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.1585E+04	6.1214E+04	1.0261E+05	1.4434E+05
Percolation or leakance through Layer 11 (m3)	3.1601E+04	5.6659E+04	4.4696E+04	7.3275E+04

	Year-5 (m3)	Year-6 (m3)	Year-7 (m3)	Year-8 (m3)
Precipitation (m3)	8.9468E+05	1.0766E+06	1.2711E+06	1.2354E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.2535E+05	7.1980E+05	9.3318E+05	7.8761E+05
Change in water storage (m3)	1.3630E+05	1.8350E+05	1.3392E+05	2.3009E+05
Water budget balance (m3)	-1.3437E-02	-1.6169E-02	-1.9091E-02	-1.8554E-02
Soil water (m3)	6.7029E+06	6.8864E+06	7.0203E+06	7.2504E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	1.7750E+05	2.0155E+05	2.1427E+05	2.4038E+05
Percolation or leakance through Layer 11 (m3)	1.3303E+05	1.7332E+05	2.0405E+05	2.1774E+05
	Year-9 (m3)	**Year-10 (m3)**	**Year-11 (m3)**	**Year-12 (m3)**
Precipitation (m3)	1.1816E+06	1.4372E+06	1.3094E+06	9.0391E+05
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	7.1859E+05	9.2383E+05	6.3671E+05	7.3503E+05
Change in water storage (m3)	2.1594E+05	2.3467E+05	3.5042E+05	-2.0295E+05
Water budget balance (m3)	-1.7745E-02	-2.1585E-02	-1.9666E-02	-1.3575E-02
Soil water (m3)	7.4663E+06	7.7010E+06	8.0514E+06	7.8485E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	2.6632E+05	3.0676E+05	3.4950E+05	3.6422E+05
Percolation or leakance through Layer 11 (m3)	2.4705E+05	2.7872E+05	3.2232E+05	3.7183E+05
	Year-13 (m3)	**Year-14 (m3)**	**Year-15 (m3)**	**Year-16 (m3)**
Precipitation (m3)	8.6413E+05	1.1679E+06	1.4599E+06	1.2940E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.0721E+05	7.0119E+05	8.6469E+05	7.4445E+05
Change in water storage (m3)	-9.2040E+04	1.2986E+05	2.4068E+05	1.5557E+05
Water budget balance (m3)	-1.2978E-02	-1.7540E-02	-2.1926E-02	-1.9433E-02
Soil water (m3)	7.7564E+06	7.8863E+06	8.1270E+06	8.2825E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	3.4055E+05	3.4458E+05	3.7373E+05	4.0394E+05
Percolation or leakance through Layer 11 (m3)	3.4896E+05	3.3683E+05	3.5456E+05	3.9395E+05
	Year-17 (m3)	**Year-18 (m3)**	**Year-19 (m3)**	**Year-20 (m3)**
Precipitation (m3)	8.9082E+05	1.2082E+06	1.2360E+06	1.7172E+06
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	6.8516E+05	7.9072E+05	8.3189E+05	9.9462E+05
Change in water storage (m3)	-2.1109E+05	2.5733E+04	5.4708E+03	3.1126E+05
Water budget balance (m3)	-1.3379E-02	-1.8145E-02	-1.8563E-02	-2.5789E-02
Soil water (m3)	8.0714E+06	8.0972E+06	8.1027E+06	8.4139E+06
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	4.0834E+05	3.9153E+05	4.0114E+05	4.3975E+05
Percolation or leakance through Layer 11 (m3)	4.1675E+05	3.9171E+05	3.9867E+05	4.1127E+05
	Year-21 (m3)	**Year-22 (m3)**	**Year-23 (m3)**	**Total (m3)**
Precipitation (m3)	1.3388E+06	1.3906E+06	1.4557E+06	2.8281E+07
Runoff (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Evapotranspiration (m3)	8.5213E+05	8.8344E+05	1.0227E+06	1.8366E+07
Change in water storage (m3)	3.5832E+04	4.7378E+04	-3.6985E+04	3.3276E+06
Water budget balance (m3)	-2.0107E-02	-2.0885E-02	-2.1862E-02	-4.2474E-01
Soil water (m3)	8.4497E+06	8.4971E+06	8.4601E+06	1.7307E+08
Snow water (m3)	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Percolation or leakance through Layer 10 (m3)	4.5113E+05	4.6502E+05	4.7027E+05	6.9502E+06
Percolation or leakance through Layer 11 (m3)	4.5084E+05	4.5977E+05	4.6991E+05	6.5875E+06

APPENDIX C
MATERIALS PROPERTIES

Table C-1 Default soil, waste, and geosynthetic characteristics.

Classification			Total Porosity	Field Capacity	Wilting Point	Saturated Hydraulic Conductivity
HELP	USDA	USCS	vol/vol	vol/vol	vol/vol	cm/sec
1	CoS	SP	0.417	0.045	0.018	1.0×10^{-2}
2	S	SW	0.437	0.062	0.024	5.8×10^{-3}
3	FS	SW	0.457	0.083	0.033	3.1×10^{-3}
4	LS	SM	0.437	0.105	0.047	1.7×10^{-3}
5	LFS	SM	0.457	0.131	0.058	1.0×10^{-3}
6	SL	SM	0.453	0.190	0.085	7.2×10^{-4}
7	FSL	SM	0.473	0.222	0.104	5.2×10^{-4}
8	L	ML	0.463	0.232	0.116	3.7×10^{-4}
9	SiL	ML	0.501	0.284	0.135	1.9×10^{-4}
10	SCL	SC	0.398	0.244	0.136	1.2×10^{-4}
11	CL	CL	0.464	0.310	0.187	6.4×10^{-5}
12	SiCL	CL	0.471	0.342	0.210	4.2×10^{-5}
13	SC	SC	0.430	0.321	0.221	3.3×10^{-5}
14	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}
15	C	CH	0.475	0.378	0.265	1.7×10^{-5}
16	Barrier Soil		0.427	0.418	0.367	1.0×10^{-7}
17	Bentonite Mat (0.6 cm)		0.750	0.747	0.400	3.0×10^{-9}
18	Municipal Waste (900 lb/yd^3 or 312 kg/m^3)		0.671	0.292	0.077	1.0×10^{-3}
19	Municipal Waste (channeling and dead zones)		0.168	0.073	0.019	1.0×10^{-3}
20	Drainage Net (0.5 cm)		0.850	0.010	0.005	$1.0 \times 10^{+1}$
21	Gravel		0.397	0.032	0.013	3.0×10^{-1}
22	L*	ML	0.419	0.307	0.180	1.9×10^{-5}
23	SiL*	ML	0.461	0.360	0.203	9.0×10^{-6}
24	SCL*	SC	0.365	0.305	0.202	2.7×10^{-6}
25	CL*	CL	0.437	0.373	0.266	3.6×10^{-6}
26	SiCL*	CL	0.445	0.393	0.277	1.9×10^{-6}
27	SC*	SC	0.400	0.366	0.288	7.8×10^{-7}
28	SiC*	CH	0.452	0.411	0.311	1.2×10^{-6}
29	C*	CH	0.451	0.419	0.332	6.8×10^{-7}
30	Coal-Burning Electric Plant Fly Ash*		0.541	0.187	0.047	5.0×10^{-5}
31	Coal-Burning Electric Plant Bottom Ash*		0.578	0.076	0.025	4.1×10^{-3}
32	Municipal Incinerator Fly Ash*		0.450	0.116	0.049	1.0×10^{-2}
33	Fine Copper Slag*		0.375	0.055	0.020	4.1×10^{-2}
34	Drainage Net (0.6 cm)		0.850	0.010	0.005	$3.3 \times 10^{+1}$

Table C-1(*cont.)* Default soil, waste, and geosynthetic characteristics.

