THE SPATIAL FLOODING SIMULATION BY USING GEOGRAPHIC INFORMATION SYSTEMS CASE STUDY: FLOOD CONTROL AND PROTECTED AREA OF EAST BANGKOK BANK

DAMRONG SIAMMAI

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This thesis is dedicated to my dear mother and father who give a wonderful life and opportunity for me and my graduate study. Also are my brother and sister who always encourage and support everything for me.

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The objective of this study is to form spatial flooding simulation for display of flood problem on tangible condition. Due to the limitations of spatial data it is necessary to construct the spatial flood model in ideal scenario by using the Geographic Information Systems (GIS) as a tool for the study. This study was defined by four events of the daily rainfall and water level on 18 September 1998, 19 September 1998, 20 September 1998 and 1 October 1998. The study area was provided as main area and sub-area 01 and sub area 02. The criterion for area was provided on the linking of canal network system in study area, the integration between elevation and equivalent water level line in GIS operation for analysis of flood area, flood depth and flood volume. Flood depth analysis in model simulation is used for flood depth calibration with real events. The elevation in 1986 and 1995 were used for flood model simulation in this study.

The result of spatial flood simulation within elevation in 1986 in the event on 18 September 1998 dealt with a flooded area of around 134,406,400 square meters, 19 September 1998 was around 131,959,200 square meters, 20 September 1998 was around 114,432,800 square meters and 1 October 1998 was around 57,310,000 square meters. The result of flood volume is around 582,235 cubic meter, 611,272.00 cubic meters, 618,989 cubic meters, and 429,322 cubic meters respectively. The result of spatial flood simulation within elevation in 1995 in the event on 18 September 1998 dealt with a flooded area of around 95,246,000 square meters, 19 September 1998 was around 91,843,200 square meters, 20 September 1998 was around 75,585,600 square meters and 1 October 1998 was around 20,284,000 square meters. The volume of flood was around 422,871 cubic meters, 427,421 cubic meters, 422,807 cubic meters, and 44,886 cubic meters respectively. All the flooded areas and food volumes depended on the water level above elevation in each event. It was found from flood depth calibration within elevation 1986 that almost all of flood depth in the model was different from that in real events. When we used elevation 1995 and defined the assumption of elevation changing since year 1986 to 1995, as if it is really an occurrence of flood events, they must effect flood events both in real situation and model construction. It means that flood depths in model by use of elevation in year 1995 was more nearly the same as that in real situation, but it was found that in result of flood depth calibration was by contrast with the assumption, was at the same position that accorded with it. The hypothesis evaluation by use of the statistic method " paired-samples T test " for evaluation between interval of the mean of flood depth in real event and flood depth in model that was in same position. The result of study found that flood depth in model was different from flood depth in real events at 0.05 significance level or 95 % confidence.

This study can be summarized that the Geographic Information Systems (GIS) can simulate spatial flood condition on tangible scenario but it is not absolutely accurate or match with real situation. There are other variables, which are not used for model simulation such as polder system, pumping and timing etc. However, this study is an attempt for displaying a tangible scenario of flood condition and trend of flood problems. This research is a pilot study which is necessary to intensify the study in the future.

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คำสำคัญ : พื้นที่/ น้ำท่วม/ แบบจำลอง/ การจำลองสภาพ/ การเปรียบเทียบผล

ดำรง เสียมไหม : การจำลองสภาวะน้ำท่วมเชิงพื้นที่โดยใช้ระบบสารสนเทศภูมิศาสตร์ กรณีศึกษา : พื้นที่ควบคุมและป้องกันน้ำท่วมฝั่งตะวันออกของกรุงเทพมหานคร (THE SPATIAL FLOODING SIMULATION BY USING GEOGRAPIC INFORMATION SYSTEMS CASE STUDY: FLOOD CONTROL AND PROTECTED AREA OF EAST BANGKOK BANK) คณะกรรมการควบคุมวิทยานิพนธ์ : รุ่งจรัส หุตะเจริญ, M.Sc., ชูเกียรติ ทรัพย์ไพศาล, M.Eng., พีระพงษ์ ศิริเกษม, Ph.D., ประพฤติ เกิดสืบ, M.Sc. 90 หน้า. ISBN 974 - 663-552-2