Classification		Total Porosity	Field Capacity	Wilting Point	Saturated Hydraulic Conductivity
HELP	Geomembrane Material	vol/vol	vol/vol	vol/vol	cm/sec
35	High Density Polyethylene (HDPE)				2.0×10^{-13}
36	Low Density Polyethylene (LDPE)				4.0×10^{-13}
37	Polyvinyl Chloride (PVC)				2.0×10^{-11}
38	Butyl Rubber				1.0×10^{-12}
39	Chlorinated Polyethylene (CPE)				4.0×10^{-12}
40	Hypalon or Chlorosulfonated Polyethylene (CSPE)				3.0×10^{-12}
41	Ethylene-Propylene Diene Monomer (EPDM)				2.0×10^{-12}
42	Neoprene				3.0×10^{-12}

APPENDIX D
PROGRAM DETAILS

ABSTRACT: The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts weather, soil and design data and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. The program was developed to conduct water balance analyses of landfills, cover systems, and solid waste disposal and containment facilities. As such, the model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection, and liner leakage that may be expected to result from the operation of a wide variety of landfill designs. The primary purpose of the model is to assist in the comparison of design alternatives as judged by their water balances. The model, applicable to open, partially closed, and fully closed sites, is a tool for both designers and permit writers. This report documents the solution methods and process descriptions used in Version 3 of the HELP model. Program documentation including program options, system and operating requirements, file structures, program structure and variable descriptions are provided in a separate report. Section 1 provides basic program identification. Section 2 provides a narrative description of the simulation model. Section 3 presents data generation algorithms and default values used in Version 3. Section 4 describes the method of solution and hydrologic process algorithms. Section 5 lists the assumptions and limitations of the HELP model. The user interface or input facility is written in the Quick Basic environment of Microsoft Basic Professional Development System Version 7.1 and runs under DOS 2.1 or higher on IBM-PC and compatible computers. The HELP program uses an interactive and a user-friendly input facility designed to provide the user with as much assistance as possible in preparing data to run the model. The program provides weather and soil data file management, default data sources, interactive layer editing, on-line help, and data verification and accepts weather data from the most commonly used

sources with several different formats. HELP Version 3 represents a significant advancement over the input techniques of Version 2. Users of the HELP model should find HELP Version 3 easy to use and should be able to use it for many purposes, such as preparing and editing landfill profiles and weather data. Version 3 facilitates use of metric units, international applications, and designs with geosynthetic materials.

1. PROGRAM IDENTIFICATION

PROGRAM TITLE: Hydrologic Evaluation of Landfill Performance (HELP) Model

WRITERS: Paul R. Schroeder, Tamsen S. Dozier, John W. Sjostrom and Bruce M. McEnroe

ORGANIZATION: U.S. Army Corps of Engineers, Waterways Experiment Station (WES)

DATE: September 1994

UPDATE: None Version No.: 3.00

SOURCE LANGUAGE: The simulation code is written in ANSI FORTRAN 77 using Ryan-McFarland Fortran Version 2.44 with assembly language and Spindrift Library extensions for Ryan-McFarland Fortran to perform system calls, and screen operations. The user interface is written in BASIC using Microsoft Basic Professional Development System Version 7.1. Several of the user interface support routines are written in ANSI FORTRAN 77 using Ryan-McFarland Fortran Version 2.44, including the synthetic weather generator and the ASCII data import utilities.

HARDWARE: The model was written to run on IBM-compatible personal computers under the DOS environment. The program requires an IBM-compatible 8088, 80286, 80386 or 80486-based CPU (preferably 80386 or 80486) with an 8087, 80287, 80387 or 80486 math co-processor. The computer system must have a monitor (preferably color EGA or better), a 3.5- or 5.25-inch floppy disk drive (preferably 3.5-inch double-sided, highdensity), a hard disk drive with 6 MB of available storage, and 400k bytes or more of
available low level RAM. A printer is needed if a hard copy is desired.

AVAILABILITY: The source code and executable code for IBM-compatible personal computers are available from the National Technical Information Service (NTIS). Limited distribution immediately following the initial distribution will be available from the USEPA Risk Reduction Engineering Laboratory, the USEPA Center for Environmental Research Information and the USAE Waterways

Experiment Station. **ABSTRACT:** The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts weather, soil and design data and uses solution techniques that account for surface storage, snowmelt, runoff, infiltration, vegetative growth, evapotranspiration, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. Landfill systems including combinations of vegetation, cover soils, waste cells, lateral drain layers, barrier soils, and synthetic geomembrane liners may be modeled. The program was developed to conduct water balance analyses of landfills, cover systems, and solid waste disposal facilities. As such, the model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection, and liner leakage that may be expected to result from the operation of a wide variety of landfill designs. The primary purpose of the model is to assist in the comparison of design alternatives as judged by their water balances. The model, applicable to open, partially closed, and fully closed sites, is a tool for both designers and permit writers. The HELP model uses many process descriptions that were previously developed, reported in the literature, and used in other hydrologic models. The optional synthetic weather generator is the WGEN model of the U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) (Richardson and Wright, 1984). Runoff modeling is based on the USDA Soil Conservation Service (SCS) curve number method presented in Section 4 of the National Engineering Handbook (USDA, SCS, 1985). Potential evapotranspiration is modeled by a modified Penman method (Penman, 1963). Evaporation from soil is modeled in the manner developed by Ritchie (1972) and used in various ARS models including the Simulator for Water Resources in Rural Basins (SWRRB) (Arnold et al., 1989) and the Chemicals, Runoff, and Erosion from Agricultural Management System (CREAMS) (Knisel, 1980). Plant transpiration is computed by the Ritchie's (1972) method used in SWRRB and CREAMS. The vegetative growth model was extracted from the SWRRB model. Evaporation of interception, snow and surface water is based on an energy balance. Interception is modeled by the method proposed by Horton (1919). Snowmelt modeling is based on the SNOW-17 routine of the National Weather Service River Forecast System (NWSRFS) Snow Accumulation and Ablation Model (Anderson,

1973). The frozen soil submodel is based on a routine used in the CREAMS model (Knisel et al., 1985). Vertical drainage is modeled by Darcy's (1856) law using the Campbell (1974) equation for unsaturated hydraulic conductivity based on the Brooks-Corey (1964) relationship. Saturated lateral drainage is modeled by an analytical approximation to the steady-state solution of the Boussinesq equation employing the Dupuit-Forchheimer (Forchheimer, 1930) assumptions. Leakage through geomembranes is modeled by a series of equations based on the compilations by Giroud et al. (1989, 1992). The processes are linked together in a sequential order starting at the surface with a surface water balance; then evapotranspiration from the soil profile; and finally drainage and water routing, starting at the surface with infiltration and then proceeding downward through the landfill profile to the bottom. The solution procedure is applied repetitively for each day as it simulates the water routing throughout the simulation period.

2. NARRATIVE DESCRIPTION

The HELP program, Versions 1, 2 and 3, was developed by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, for the U.S. Environmental Protection Agency (EPA), Risk Reduction Engineering Laboratory, Cincinnati, OH, in response to needs in the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, better known as Superfund) as identified by the EPA Office of Solid Waste, Washington,

DC. The primary purpose of the model is to assist in the comparison of landfill design alternatives as judged by their water balances. The Hydrologic Evaluation of Landfill