จุดมุ่งหมายในการศึกษาครั้งนี้ คือ การจำลองสภาพน้ำท่วมเชิงพื้นที่ เพื่อแสดงสภาวะปัญหาน้ำท่วมอย่างเป็นรูปธรรม ในภาพเหตุการณ์เชิงอุดมคติ เพราะเนื่องจากข้อจำกัดของข้อมูลเชิงพื้นที่ โดยใช้ระบบสารสนเทศภูมิศาสตร์ (Geographic Information Systems : GIS) เป็นเครื่องมือในการศึกษา การศึกษาครั้งนี้ได้กำหนดเหตุการณ์ปริมาณฝนรายวันและระดับน้ำ จำนวน 4 เหตุการณ์ คือ วันที่ 18 กันยายน 2541, 19 กันยายน 2541, 20 กันยายน 2541 และ 1 ตุลาคม 2541 และแบ่งพื้นที่ศึกษาเป็น พื้นที่หลัก (main area) กับสองพื้นที่ย่อย (sub-area) คือ พื้นที่ย่อย 01 และพื้นที่ย่อย 02 ซึ่งหลักเกณฑ์การแบ่งพื้นที่นี้ ขึ้นอยู่กับการเชื่อมโยงระบบเครือข่ายคลองในพื้นที่ศึกษา การผสมผสานระหว่าง ระดับความสูงของพื้นที่และเส้นเท่าระดับน้ำ(ม.รทก.) (Equivalent water level line) ในระบบปฏิบัติ GIS เพื่อวิเคราะห์หาพื้นที่น้ำท่วม (flood area) ความลึกน้ำท่วม (flood depth) และ ปริมาตรน้ำท่วม (flood volume) ซึ่งในส่วนของการวิเคราะห์ความลึกน้ำท่วมของแบบจำลองนี้ เพื่อใช้สำหรับการเปรียบเทียบผล (calibration) กับเหตุการณ์จริง

ผลการจำลองสภาพพื้นที่น้ำท่วมภายใต้ระดับความสูงของปี 2529 ในเหตุการณ์ วันที่ 18 กันยายน 2541 มีพื้นที่น้ำท่วมประมาณ 134,406,400 ตารางเมตร วันที่ 19 กันยายน 2541 ประมาณ 131,959,200 ตารางเมตร วันที่ 20 กันยายน 2541 ประมาณ 114,432,800 ตารางเมตร และวันที่ 1 ตุลาคม 2541 ประมาณ 57,310,000 ตารางเมตร ส่วนผลการศึกษาปริมาตรน้ำท่วม มีดังนี้ วันที่ 18 กันยายน 2541 ประมาณ 582,235 ลูกบาศก์เมตร วันที่ 19 กันยายน 2541 ประมาณ 611,272 ลูกบาศก์เมตร วันที่ 20 กันยายน 2541 ประมาณ 618,989 ลูกบาศก์เมตร และวันที่ 1 ตุลาคม 2541 ประมาณ 429,322 ลูกบาศก์เมตร ผลการจำลองสภาพพื้นที่น้ำท่วมภายใต้ระดับความสูงของปี 2538 ในเหตุการณ์ วันที่ 18 กันยายน 2541 มีพื้นที่น้ำท่วม ประมาณ 95,264,000 ตารางเมตร วันที่ 19 กันยายน 2541 ประมาณ 91,843,200 ตารางเมตร วันที่ 20 กันยายน 2541 ประมาณ 75,585,600 ตารางเมตร และวันที่ 1 ตุลาคม 2541 ประมาณ 20,284,000 ตารางเมตร ส่วนผลการศึกษาปริมาตรน้ำท่วม มีดังนี้ วันที่ 18 กันยายน 2541 ประมาณ 422,871 ลูกบาศก์เมตร วันที่ 19 กันยายน 2541 ประมาณ 427,421 ลูกบาศก์เมตร วันที่ 20 กันยายน 2541 ประมาณ 422,807 ลูกบาศก์เมตร และวันที่ 1 ตุลาคม 2541 ประมาณ 44,886 ลูกบาศก์เมตร ทั้งนี้จำนวนพื้นที่น้ำท่วมและปริมาตรน้ำท่วม ขึ้นอยู่กับ ระดับน้ำที่อยู่เหนือระดับพื้นที่ ของแต่ละเหตุการณ์ จากการเปรียบเทียบผลความลึกน้ำท่วมภายใต้ระดับความสูงของพื้นที่ ปี 2529 พบว่า ส่วนใหญ่ความลึกน้ำท่วมในแบบจำลองแตกต่างจากเหตุการณ์จริง และเมื่อใช้ระดับความสูง ปี 2538 และสันนิษฐานการเปลี่ยนแปลงของระดับความสูงในพื้นที่ศึกษา ตั้งแต่ปี 2529 ถึง 2538 ว่า ถ้าหากระดับความสูงมีอิทธิพลต่อการเกิดเหตุการณ์น้ำท่วมจริง เช่นเดียวกันจะต้องมีผลต่อเหตุการณ์น้ำท่วมทั้งในสภาพเหตุการณ์จริง และต่อการสร้างแบบจำลอง หมายความว่า ความลึกน้ำท่วมน้ำท่วมในแบบจำลอง เมื่อใช้ระดับความสูง ปี 2538 จะต้องใกล้เคียงกับเหตุการณ์จริงมากยิ่งขึ้น แต่ผลจากการศึกษาพบว่า กลับตรงกันข้ามกับข้อสันนิษฐานที่วางไว้ มีเพียงบางตำแหน่งเท่านั้น ที่สอดคล้องกับข้อสันนิษฐานดังกล่าว

ผลจากการทดสอบสมมติฐาน โดยใช้วิธีทางสถิติ เรียกว่า " Paired - samples T test " เพื่อประเมินความแตกต่างของค่าเฉลี่ยความลึกน้ำท่วมในแบบจำลอง และเหตุการณ์จริง ในตำแหน่งเดียวกัน ผลจากการศึกษาพบว่าความลึกน้ำท่วมในแบบจำลองมีความแตกต่างกับความลึกน้ำท่วมในเหตุการณ์จริงอย่างมีนัยยะสำคัญทางสถิติ ที่ระดับ 0.05 หรือ 95 เปอร์เซ็นต์ จากผลการศึกษา สรุปได้ว่า ระบบสารสนเทศภูมิศาสตร์(GIS) สามารถจำลองสภาพน้ำท่วมเชิงพื้นที่อย่างเป็นรูปธรรมได้ แต่ไม่ถูกต้องกับสถานการณ์จริง ทั้งนี้เนื่องจาก มีตัวแปรอื่นอีกหลายตัวแปร เช่น ระบบพื้นที่ปิดล้อม การสูบน้ำ และ ช่วงเวลา เป็นต้น ซึ่งไม่สามารถนำมาใช้ในการศึกษาครั้งนี้ได้ อย่างไรก็ตามการศึกษาครั้งนี้ได้พยายามแสดงสภาวะน้ำท่วมอย่างเป็นรูปธรรมและแสดงแนวโน้มของสภาพปัญหาเปรียบเสมือนกับการศึกษานำร่องเพื่อใช้สำหรับการศึกษาในระดับลึกต่อไป

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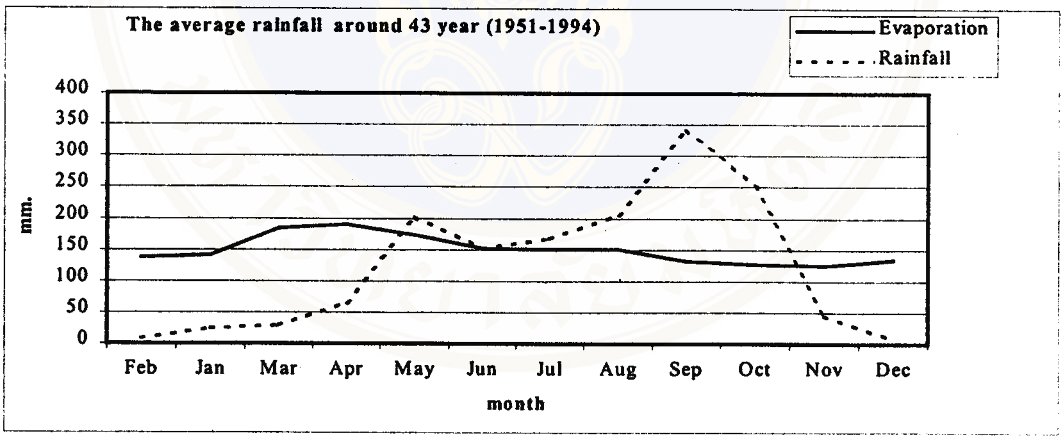
CHAPTER I

INTRODUCTION

1.1 STATE OF PROBLEM

Bangkok had a problem of flood almost every year. The flood in some years was serious and could effect damages both socially and economically continuously. From the record in year 1957 to 1996 serious flood in Bangkok was occurred 10 times, in year 1959, 1961, 1964, 1970, 1975, 1978, 1980, 1983, 1988 and 1995 (RID.1996). This problem need an urgent solutions, of which one is the management program of use of water with technology of Geographic Information Systems (GIS).

There are many factors effect a cause of flood in Thailand, but rainfall is the most important factor. The location of Thailand is little upper on tropic of cancer. There are gulf of Bengal in the west, Ocean of India in the southwest, gulf of Thailand in the south and sea of China in the east and the northeast. Those geographical factors have effect to heavy rainfall in Thailand due to influence of seawater. The average rainfall during 43 year (1951 - 1994) of Bangkok (MD, 1996) can be displayed in below figure.