Performance (HELP) model was developed to help hazardous waste landfill designers and regulators evaluate the hydrologic performance of proposed landfill designs. The model accepts weather, soil and design data and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. Results are expressed as daily, monthly, annual and long-term average water budgets. The HELP model is a quasi-two-dimensional, deterministic, water-routing model for determining water balances. The model was adapted from the HSSWDS (Hydrologic Simulation Model for Estimating Percolation at Solid Waste Disposal Sites) model of the U.S. Environmental Protection Agency (Perrier and Gibson, 1980; Schroeder and Gibson, 1982), and various models of the U.S. Agricultural Research Service (ARS), including the CREAMS (Chemical Runoff and Erosion from Agricultural Management Systems) model (Knisel, 1980), the SWRRB (Simulator for Water Resources in Rural Basins) model (Arnold et al., 1989), the SNOW-17 routine of the National Weather Service River Forecast System (NWSRFS) Snow Accumulation and Ablation Model (Anderson, 1973), and the WGEN synthetic weather generator (Richardson and Wright, 1984). HELP Version 1 (Schroeder et al., 1984a and 1984b) represented a major advance beyond the HSSWDS program (Perrier and Gibson, 1980; Schroeder and Gibson, 1982), which was also developed at WES. The HSSWDS model simulated only the cover system, did not model lateral flow through drainage layers, and handled vertical drainage only in a rudimentary manner. The infiltration, percolation and evapotranspiration routines were almost identical to those used in the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model, which was developed by Knisel (1980) for the U.S. Department of Agriculture (USDA). The runoff and infiltration routines relied heavily on the Hydrology Section of the National Engineering Handbook (USDA, Soil Conservation Service, 1985). Version 1 of the HELP model incorporated a lateral subsurface drainage model and improved unsaturated drainage and liner leakage models into the HSSWDS model. In addition, the HELP model provided simulation of the entire landfill including leachate collection and liner systems. Version 1 of the HELP program was tested extensively using both field and laboratory data. HELP Version 1 simulation results were compared to field data for 20 landfill cells from seven sites (Schroeder and Peyton, 1987a). The lateral drainage component of HELP Version 1 was tested against experimental results from two large-- scale physical models of landfill liner/drain systems (Schroeder and Peyton, 1987b). The results of these tests provided motivation for some of the improvements incorporated into HELP Version 2. Version 2 (Schroeder et al., 1988a and 1988b) presented a great enhancement of the capabilities of the HELP model. The WGEN synthetic weather generator developed by the USDA Agricultural Research Service (ARS) (Richardson and Wright, 1984) was added to the model to yield daily values of precipitation, temperature and solar radiation. This replaced the use of normal mean monthly temperature and solar radiation values and improved the modeling of snow and evapotranspiration. Also, a vegetative growth model from the Simulator for Water Resources in Rural Basins (SWRRB) model developed by the ARS (Arnold et al., 1989) was merged into the HELP model to calculate daily leaf area indices. Modeling of unsaturated hydraulic conductivity and flow and lateral drainage computations were improved. Default soil data were improved, and the model permitted use of more layers and initialization of soil moisture content. In Version 3, the HELP model has been greatly enhanced beyond Version 2. The number of layers that can be modeled has been increased. The default soil/material texture list has been expanded to contain additional waste materials, geomembranes, geosynthetic drainage nets and compacted soils. The model also permits the use of a user-built library of soil textures. Computations of leachate recirculation and groundwater drainage into the landfill have been added. Moreover, HELP Version 3 accounts for leakage through geomembranes due to manufacturing defects (pinholes) and installation defects (punctures, tears and seaming flaws) and by vapor diffusion through the liner based on the equations compiled by Giroud et al. (1989, 1992). The estimation of runoff from the surface of the landfill has been improved to account for large landfill surface slopes and slope lengths. The snowmelt model has been replaced with an energy-based model; the Priestly-Taylor potential evapotranspiration model has been replaced with a Penman method, incorporating wind and humidity effects as well as long wave radiation losses (heat loss at night). A frozen soil model has been added to improve infiltration and runoff predictions in cold regions. The unsaturated vertical drainage model has also been improved to aid in storage computations. Input and editing have been further simplified with interactive, full-screen, menu-driven input techniques. The HELP model requires daily climatologic data, soil characteristics, and design specifications to perform the analysis. Daily rainfall data may be input by the user, generated stochastically, or taken from the model's historical data base. The model contains parameters for generating synthetic precipitation for 139 U.S. cities. The historical data base contains five years of daily precipitation data for 102 U.S. cities. Daily temperature and solar radiation data are generated stochastically or may be input by the user. Necessary soil data include porosity, field capacity, wilting point, saturated hydraulic conductivity, and Soil Conservation Service (SCS) runoff curve number for antecedent moisture condition II. The model contains default soil characteristics for 42 material types for use when measurements or site-specific estimates are not available. Design specifications include such things as the slope and maximum drainage distance for lateral drainage layers, layer thicknesses, leachate recirculation procedure, surface cover characteristics and information on any geomembranes. Figure 1 is a definition sketch for a somewhat typical closed hazardous waste landfill profile. The top portion of the profile (layers 1 through 4) is the cap or cover. The bottom portion of the landfill is a double liner system (layers 6 through 11), in this case composed of a geomembrane liner and a composite liner. Immediately above the bottom composite liner is a leakage detection drainage layer to collect leakage from the primary liner, in this case, a geomembrane. Above the primary liner are a geosynthetic drainage net and a sand layer that serve as drainage layers for leachate collection. The drain layers composed of sand are typically at least 1-ft thick and have suitably spaced perforated or open joint drain pipe embedded below the surface of the liner. The leachate collection drainage layer serves to collect any leachate that may percolate through the waste layes. In this case where the liner is solely a geomembrane, a drainage net may be used to rapidly drain leachate from the liner, avoiding a significant buildup of head and limiting leakage. The liners are sloped to prevent ponding by encouraging leachate to flow toward the drains. The net effects are that very little leachate should leak through the primary liner and virtually no migration of leachate through the bottom composite liner to the natural formations below. Taken as a whole, the drainage layers, geomembrane liners, and barrier soil liners may be referred to as the leachate collection and removal system (drain/liner system) and more specifically a double liner system. Figure 1 shows eleven layers--four in the cover or cap, one as the waste layers, three in the primary leachate collection and removal system (drain/liner system) and three in the secondary leachate collection and removal system (leakage detection). These eleven layers comprise three subprofiles or modeling units. A subprofile consists of all layers between (and including) the landfill surface and the bottom of the top liner system, between the bottom of one liner system and the bottom of the next lower liner system, or between the bottom of the lowest liner system and the bottom of the lowest soil layer modeled. In the sketch, the top subprofile contains the cover layers, the middle subprofile contains the waste, drain and liner system for leachate collection, and the bottom subprofile contains the drain and liner system for leakage detection. Six subprofiles in a single landfill profile may be simulated by the model.

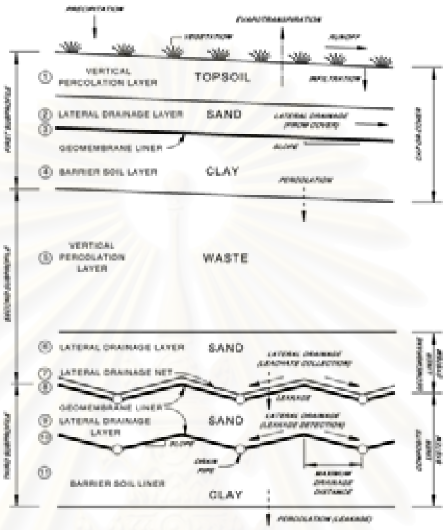


Figure 1. Schematic Profile View of a Typical Hazardous Waste Landfill

The layers in the landfill are typed by the hydraulic function that they perform. Four types are of layers are available: vertical percolation layers, lateral drainage layers, barrier soil liners and geomembrane liners. These layer types are illustrated in Figure 1. The topsoil and waste layers are generally vertical percolation layers. Sand layers above liners are typically lateral drainage layers; compacted clay layers are typically barrier soil liners. Geomembranes are typed as geomembrane liners. Composite liners are modeled as two layers. Geotextiles are not considered as layers unless they perform a unique hydraulic function. Flow in a vertical percolation layer (e.g., layers 1 and 5 in Figure 1) is either downward due to gravity drainage or extracted by evapotranspiration. Unsaturated vertical drainage is assumed to occur by gravity drainage whenever the soil moisture is greater than the field capacity (greater than the wilting point for soils in the evaporative zone) or when the soil suction of the layer below the vertical percolation layer is greater than the soil suction in the vertical percolation layer. The rate of gravity drainage (percolation) in a vertical percolation layer is assumed to be a function of the soil moisture storage and largely independent of conditions in adjacent layers. The rate can be restricted when the layer below is saturated and drains slower than the vertical percolation layer. Layers, whose primary hydraulic function is to provide storage of moisture and detention of drainage, should normally be designated as vertical percolation layers. Waste layers and layers designed to support vegetation should be designated as vertical percolation layers, unless the layers provide lateral drainage to collection systems. Lateral drainage layers (e.g., layers 2, 6, 7 and 9 in Figure 1) are layers that promote lateral drainage to collection systems at or below the surface of liner systems. Vertical drainage in a lateral drainage layer is modeled in the same manner as for a vertical percolation layer, but saturated lateral drainage is allowed. The saturated hydraulic conductivity of a lateral drainage layer generally should be greater than 1 x 10^{-3} cm/sec for significant lateral drainage to occur. A lateral drainage layer may be underlain by only a liner or another lateral drainage layer. The slope of the bottom of the layer may vary from 0 to 40 percent. Barrier soil liners (e.g., layers 4 and 11 in Figure 1) are intended to restrict vertical flow. These layers should have hydraulic conductivities substantially lower than those of the other types of layers, typically below 1 x 10^{-6} cm/sec. The program allows only downward flow in barrier soil liners. Thus, any water moving into a liner will eventually percolate through it. The leakage (percolation) rate depends upon the depth of water-saturated soil (head) above the base of the layer, the thickness of the liner and the saturated hydraulic conductivity of the barrier soil. Leakage occurs whenever the moisture content of the layer above the liner is greater than the field capacity of the layer. The program assumes that barrier soil liner is permanently saturated and that its properties do not change with time. Geomembrane liners (e.g., layers 3, 8 and 10 in Figure 1) are layers of nearly impermeable material that restricts significant leakage to small areas around defects. Leakage (percolation) is computed to be the result from three sources: vapor diffusion, manufacturing flaws (pinholes) and installation defects (punctures, cracks, tears and bad seams). Leakage by vapor diffusion is computed to occur across the entire area of the liner as a function of the head on the surface of the liner, the thickness of the geomembrane and its vapor diffusivity. Leakage through pinholes and installation defects is computed in two steps. First, the area of soil or material contributing to leakage is computed as a function of head on the liner, size of hole and the saturated hydraulic conductivity of the soils or materials adjacent to the geomembrane liner. Second, the rate of leakage in the wetted area is computed as a function of the head, thickness of soil and membrane and the saturated hydraulic conductivity of the soils or materials adjacent to the geomembrane liner.