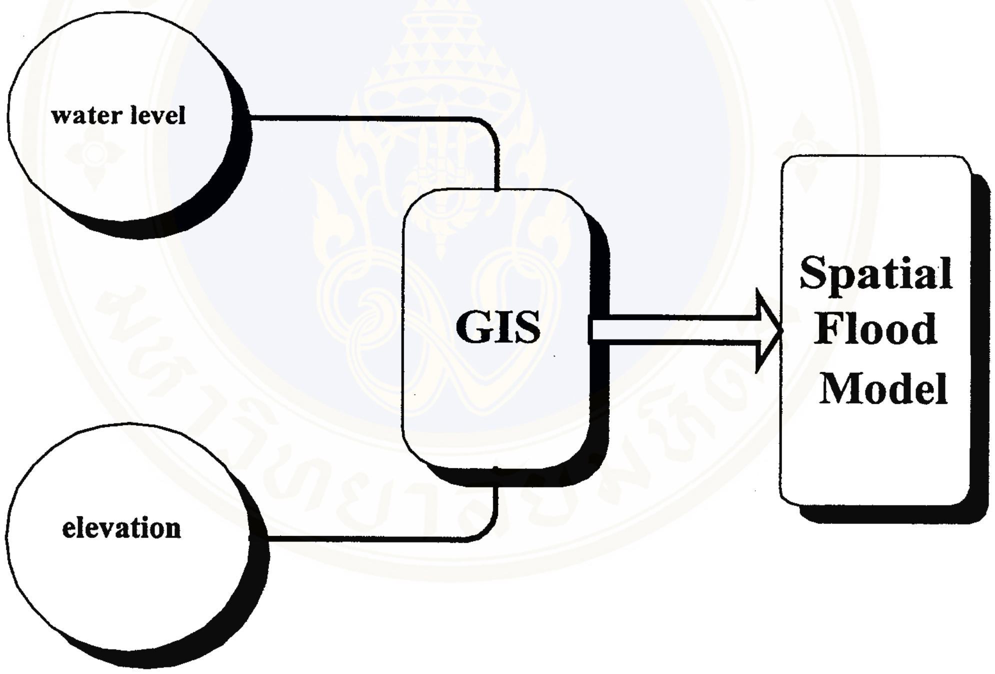
Source: M.D. 1996

Refer to above figure, the period since May to October had excess rainfall. Whereas the drainage systems of Bangkok were not efficient enough, the flood was then occurred. The other factors such as land subsidence, high sea level, and water discharge from upper basin and Bangkok locating at the end of flood plain in Chao Phraya river basin. Some area such as Ram Kham Haeng University, Hua Maak (AIT.1981), had been the most seriously effected by flood in Bangkok.

To demonstrate the status of flood problem in tangible scenario, this study has an aim to simulate of spatial flood condition with Geographical Information Systems (GIS) by displaying the relationship between water level (m.msl) and elevation (m.msl.). In case that volume of water is beyond the carrying capacity in flood control system, the model will display of flood area, flood depth and flood volume.

1.2 CONCEPTUAL FRAMEWORK

The conceptual framework of this study bases on the assumption that cause of flooding from the retention area for floodwater is storage such as pond, canal and pumping can not reserve sufficiently. Thus, there are questions how we can simulate the tangible flooding condition. Alternatively we use the Geographical Information Systems as a tool for the spatial flooding simulation. Within many stipulations, we can construct the ideal model with factors as a figure bellowed:



1.3 OBJECTIVES

1.To study the simulation of spatial flooding condition with geographical information systems (GIS).

2.To calibrate the spatial flood model with real events.

1.4 SCOPE OF STUDY

1.4.1 Scope of studied area

Flood control and protected area of East Bangkok Bank around 664 square kilometers as figure 1.1

1.4.2 Scope of methodology

1. Study of rainfall and water level data in year 1998, selecting of flooded events on rainstorm day.

2.The simulation of the spatial flooding condition with geographic information systems (GIS) to integrating between water level and elevation.

3.The calibration model against real events.

1.5 HYPOTHESIS

From the literature review Rahman, (1992) studied the application of geographic information systems for flood map construction in polder area of Menga-Dunagoda City, Bangaladesh. Silapathong, (1995) studied the application of remote sensing and GIS for flooding evaluation from high tide level factor in area of east Bangkok bank and Bang Pakong area, Thailand. The research of Rahmand and Silapathong suggested that the methodology in Geographic Information Systems (GIS) could simulate the spatial flood condition. Which the result of study depends on the data correction and variables definition in GIS process. So that the present study applied the methodology as mentioned aboved and the hypothesis is defined that the Geographic Information Systems (GIS) can simulate spatial flood condition on tangible scenario and neighborhood with real situation.

1.6 THE EXPECTED RESULTS

The expected results compose of model or equation for flood conditional prediction under the geographic information systems (GIS). The results of GIS mapping operation consists of flood area, boundary of flood area, flood position and location, and the numeric of flood depth and flood volume in each event. The models can be used as alternative for implementation of flood control and protection in study area.

1.7 THE LIMITATION OF STUDY

There are many factors of urban flooding, but this study due to limitation of exiting data, data updating, such as the ground elevation that changes by types of landuse that interrupt the drainage system. In addition the resources of budget and time were limited, this study therefor uses the factors, which cause flood i.e. rainfall, water level and elevation. The model can not be absolutely similar to real events. It needs further study by using the other factors and data updating as much as it can.

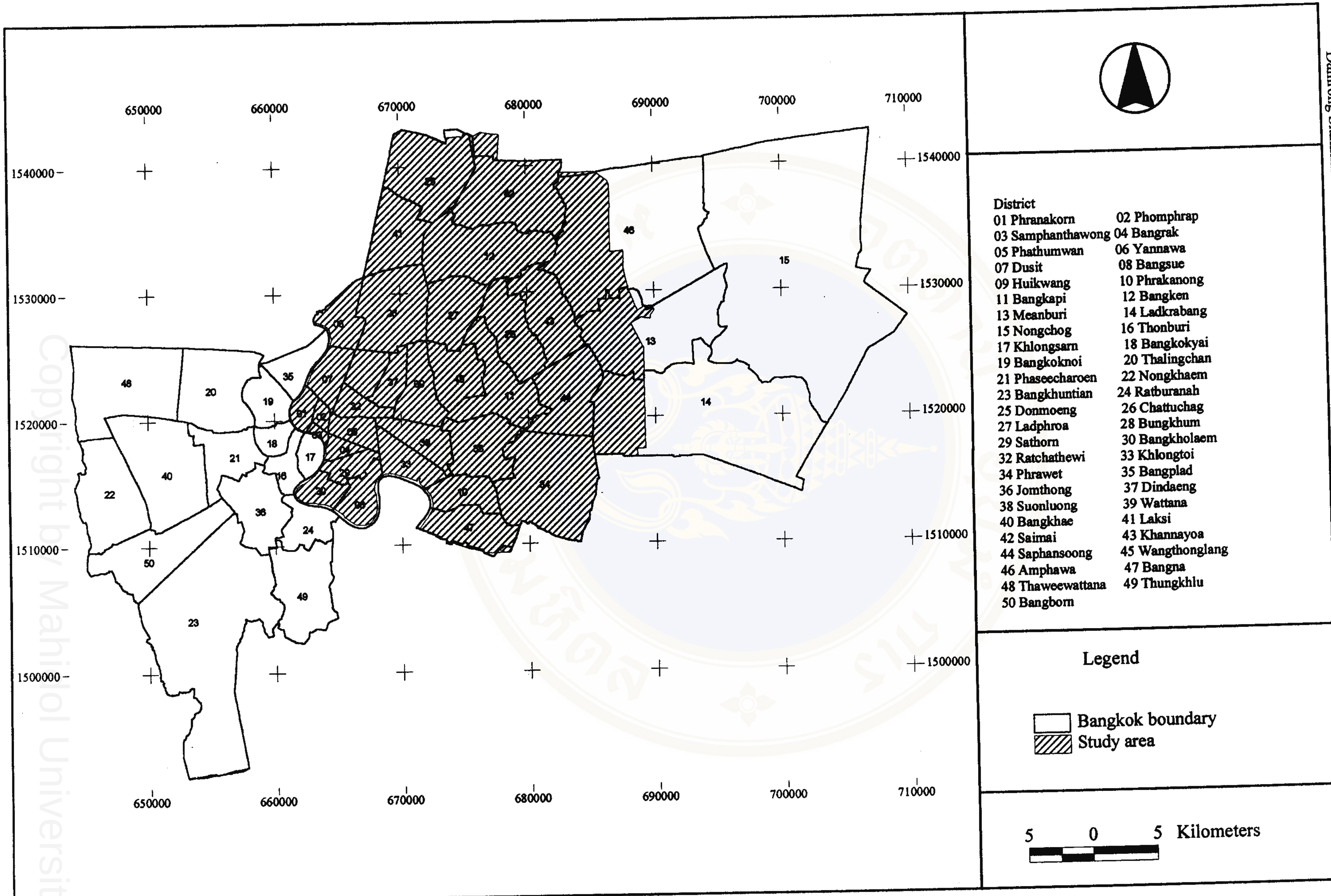


Figure 1.1 showed the study area

CHAPTER II

LITERATURE REVIEW

2.1 DEFINITION

2.1.1 System

Dent and Blackie, (1979) defined system is a complex set of related components within an autonomous framework. Robert, (1983) system is collection of interacting elements that function together for some purposes. Gordon, (1969) system is an aggregation or assemblage of objects joined in some regular interacting or interdependence. Maisel, and Gnugnoli, (1972) system is a collection of regularly interacting or interdependent components (such as machines, people, information, and communications), acting as unit in carrying out an implicitly or explicitly defined mission. Bertalanffy, (1985) system is a whole of elements in interrelation, connection with one another.

2.1.2 Simulation

Dent and Blackie, (1979) define the simulation is an action or performance to simulate which is to imitate something. Simulation is the imitation of the operation of real - world process or system over time

2.1.3 Model

Churchman, (1971) defined model as a miniature that represents a real objects and classifies such two types. Physical model are look like and often function in a similar way to the real object such children ' s toy, structures and layout of park and city. Symbolic models are abstract in form and are perhaps more difficult to comprehend than physical model. It usually represents or mimics the real system.