3.DATA GENERATION AND DEFAULT VALUES

3.1 OVERVIEW

The HELP model requires general climate data for computing potential vapotranspiration; daily climatologic data; soil characteristics; and design specifications to perform the analysis. The required general climate data include growing season, average annual wind speed, average quarterly relative humidities, normal mean monthly temperatures, maximum leaf area index, evaporative zone depth and latitude. Default values for these parameters were compiled or developed from the "Climates of the States" (Ruffner, 1985) and "Climatic Atlas of the United States" (National Oceanic and Atmospheric Administration, 1974) for 183 U.S. cities. Daily climatologic (weather) data requirements include precipitation, mean temperature and total global solar radiation. Daily rainfall data may be input by the user, generated stochastically, or taken from the model's historical data base. The model contains parameters for generating synthetic precipitation for 139 U.S. cities. The historical data base contains five years of daily precipitation data for 102 U.S. cities. Daily temperature and solar radiation data are generated stochastically or may be input by the user. Necessary soil data include porosity, field capacity, wilting point, saturated hydraulic conductivity, initial moisture storage, and Soil Conservation Service (SCS) runoff curve number for antecedent moisture condition II. The model contains default soil characteristics for 42 material types for use when measurements or site-specific estimates are not available. The porosity, field capacity, wilting point and saturated hydraulic conductivity are used to estimate the soil water evaporation coefficient and Brooks-Corey soil moisture retention parameters. Design specifications include such items as the slope and maximum drainage distance for lateral drainage layers; layer thicknesses; layer description; area; leachate recirculation procedure; subsurface inflows; surface characteristics; and geomembrane characteristics.

3.2 SYNTHETIC WEATHER GENERATION

The HELP program incorporates a routine for generating daily values of precipitation, mean temperature, and solar radiation. This routine was developed by the USDA Agricultural Research Service (Richardson and Wright, 1984) based on a procedure described by Richardson (1981). The HELP user has the option of generating synthetic daily precipitation data rather than using default or user-specified historical data. Similarly, the HELP user has the option of generating synthetic daily mean temperature and solar radiation data rather than using user-specified historical data. The generating routine is designed to preserve the dependence in time, the correlation between variables and the seasonal characteristics in actual weather data at the specified location. Coefficients for weather generation are available for up to 183 cities in the United States. Daily precipitation is generated using a Markov chain-two parameter gamma distribution model. A first-order Markov chain model is used to generate the occurrence of wet or dry days. In this model, the probability of rain on a given day is conditioned on the wet or dry status of the previous day. A wet day is defined as a day with 0.01 inch of rain or more. The model requires two transition probabilities: P_i(W/W), the probability of a wet day on day i given a wet day on day i-1; and P_i(W/D), the probability of a wet day on day i given a dry day on day i-1. When a wet day occurs, the two-parameter gamma distribution function, which describes the distribution of daily rainfall amounts, is used to generate the precipitation amount. The density function of the two-parameter gamma distribution is given by

$$f(p) = \frac{p^{\alpha-1} e^{-p/\beta}}{\beta^{\alpha} \Gamma(\alpha)} \tag{1}$$

where

f(p) = density function

p = the probability

α *and* β = distribution parameters

Γ = the gamma function of α

e = the base of natural logarithms

The values of P(W/W), P(W/D), α and β vary continuously during the year for most locations. The precipitation generating routine uses monthly values of the four parameters. The HELP program contains these monthly values for 139 locations in the United States. These values were computed by the Agricultural Research Service from 20 years (1951-1970) of daily precipitation data for each location. Daily values of maximum temperature, minimum temperature and solar radiation are generated using the equation

$$t_i(j) = m_i(j)\,[\chi_i(j) \cdot c_i(j) + 1] \qquad (2)$$

where

$t_i(j)$ = daily value of maximum temperature (j=1), minimum temperature (j=2), or solar radiation (j=3)

$m_i(j)$ = mean value on day i

$c_i(j)$ = coefficient of variation on day i

$\chi_i(j)$ = stochastically generated residual element for day i

The seasonal change in the means and coefficients of variation is described by the harmonic equation

$$u_i = \bar{u} + C \cos\left[\frac{2\pi}{365}(i - T)\right] \qquad (3)$$

where

u_i = value of $m_i(j)$ or $c_i(j)$ on day i

$\bar{u}$ = mean value of u_i

C = amplitude of the harmonic

T = position of the harmonic in days

The Agricultural Research Service computed values of these parameters for the three variables on wet and dry days from 20 years of weather data at 31 locations. The HELP model contains values of these parameters for 184 cities. These values were taken from contour maps prepared by Richardson and Wright (1984). The residual elements for Equation 2 are generated using a procedure that preserves important serial correlations and cross-correlations. The generating equation is

$$\chi_i(j) = (A \cdot \chi_{i-1}(j)) + (B \cdot \epsilon_i(j)) \tag{4}$$

where

$\chi_i(j)$ = 3 x 1 matrix for day i whose elements are residuals of maximum temperature (j=1), minimum temperature (J=2), and solar radiation (J=3)

$\varepsilon_{i(j)}$ = 3 x 1 matrix of independent random components for item j

A and B = 3 x 3 matrices whose elements are defined such that the new sequences have the desired serial correlation and cross-correlation coefficients Richardson (1981) computed values of the relevant correlation coefficients from 20 years of weather data at 31 locations. The seasonal and spatial variation in these correlation coefficients were found to be negligible. The elements of the A and B matrices are therefore treated as constants.

3.3 MOISTURE RETENTION AND HYDRAULIC CONDUCTIVITY PARAMETERS

The HELP program requires values for the total porosity, field capacity, wilting point, and saturated hydraulic conductivity of each layer that is not a liner. Saturated hydraulic conductivity is required for all liners. Values for these parameters can be specified by the user or selected from a list of default values provided in the HELP program. The values are used to compute moisture storage, unsaturated vertical drainage, head on liners and soil water evaporation.

3.3.1 Moisture Retention Parameters

Relative moisture retention or storage used in the HELP model differs from the water contents typically used by engineers. The soil water storage or content used in the HELP model is on a per volume basis (θ), volume of water (V_w) per total (bulk--soil, water and air) soil volume ($V_t = V_s + V_w + V_a$), which is characteristic of practice in agronomy and soil physics. Engineers more commonly express moisture content on a per mass basis (w), mass of water (M_w) per mass of soil (M_s). The two can be related to each other by knowing the dry bulk density (ρ_{db}) and water density (ρ_w), the dry bulk specific gravity (Γ_{db}) of the soil (ratio of dry bulk density to water density), ($\theta = w\ \Gamma_{db}$), or the wet bulk density (ρ_{wb}), wet bulk specific gravity (Γ_{wb}) of the soil (ratio of wet bulk density to water density), ($\theta = [w\ \Gamma_{wb}] / [1 + w]$). Total porosity is an effective value, defined as the volumetric water content (volume of water per total volume) when the pores contributing to change in moisture storage are at saturation. Total porosity can be used to describe the volume of active pore space present in soil or waste layers. Field capacity is the volumetric water content at a soil water suction of 0.33 bars or remaining after a prolonged period of gravity drainage without additional water supply. Wilting point is the volumetric water content at a suction of 15 bars or the lowest volumetric water content that can be achieved by plant transpiration (See Section 4.11). These moisture retention parameters are used to define moisture storage and relative unsaturated hydraulic conductivity. The HELP program requires that the wilting point be greater than zero but less than the field capacity. The field capacity must be greater than the wilting point and less than the porosity. Total porosity must be greater than the field capacity but less than 1. The general relation among moisture retention parameters and soil texture class is shown in Figure 2. The HELP user can specify the initial volumetric water contents of all non-liner layers. Soil liners are assumed to remain saturated at all times.