Goodchild, Parks and Steyaert, (1993) mention to models can classify into three major categories: scales, conceptual, and mathematical. Scale model an example would be a scale-down replica of a mountain range or an airplane wing for use in wind tunnel experiments. There is analog scale model such as topographic map. Conceptual Model is frequently used in the modeling process in block diagrams that show major systems, process, and qualitative interrelationship between subsystems. Mathematical models can be further classified as either deterministic or statistical. Statistical or probability model contains at least one stochastic process represented by one or more random variables. A deterministic model does not have any random variables. Thus a stochastic model output data that are also random variables, and a deterministic model has a unique set of output data for a given set (Law and Kelton, 1982)

2.2 PROCEDURE IN SYSTEM SIMULATION: A MODELING APPROACH

Jongkeawwattana, (1995) mention to the procedure in system simulation can classify into six steps as followed.

Step 1: Problem identification, statement of objectives and system definition

Problem identification is the initial step prior to do any other step in system simulation analysis processes. The explicit define problems and objectives will make clear exactly what problem the model will be use to solve and to what degree of detail information is required from the model.

Step 2: Collecting and analysis of data

The mechanistic model is a large extend dependent on the data available or on the feasibility of generating data within the time limits set by the research. Each relationship among variables as defined in step 1 need to be quantified. Such relationship could be constructed using curve fitting technique or table function. An ideal structure of the model may have to be forsaken because of data limitations. The structure and quantification of the model are thus intimately bound together; both eventually influencing the effectiveness of the final model.

Step 3: Model construction

The first move in model construction is to summarize the details of system from step 1 presented them as "causal loop diagram and flow diagram. Consequently, the symbolic model (flow diagram) need to be expressed as a series of relations and equation in a computer language using information from step 2. Selection of suitable computer language is a major concern at this point. The availability of alternative is a key decision will be whether to use a special-purpose simulation language (e.g. DYNAMO, ACSL, and CSMP) or a general-purpose language (e.g. FORTRAN, BASIC, PASCAL, and C).

Step 4: Model validation

Model validation involves a testing the model constructed in step 3. The model needs to mimic the real system sufficiently well to fulfill the purposes for which it was developed. Hence, we need to compare the model output behavior and figures (value) are matched. When we are confident that the behavior of the model is satisfactory.

Step 5: Sensitivity analysis

Sensitivity analysis is a procedure carried out on the completed and, at least partly, validated model that involves exploring the operation and performance of the model. In successive runs of the model under identical environmental condition, the value of parameter may be changed. The resultant modification in output will be analyzed to determine whether or not the changed parameter values are material consequence. A sensitive parameter is one, which causes a major change in model output; the model is said to be sensitive to such parameter.

Step 6: Application of the model

After passing the validation and sensitivity analysis steps, the model can be implemented confidently to achieve the purposes set at the earlier step. Generally, the model would help management strategies of a real system like farming system and population control system. Moreover, the model could also provide knowledge that regard to the understanding of the system, which can guide the research program.

2.3 MODEL CALIBRATION, VALIDATION AND VERIFICATION

2.3.1 Model calibration

Banks, Carson and Nelson, (1996) defined Model calibration is the interactive process of comparing the model to the real system, making adjustments to the model, comparing the revised model to reality, making additional adjustments, comparing again and so on.

2.3.2 Model validation

Model validation is a process to ensure the agreement between the model-behavior and behavior of the real system. Lemon (1977) defined the term validation as comparison of a verified model to the real world and determination if it suitable for its intended purpose. Forrester and Senge (1980) stated that validation is the process of establishing confidence in the soundness and useful the model. Whisler et. al (1986) defined more detail definition of model validation as comparison of the predictions of a verified model with experimental observations other than those use to build and calibrate the model, and identification and correction of errors in the model until it is suitable for its intended purpose.

2.3.3 Model verification

Mihram (1972) defined verification as stage of model s development during which the model s responses are compare with those which whole be anticipated to appear if indeed the model s structure were programmed as intended. Dent and Blackie (1979) coined the term verification as a process in model development whereby the computer program of the model is checked for logical consistency.

2.4 CAUSE OF FLOODING

Tingsanchali, T. (1996) mention to the general flooding are cause by overbank flows due to excessive high river discharges from upland area, heavy local rainfall and high tides. In the cities where excessive pumping of groundwater is experienced, Land subsidence usually occurs. This land subsidence causes local depressions and severely affects land drainage directions. In low land area, land subsidence may cause severely flooding for long period. Constructing ring dikes, internal drainage system and pumping stations can solve these flooding. Also due to land subsidence, the storm sewer pipes may be broken and some have their slope changes or even reversed. Poor drainage is one of the major factors in enhancing flooding. All of these described factors if occurred at the same time will produce the worst flooding condition.