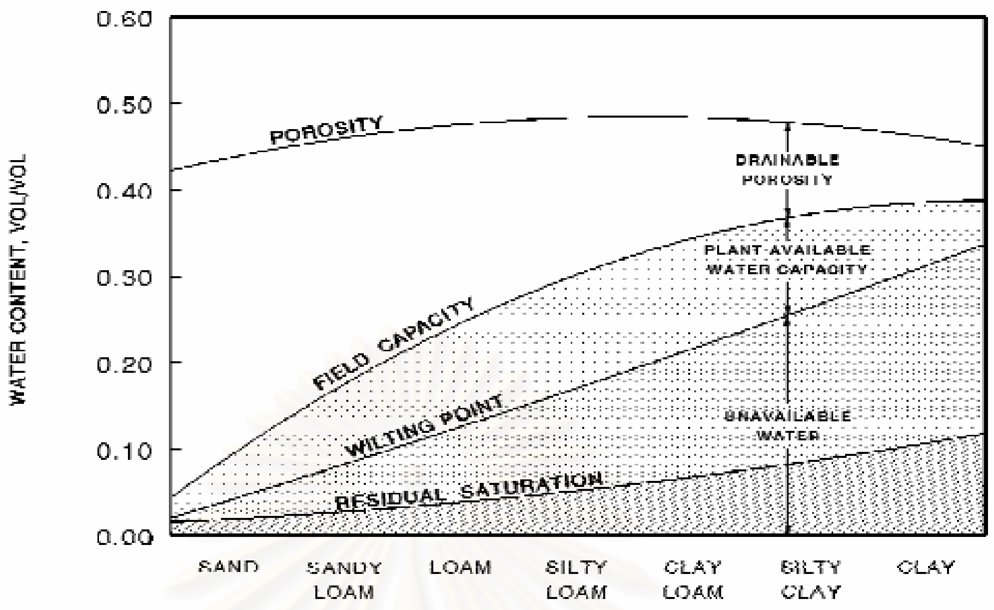


Figure 2. Relation Among Moisture Retention Parameters and Soil Texture Class

If initial water contents are not specified, the program assumes values near the steady- state values (allowing no Figure 2. Relation Among Moisture Retention Parameters and Soil Texture Class long-term change in moisture storage) and runs a year of simulation to initialize the moisture contents closer to steady state. The soil water contents at the end of this year are substituted as the initial values for the simulation period. The program then runs the complete simulation, starting again from the beginning of the first year of data. The results of the volumetric water content initialization period are not reported in the output.

3.3.2 Unsaturated Hydraulic Conductivity

Darcy's constant of proportionality governing flow through porous media is known quantitatively as hydraulic conductivity or coefficient of permeability and qualitatively as permeability. Hydraulic conductivity is a function of media properties, such as particle size, void ratio, composition, fabric, degree of saturation, and the kinematic viscosity of the fluid moving through the media. The HELP program uses the saturated and unsaturated hydraulic conductivities of soil and waste layers to compute vertical drainage, lateral drainage and soil liner percolation. The vapor diffusivity for geomembranes is specified as a saturated hydraulic conductivity to compute leakage through geomembranes by vapor diffusion.

Saturated Hydraulic Conductivity

Saturated hydraulic conductivity is used to describe flow through porous media where the void spaces are filled with a wetting fluid (e.g., water). The saturated hydraulic conductivity of each layer is specified in the input. Equations for estimating the hydraulic conductivity for soils and other materials are presented in Appendix A of the HELP Program Version 3 User's Guide.

Unsaturated Hydraulic Conductivity

Unsaturated hydraulic conductivity is used to describe flow through a layer when the void spaces are filled with both wetting and non-wetting fluid (e.g., water and air). The HELP program computes the unsaturated hydraulic conductivity of each soil and waste layer using the following equation, reported by Campbell (1974):

$$K_u = K_s \left[\frac{\theta - \theta_r}{\phi - \theta_r}\right]^{3+\left(\frac{2}{\lambda}\right)} \quad (5)$$

where

K_u = unsaturated hydraulic conductivity, cm/sec

K_s = saturated hydraulic conductivity, cm/sec

θ = actual volumetric water content, vol/vol

θ_r = residual volumetric water content, vol/vol

ϕ = total porosity, vol/vol

λ = pore-size distribution index, dimensionless

Residual volumetric water content is the amount of water remaining in a layer under infinite capillary suction. The HELP program uses the following regression equation, developed using mean soil texture values from Rawls et al. (1982), to calculate the residual volumetric water content:

$$\theta_r = \begin{cases} 0.014 + 0.25\,WP & for\ WP \geq 0.04 \\ 0.6\,WP & for\ WP < 0.04 \end{cases}$$

(6)

where

WP = volumetric wilting point, vol/vol

The residual volumetric water content and pore-size distribution index are constants in the Brooks-Corey equation relating volumetric water content to matrix potential (capillary pressure and adsorptive forces) (Brooks and Corey, 1964):

$$\frac{\theta - \theta_r}{\phi - \theta_r} = \left(\frac{\psi_b}{\psi}\right)^{\lambda}$$

(7)

where

ψ = capillary pressure, bars

ψ_b = bubbling pressure, bars

Bubbling pressure is a function of the maximum pore size forming a continuous network of flow channels within the medium (Brooks and Corey, 1964). Brakensiek et al. (1981) reported that Equation 7 provided a reasonably accurate representation of water retentionand matrix potential relationships for tensions greater than 50 cm or 0.05 bars (unsaturated conditions). The HELP program solves Equation 7 for two different capillary pressures simultaneously to determine the bubbling pressure and pore-size distribution index of volumetric moisture content for use in Equation 7. The total porosity is known from the input data. The capillary pressure-volumetric moisture content relationship is known at two points from the input of field capacity and wilting point. Therefore, the field capacity is inserted in Equation 7 as the volumetric moisture content and 0.33 bar is inserted as the capillary pressure to yield one equation. Similarly, the wilting point and 15 bar are inserted in Equation 7 to yield a second equation. Having two equations and two unknowns (bubbling pressure and pore-size distribution index), the two equations are solved simultaneously to yield the unknowns. This process is repeated for each layer to obtain the parameters for computing moisture retention and unsaturated drainage.

3.3.3 Saturated Hydraulic Conductivity for Vegetated Materials

The HELP program adjusts the saturated hydraulic conductivities of soils and waste layers in the top half of the evaporative zone whenever those soil characteristics were selected from the default list of soil textures. This adjustment, developed for the model from changes in runoff characteristics and minimum infiltration rates as function of vegetation, is made to account for channeling due to root penetration. These adjustments for vegetation are not made for user-specified soil characteristics; they are made only for default soil textures, which assumed that the soil layer is unvegetated and free of continuous root channels that provide preferential drainage paths. The HELP program calculates the vegetated saturated hydraulic conductivity as follows:

$$(K_s)_v = (1.0 + 0.5966\,LAI + 0.132659\,LAI^2 + 0.1123454\,LAI^3 - 0.04777627\,LAI^4 + 0.004325035\,LAI^5)\,(K_s)_{uv} \quad (8)$$

$(K_s)_v$ = saturated hydraulic conductivity of vegetated material in top half of evaporative zone, cm/sec

LAI = leaf area index, dimensionless (described in Section 4.11)

$(K_s)_{uv}$ = saturated hydraulic conductivity of unvegetated material in top half of evaporative zone, cm/sec

3.4 EVAPORATION COEFFICIENT

The evaporation coefficient indicates the ease with which water can be drawn upward through the soil or waste layer by evaporation. Using laboratory soil data Ritchie (1972) indicated that the evaporation coefficient (in mm/day$_{0.5}$) can be related to the unsaturated hydraulic conductivity at 0.1 bar capillary pressure (calculated using Equations 5 and 7). The HELP program uses the following form of Ritchie’s equation to compute the evaporation coefficient:

$$CON = \begin{cases} 3.30 & (K_u)_{0.1\ bar} \leq 0.05\ cm/day \\ 2.44 + 17.19\ (K_u)_{0.1\ bar} & 0.05\ cm/day < (K_u)_{0.1\ bar} < 0.178\ cm/day \\ 5.50 & (K_u)_{0.1\ bar} \geq 0.178\ cm/day \end{cases} \qquad (9)$$

where

CON = evaporation coefficient, mm/day$^{0.5}$

$(K_u)_{0.1\ bar}$ = unsaturated hydraulic conductivity at 0.1 bar capillary pressure, cm/sec

The HELP program imposes upper and lower limits on the evaporation coefficient so as not to yield a capillary flux outside of the range for soils reported by Knisel (1980). If the calculated value of the evaporation coefficient is less than 3.30, then it is set equal to 3.30, and if the evaporation coefficient is greater than 5.50, then it is set equal to 5.50. The user cannot enter the evaporation coefficient independently. Since Equation 9 was developed for soil materials, the HELP program imposes additional checks on the evaporation coefficient based on the relative field capacity and saturated hydraulic conductivity of each soil and waste layer. Relative field capacity is calculated using the following equation:

$$FC_{rel} = \frac{FC - \theta_r}{\phi - \theta_r} \qquad (10)$$

where

FC_{rel} = relative field capacity, dimensionless

FC = field capacity, vol/vol

If the relative field capacity is less than 0.20 (typical of sand), then the evaporation coefficient is set equal to 3.30. Additionally, if the saturated hydraulic conductivity is less than 5 x 10^{-6} cm/sec (the range of compacted clay), the evaporation coefficient is set equal to 3.30.

3.5 DEFAULT SOIL AND WASTE CHARACTERISTICS

The total density of soil and waste layers can be defined as the mass of solid and water particles per unit volume of the media. The total density of these layers is dependent on the density of the solid particles, the volume of pore space, and the amount of water in each layer. As previously discussed, total porosity can be used to describe the volume of pore space in a soil or waste layer. Therefore, total porosity can be used to indicate the density of soil and waste layers. The density of soil and waste layers can be increased by compaction, static loading, and/or dewatering of soil and waste layers. Compaction increases density through the application of mechanical energy. Static loading increases density by the application of of the weight of additional soil, barrier, or waste layers. Dewatering increases density by removing pore water and/or reducing the pore pressures in the layer. Dewatering can be accomplished by installing horizontal and/or vertical drains, trenches, water wells, and/or the application of electrical currents. The HELP program provides default values for the total porosity, field capacity, wilting point, and saturated hydraulic conductivity of numerous soil and waste materials as well as geosynthetic materials.

3.5.1 Default Soil Characteristics

Information on default soil moisture retention values for low, moderate and highdensity soil layers is provided in the following sections. High-density soil layers are also described as soil liners. Application of the default soil properties should be limited to planning level studies and are not intended to replace design level laboratory and field testing programs.

Low-Density Soil Layers

Rawls et al. (1982) reported mean values for total porosity, residual volumetric water content, bubbling pressure, and pore-size distribution index, for the major US Department of Agriculture (USDA) soil texture classes. These values were compiled from 1,323 soils with about 5,350 horizons (or layers) from 32 states. The geometric mean of the bubbling pressure and pore-size distribution index and the arithmetic mean of total porosity and residual volumetric water content for each soil texture class were substituted into Equation 7 to calculate the field capacity (volumetric water content at a capillary pressure of 1/3 bar) and wilting point (volumetric water content at a capillary pressure of 15 bars) of each soil texture class. Rawls et al. (1982) also reported saturated hydraulic conductivity values for each major USDA uncompacted soil texture class. These values were derived from the results of numerous experiments and compared with similar data sets. Default characteristics for the coarse and fine sands (Co and F) were developed by interpolating between Rawls' data. Freeze and Cherry (1979) reported that typical unconsolidated clay total porosities range from 0.40 to 0.70. Rawls' sandy clay, silty clay, and clay had total porosities of 0.43, 0.48, and 0.47, respectively. Therefore, Rawls' loam and clay soils data are considered to represent conditions typical of minimal densification efforts or low-density soils. Default characteristics for Rawls et al. (1982) low-density soil layers are summarized in Table 1. The USDA soil textures reported in Table 1 were converted to Unified Soil Classification System (USCS) soil textures using a soil classification triangle provided in McAneny et al. (1985).

Moderate-Density Soil Layers

Rawls et al. (1982) presented the following form of Brutsaert's (1967) saturated hydraulic conductivity equation:

$$K_s = a \frac{(\phi - \theta_r)^2}{(\psi_b)^2} \frac{\lambda^2}{(\lambda + 1)(\lambda + 2)} \quad (11)$$

where

K_s = saturated hydraulic conductivity, cm/sec

Since densification is known to decrease the saturated hydraulic conductivity of a soil layer, the total porosity, residual volumetric water content, bubbling pressure, and poresize distribution index data reported in Rawls et al. (1982) were adjusted by a fraction of a standard deviation and substituted into Equation 11 to reflect this decrease. Examination of Equation 11 and various adjustments to Rawls' reported data indicated that a reasonable representation of moderate-density soil conditions can be obtained by a 0.5 standard deviation decrease in the total porosity and pore-size distribution index and a 0.5 standard deviation increase in the bubbling pressure and residual saturation of Rawls' compressible soils (e.g. loams and clays). These adjustments were substituted into Equations 7 and 11 to determine the total porosity, field capacity, wilting point, and hydraulic conductivity of these soils. The values obtained from these adjustments are thought to represent moderate-density soil conditions typical of compaction by vehicle traffic, static loading by the addition of soil or waste layers, etc.

High-Density Soil Layers

Similar to moderate-density soil layers, densification produces a high-density, low saturated hydraulic conductivity soil layer or soil liner. Due to the geochemical and low saturated hydraulic conductivity properties of clay, soil liners are typically constructed of compacted clay. Elsbury et al. (1990) indicated that the hydraulic conductivity of clay liners can be impacted by the soil workability, gradation, and swell potential; overburden

stress on the liner; liner thickness; liner foundation stability; liner desiccation and/or freeze and thawing; and degree of compaction. Compaction should destroy large soil clods and provide interlayer bonding. The process can be impacted by the lift thickness; soil water content, dry density, and degree of saturation; size of soil clods; soil preparation; compactor type and weight; number of compaction passes and coverage; and construction quality assurance. The HELP program provides default characteristics for clay soil liners with a saturated hydraulic conductivity of $1x10_{-7}$ and $1x10_{-9}$ cm/sec. Similar to the procedure used to obtain the default moderate-density clay soil properties, Rawls et al.'s (1982) reported total porosity, pore-size distribution index, bubbling pressure, and residual saturation for clay soil layers were adjusted to determine the field capacity and wilting point of the $1x10_{-7}$ cm/sec clay liner. A hydraulic conductivity of $6.8x10_{-8}$ cm/sec was obtained by substituting a 1 standard deviation decrease in Rawls' reported total porosity and pore-size distribution index and a 1 standard deviation increase in Rawls' reported bubbling pressure and residual saturation into Equation 11. These adjustments were substituted into Equation 7 to obtain a field capacity and wilting point representative of the $1x10_{-7}$ cm/sec soil liner.

3.5.2 Default Waste Characteristics

Municipal waste properties provided in Tchobanoglous et al. (1977) and Equations 6 and 7 were used to determine the total porosity, field capacity, and wilting point of a well compacted municipal waste. The field capacity and wilting point were calculated using Tchobanoglous et al.'s high and low water content values, respectively. Oweis et al. (1990) provided information on the in-situ saturated hydraulic conductivity of municipal waste. Zeiss and Major (1993) described the moisture flow through.

3.5.3 Default Geosynthetic Material Characteristics

The values were extracted from Geotechnical Fabrics Report--1992 Specifiers Guide (Industrial Fabrics Association International, 1991) and Giroud and Bonaparte (1985).

3.6 SOIL MOISTURE INITIALIZATION

The soil moisture of the layers may be initialized by the user or the program. If initialized by the program, the soil moisture is initialized near steady-state using a three step procedure. The first step sets the soil moisture of all liners to porosity or saturation and the moisture of all other layers to field capacity. In the second step the program computes a soil moisture for each layer below the top liner system. These soil moistures are computed to yield an unsaturated hydraulic conductivity equal to 85% of the lowest effective saturated hydraulic conductivity of all liner systems above the layer, including consideration for geomembrane liners. If the unsaturated hydraulic conductivity is greater than 5×10^{-7} cm/sec or if the computed soil moisture is less than field capacity, the soil moisture is set to equal the field capacity. In all other cases, the computed soil moistures are used. The third step in the initialization consists of running the model for one year of simulation using the first year of climatological data and the initial soil moistures selected in step 2. At the end of the year of initialization, the soil moistures existing at that point are reported as the initial soil moistures. The simulation is then started using the first year of climatological data again.

3.7 DEFAULT LEAF AREA INDICES AND EVAPORATIVE ZONE DEPTHS

Recommended default values for leaf area index and evaporative depth are given in the program. Figures 3, 4 and 5 show the geographic distribution of the default values for minimum and maximum evaporative depth and maximum leaf area index. The Figure 3. Geographic Distribution of Maximum Leaf Area Index evaporative zone depths are based on rainfall, temperature and humidity data for the climatic regions. The estimates for minimum depths are based loosely on literature values (Saxton et al., 1971) and unsaturated flow model results for bare loamy soils (Thompson and Tyler, 1984; Fleenor, 1993), while the maximum depths are for loamy soils with a very good stand of grass, assuming rooting depths will vary regionally with plant species and climate. The zones and values for the maximum leaf area index are based on recommendations in the documentation for the Simulator for Water Resources in Rural Basins (SWRRB) model (Arnold et al., 1989), considering both rainfall and temperature.