2.5 FLOODING IN BANGKOK

Department of Drainage and Sewerage (DDS), BMA (1996) mention to the factor causes flooding in Bangkok fine that there are many factors. The important are hydro- meteorology and Bangkok area as followed:

2.5.1 Hydro - meteorology

Flooding in Bangkok cause from hydro- meteorology consist of rainfall, agricultural water, water from upper basin, high sea level and water level is refer to DDS, (1996) mention in detail as followed:

1) Rainfall

The rainy season begins in May and ends in October. They are maximum of frequency and quantity of rainfall between August and middle of October. During this period a Tropical Cyclone blows into Thailand and passes near to Bangkok area. The average rainfall around the year recorded at Meteorological Department Station is about 1,400 mm.

2) Agricultural water

Rainfall or agricultural water in nearly area from North and East of Bangkok flown into flood protection area from stripes of declined area. The serious flood depends on quantity and water level from the outside of area.

3) Water from upper basin

The rainfall in Chao Praya basin is provided into agricultural area and other area, which is more than 160,000 km^2. The partial of water is stored in dams whereas 70 % of the excess water flows down to Bangkok and effects water level in Chao Praya River. The maximum water level is occurred in October to November every year.

4) High sea level

When the sea water level is changed by natural flow, it effects the tide in Chao Praya River part of Bangkok. The maximum high sea level is occurred from October to November every year.

5) Water level

Water from upper basin, which is high in quantity besides high sea level during October and November is another factor effecting water level in Chao Praya River to be higher than normal level such as event in year 1975, 1978, 1980, 1983 and the end of year 1995. The maximum of water levels measured at Memorial Bridge were 2.10, 205, 2.05, 2.13 and 2.27above mean sea level (msl.) respectively.

2.5.2 Bangkok area

Flooding in Bangkok cause from the condition of Bangkok area consist of city plan, drainage system and land subsidence is refer to DDS, (1996) mention in detail as followed:

1) City Plan

Bangkok in the past had a lot of canals, ditches, swamps and brooks to store of water then there was not serious flood. In the present, because of the rapid growth of urban and lack of city plan and land use control, the water storage areas are not enough, and more over be replaced by building and road construction. When there is a heavy rain, the drainage system can not overtake it, hence cause flash flood and serious flood on the roads and other area.

2) Drainage system

From the problem that city plan and the master plan of drainage, and is not complete, the canals and ditches are filled for road construction and the main drainage pipes are not enough. The drainage pipes are almost smaller than designed by master plan moreover canals and ditches are use passed, until they are narrowed and can not be dig to enough depth.

3) Land subsidence

Land subsidence is the most serious problem. It can damage the structure of flood protection and drainage system, which has been invested in the future to be failed. It can not be broken be off or no appropriate measures for it. Table 2.1 shows rate of land subsidence of Bangkok in year 1978 – 1990, before and after controlled by Department of Geological Resource.

Tables 2.1 shows rate of land subsidence of Bangkok in 1978 to 1990

Year	Bangkok Area	Rate of subsidence (cm.)
	<u>Before controlled</u>	
1978 – 1981	1.East Suburban area	10
	2. City Core	5-10
	<u>After controlled</u>	
1988 – 1989	1.East Suburban area	3-5
	2. City Core	2-3
1988 – 1990	1.East Suburban area	2-3
	2. City Core	1-3

Source: AIT, 1981

2.6 GEOGRAPHIC INFORMATION SYSTEMS (GIS)

2.6.1 Definition

There are many definitions of GIS, all this it depends on types of application, because the technology of GIS is worldwide development, complexity and it is change all time.

Geographical Information System means the series of equipment that enable for collecting, storing, retrieving, transformation and displaying of spatial data that appearance in the nature. (Burrough, 1986)

Geographical Information System means the data entry of spatial information into computer database management, by use software for graphic production and the computer enable for multiple layers displaying or overlay techniques evaluation for planning and solving the problem and management. (Thantiwetchakul, 1991)

2.6.2 Geographic databases

Gatrell, (1991) defined the geographic database is a collection of spatially referenced data that acts as a model of reality. Space is defined as relationship between objects.

Gatrell, (1991) mention to the geographic data can classified into three components consist of geographic position, attributes and time as followed:

2.6.2.1 Position

Position refers to the fact that each feature has a location that must be specified in a unique way. Elements within geographical space can be referenced in the following manner:

1) Absolute such as coordinate position using a coordinate system e.g., cartesian (X, Y, Z) or global geographic (latitude, longitude, altitude).

2) Relative which location with reference to some other object , e.g., topologic position which is described through relationships to other object (N,S,W,E; below, above, left, right) or proximity(near, far)

2.6.2.2 Attributes

Attribute is a characteristic of entity and attributes value is the actual measurement that is stored in the database. Attributes are often termed non-spatial data and can be categorized there are nominal, ordinal, interval and ratio

2.6.2.3 Time

Time is important and critical since geographic information is referenced to a point in time or period of time. Temporal data can be described in term of:

- Time duration. Time span of the current database.