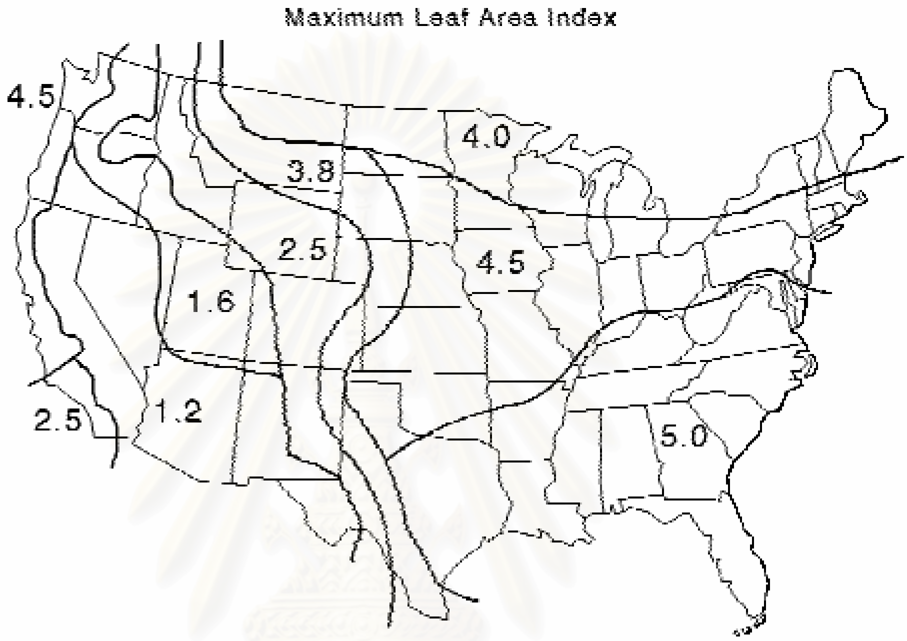


Figure 3. Geographic Distribution of Maximum Leaf Area Index

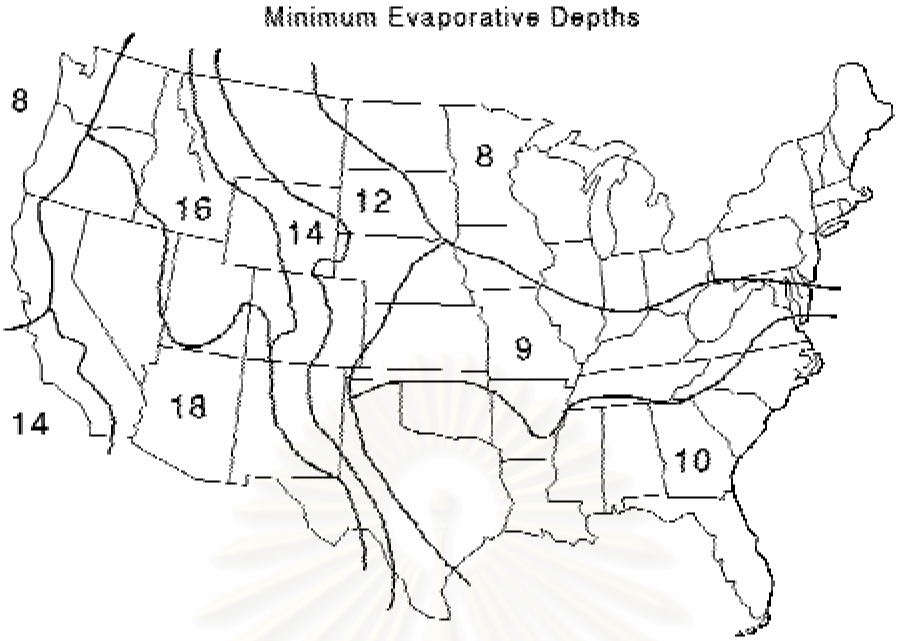


Figure 4. Geographic Distribution of Minimum Evaporative Depth

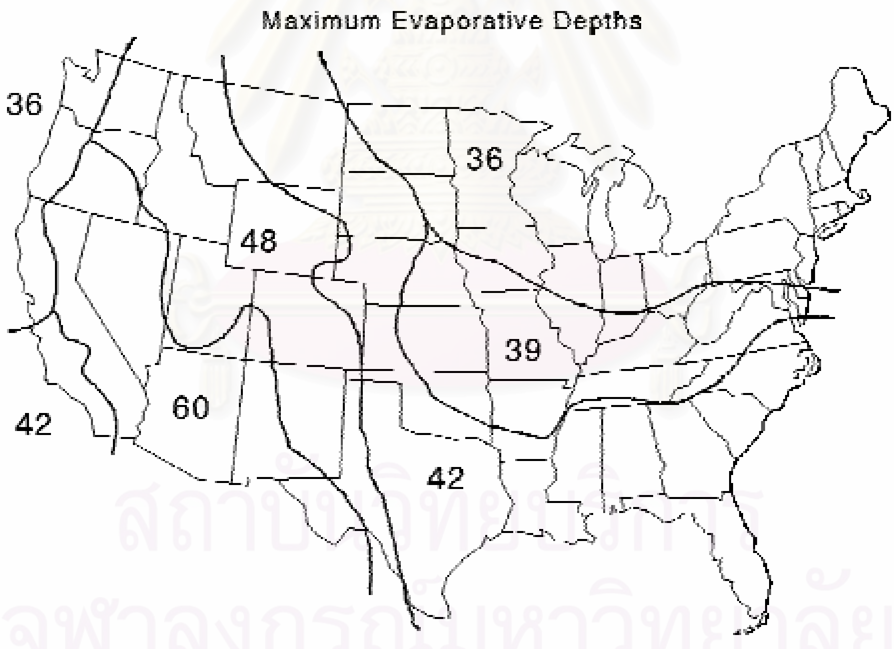


Figure 5. Geographic Distribution of Maximum Evaporative Depth

5. ASSUMPTIONS AND LIMITATIONS

5.1 METHODS OF SOLUTION

The modeling procedures documented in the previous section are necessarily based on many simplifying assumptions. Most of these are stated in the sections documenting the individual procedures. Generally, these assumptions are reasonable and consistent with the objectives of the program when applied to standard landfill designs. However, some of these assumptions may not be reasonable for unusual designs. The major assumptions and limitations of the program are summarized below. Precipitation on days when the mean air temperature is below freezing is assumed to occur as snow. Snowmelt is assumed to be a function of energy from air temperature, solar radiation and rainfall. Solar radiation effects are included in an empirical melt factor. In addition, groundmelt is assumed to occur at a constant rate of 0.5 mm/day as long as the ground is not frozen. Snow and snowmelt are subject to evaporation prior to runoff and infiltration. The program does not consider the effects of aspect angle or drifting in its accounting of snow behavior. Prediction of frozen soil conditions is a simple, empirical routine based on antecedent air temperatures. Thaws are based on air temperatures and climate data. Soils while frozen are assumed to be sufficiently wet so as to impede infiltration and to promote runoff. Similarly, no evapotranspiration and drainage are permitted from the evaporative zone while frozen. Runoff is computed using the SCS method based on daily amounts of rainfall and snowmelt. The program assumes that areas adjacent to the landfill do not drain onto the landfill. The time distribution of rainfall intensity is not considered. The program cannot be expected to give accurate estimates of runoff volumes for individual storm events on the basis of daily rainfall data. However, because the SCS rainfall-runoff relationship is based on considerable daily field data, long-term estimates of runoff should be reasonable. One would expect the SCS method to underestimate runoff from short duration, high intensity storms; larger curve numbers could be used to compensate if most of the precipitation is from short duration, high intensity storms. The SCS method does not explicitly consider the length and slope of the surface over which overland flow occurs; however, a routine based on a kinematic wave model was developed to account for surface slope and length. Potential evapotranspiration is modeled by an energy-based Penman method. As applied, the program uses average quarterly relative humidity and average annual wind speed. It is assumed that these data yield representative monthly results. Similarly, the program assumes that the relative humidity is 100% on days when precipitation occurs. The program uses an albedo of 0.23 for soils and vegetation and 0.60 for snow. The actual evapotranspiration is a function of other data, also. The solar radiation and temperature data are often synthetically generated. The vegetation data is generated by a vegetative growth model. The evaporative zone depth is assumed to be constant throughout the simulation period. However, outside of the growing season, the actual depth of evapotranspiration is limited to the maximum depth of evaporation of soil water, which is a function of the soil saturated hydraulic conductivity. Vegetative growth is based on a crop growth model. Growth is assumed to occur during the first 75% of the growing season based on heating units. Recommendations for the growing season are based primarily for summer grasses and assume that the growing season is that portion of the year when the temperature is above 50 to 55 °F. However, the user may specify a more appropriate growing season for different vegetation. The optimal growth temperature and the base temperature are based on a mixture of winter and summer perennial grasses. It is assumed that other vegetation have similar growth constraints and conditions. It is further assumed that the vegetation is not harvested. The HELP program assumes Darcian flow for vertical drainage through homogeneous, temporally uniform soil and waste layers. It does not consider preferential flow through channels such as cracks, root holes or animal burrows. As such, the program will tend to overestimate the storage of water during the early part of the simulation and overestimate the time required for leachate to be generated. The effects of these limitations can be minimized by specifying a larger effective saturated hydraulic conductivity and a smaller field capacity. The program does increase the effective saturated hydraulic conductivity of default soils for vegetation effects. Vertical drainage is assumed to be driven by gravity alone and is limited only by the saturated hydraulic conductivity and available storage of lower segments. If unrestricted, the vertical drainage rate out of a segment is assumed to equal the unsaturated hydraulic conductivity of the segment corresponding to its moisture content, provided that moisture content is greater than the field capacity or the soil suction of the segment is less than the suction of

the segment directly below. The unsaturated hydraulic conductivity is computed by Campbell hydraulic equation using Brooks-Corey parameters. It is assumed that all materials conducting unsaturated vertical drainage have moisture retention characteristics that can be well represented by Brooks-Corey parameters and the

Campbell equation. The pressure or soil suction gradient is ignored when applying the Campbell equation; therefore, the unsaturated drainage and velocity of the wetting front may be underestimated. This is more limiting for dry conditions in the lower portion of the landfill; the effects of this limitation can be reduced by specifying a larger saturated hydraulic conductivity. For steady-state conditions, this limitation has little or no effect. The vertical drainage routine does not permit capillary rise of water from below the evaporative zone depth. Evapotranspiration is not modeled as capillary rise, but rather as a distributed extraction that emulates capillary rise. This is limiting for dry conditions where the storage of water to satisfy evaporative demand is critical and for designs where the depth to the liner is shallow. This limitation can be reduced by increasing the field capacity in the evaporative zone and the evaporative zone depth. Percolation through soil liners is modeled by Darcy's law, assuming free drainage from the bottom of the liner. The liners are assumed to be saturated at all times, but leakage occurs only when the soil moisture of the layer above the liner is greater than the field capacity. The program assumes that an average hydraulic head can be computed from the soil moisture and that this head is applied over the entire surface of the liner. As such, when the liner is leaking, the entire liner is leaking at the same rate. The liners are assumed to be homogeneous and temporally uniform. Leakage through geomembrane is modeled by a family of theoretical and empirical equations. In all cases, leakage is a function of hydraulic head. The program assumes that holes in the geomembrane are dispersed uniformly and that the average hydraulic head is representative of the head at the holes. The program further assumes that the holes are predominantly circular and consist of two sizes. Pinholes are assumed to be 1 mm in diameter while installation defects are assumed to have an cross-sectional area of 1 cm_2. It is assumed that holes of other shapes and sizes could be represented as some quantity of these characteristic defects. Leakage through holes in geomembranes is often restricted by an adjacent layer or soil or material termed the controlling soil layer. Materials having a saturated hydraulic conductivity greater than or equal to $1x10^{-1}$ cm/sec are considered to be a high permeability material; materials having a saturated hydraulic conductivity greater than or equal to $1x10^{-4}$ cm/sec but less than $1x10^{-1}$ cm/sec are considered to be a medium permeability material; and materials having a saturated hydraulic conductivity less than $1x10^{-4}$ cm/sec are considered to be a low permeability material. The program assumes that no aging of the liner occurs during a simulation. The lateral drainage model is based on the assumption that the lateral drainage rate and average saturated depth relationship that exists for steady-state drainage also holds for unsteady drainage. This assumption is reasonable for leachate collection, particularly for closed landfills where drainage conditions should be fairly steady. Where drainage conditions are more variable, such as in the cover drainage system, the lateral drainage rate is underestimated when the saturated depth is building and overestimated when the depth is falling. Overall, this assumption causes the maximum depth to be slightly overestimated and the maximum drainage rate to be slightly underestimated. The longterm effect on the magnitude of the water balance components should be small. As with leakage or percolation through liners, the average saturated depth is computed from the gravity water and moisture retention properties of the drain layer and other layers when the drain layer is saturated. The program assumes that horizontal and vertical saturated hydraulic conductivity to be of similar magnitude and that the horizontal value is specified for lateral drainage layer. Subsurface inflow is assumed to occur at a constant rate and to be uniformly distributed spatially throughout the layer, despite entering the side. This assumption causes a delay in its appearance in the leachate collection and more rapid achievement of steady-state moisture conditions. This limitation can be minimized by dividing the landfill into sections where inflow occurs and sections without inflow. Leachate recirculation is assumed to be uniformly distributed throughout the layer by a manifold or distribution system. Leachate collected on one day for recirculation is distributed steadily throughout the following day.

5.2 LIMITS OF APPLICATION

The model can simulate water routing through or storage in up to twenty layers of soil, waste, geosynthetics or other materials for a period of 1 to 100 years. As many as five liner systems, either barrier soil, geomembrane or composite liners, can be used. The model has limits on the order that layers can be arranged in the landfill profile. Each layer must be described as being one of four operational types: vertical percolation, lateral drainage, barrier soil liner or geomembrane liner. The model does not permit a vertical percolation layer to be placed directly below a lateral drainage layer. A barrier soil liner may not be placed directly below another barrier soil liner. A geomembrane liner may not be placed directly below another geomembrane liner. Three or more liners, barrier soil or geomembrane, cannot be placed adjacent to each other. The top layer may not be a barrier soil or geomembrane liner. If a liner is not placed directly below the lowest lateral drainage layer, the lateral drainage layers in the lowest subprofile are treated by the model as vertical percolation layers. If a geomembrane liner is specified as the bottom layer, the soil or material above the liner is assumed to be the controlling soil layer. No other restrictions are placed on the order of the layers. The lateral drainage equation was developed and tested for the expected range of hazardous waste landfill design specifications. The ranges examined for slope and maximum drainage length of the drainage layer were 0 or 30 percent and 25 to 2000 feet; however, the formulation of the equations indicates that the range of the slope could be extended readily to 50 percent and the length could be extended indefinitely. Several relations must exist between the moisture retention properties of a material. The porosity, field capacity and wilting point can theoretically range from 0 to 1 in units of volume per volume, but the porosity must be greater than the field capacity, and the field capacity must be greater than the wilting point. The general relation between soil texture class and moisture retention properties is shown in Figure 2. The initial soil moisture content cannot be greater than the porosity or less than the wilting point. If the initial moisture contents are initialized by the program, the moisture contents are set near the steady-state values. However, the moisture contents of layers below the top liner system or cover system are specified too high for arid and semi-arid locations and too low for very wet locations, particularly when thick profiles are being modeled. Values for the maximum leaf area index may range from 0 for bare ground to 5.0 for 109 an excellent stand of grass. Greater leaf area indices may be used but have little impact on the results. Detailed recommendations for leaf area indices and evaporative depths are given in the program. For numerical stability, the minimum evaporative zone depth should be at least 3 inches. The program computes the evaporation coefficient for the cover soils based on their soil properties. The default values for the evaporation coefficient are based on experimental results reported by Ritchie (1972) and others. The model imposes upper and lower limits of 5.50 and 3.30 for the evaporation coefficient so as not to exceed the range of experimental data. The program performs water balance analysis for a minimum period of one year. All simulations start on the January 1 and end on December 31. The condition of the landfill, soil properties, thicknesses, geomembrane hole density, maximum level of vegetation, etc., are assumed to be constant throughout the simulation period. The program cannot simulate the actual filling operation of an active landfill. Active landfills are modeled a year at a time, adding a yearly lift of material and updating the initial moisture of each layer for each year of simulation.

BIOGRAPHY

Miss Hareuthai Thaiyatham was born on July 16, 1980 at Ladprow district, Bangkok and graduated from high school at Bodindecha School in 1997. She has been graduated the bachelor degree of Environmental Science from Thammasat University in 2001. After graduation, she worked at STS Engineering Consultants Company until 2003. She entered the Master of Science in Environmental Management Program at Chulalongkorn University in 2003.