- Temporal resolution. The discrete time interval for which data sets are collected and aggregated per unit of time., e.g., daily or monthly data on precipitation, flow characteristics, etc.

- Temporal frequency. The frequency over time (rate) at which observations are collected or stored, e.g., river gauge reading three time a day, average daily discharges, etc.

2.6.3 Geographic data types

Healey, (1991) mention to the geographic data types can classify into four primitive types there are points, lines, polygons and continuos surface as followed:.

2.6.3.1 Point data

Points (0-dimension: an object that has position in space but not length) are the simplest type of spatial data. The can be considered to embrace all spatial entities that are positioned or described by a single x,y coordinate pair.

2.6.3.2 Line data

Line entities (1-dimension: an object of length) are all linear features built up of straight-line segments made up of two or more coordinates. In the GIS, a line is set of connected points, with a beginning node, an end node, possibly intersection node, and labels.

2.6.3.3 Polygon or area data

Polygons (2-dimension, an object of length and width) They are bounded regions and the boundaries may be defined by natural phenomena such as landform or by man such as forest stands or land use units.

2.6.3.4 Continuous surface

A continuous surface is the representation of z value of an entire x-y domain. Common data base contents of such surface are digital elevation models (DEM), a ground water surface or a precipitation field, represented by isohyets. Visualization of x-y-z values of a map or image is a common capability of GIS system, which may also fruitfully employed in the analysis of the nature of hydrologic variables.

2.6.4 Data structure

Healey (1991) mention to the spatial distribution of points, lines, areas and surfaces are represented in digital form. Whereas Aronoff, (1989) the data structure can classify into two basic types of spatial models that is raster and vector model as followed:

2.6.4.1 Vector model

Vector is defined as a quantity with a starting coordinate and an associated displacement and direction. The fundamental primitive in the vector model is the point. Connecting points with straight lines creates objects, areas are defined by sets of lines. In vector model, the points and lines that define their boundary represent model objects. The position of each object is defined by its placement in a map space that is organized by a coordinate reference system.

2.6.4.2 Raster model

Raster is defined as a grid or cellular organization of spatial data. In a raster structure, a value for the parameter of interest is developed for every cell in an array over space. Each cell in a raster file is assigned only one value; different attributes are stored as separate data files. The raster model is easily interfaced with the hardware devices commonly used for the input and output of spatial data.

2.6.5 Digital elevation models

Moore, (1993) to defined the digital elevation models (DEM) is an ordered of numbers that represents the spatial distribution of elevation above some arbitrary datum in the landscape.

2.6.5.1 The structure of DEMs

Moore, Gallant and Guerra (1993) mention to the basic structure of DEM can classified into three forms there are line model, triangulated irregular network and the grid network as followed:

1) Line model

The line model describes the elevation of terrain by contours (stored as Digital Line Graph, DGLs), the x,y coordinate pairs along each contour of specified elevation.

2) Triangulated irregular network (TIN)

The TIN model splits up the surface into triangular elemental planes. Points (nodes) that are located at positions sample the terrain surface, which capture the terrain characteristics. Three nodes are reference points for the triangular facets; they will not be changed by procedures such as interpolation.

3) Grid structure

Grid-base methods may involve the use of regularly spaced triangular, square or regular grid. The elemental area is the cell bounded by three or four adjacent grid points, depending on the method. The raster-base GISs uses the square grid network.

2.6.6 Integrated data analysis of spatial and attribute data

Aronoff, (1990) mention to the integration between spatial data and attribute data it depended on the sophistication the GIS and the purpose for which it has been designed. Four groups can be distinguished as followed:

2.6.6.1 Retrieval, (re) classification and measurement operations

These operations share the characteristic that no changes are made the spatial and attribute database. Four groups can be distinguished

1) Retrieval

Retrieval operations consist of the selective retrieval, manipulation and output of spatial data. There are no modifications to the geographic location of spatial entities and no new spatial featured are created.

2) (Re) classification

(Re) classification operations involve the reassignment of new thematic values to units of an exiting map. This recording can be function of the initial value, position, size or shape of the configuration of the spatial entities.

3) Measurement

Measurement operations involve the calculation of lengths, perimeters, area, volume or occurrences. Lengths, perimeters and areas are normally calculated and stored as attributes of the spatial data.

2.6.6.2 Overlay operation

Berry, (1987) mention to the overlaying of maps results in the creation of new spatial entities. The values assigned to a certain location are computed as a function of the independent values associated with the same location in two or more separate maps. Overlay calculations are most easily carried out using raster data structures and can classify into three approaches as followed.

1) Arithmetical overlaying

Arithmetical overlaying included operations such as addition, subtraction, multiplication and division of each value in a data layer by the value in the corresponding location in the second data layer.

2) Logical overlaying

Logical overlay operations work with the logical operators AND, OR and XOR. This results in an overlay where two or more values are present (AND : intersection), where any of the values is present (OR: union) or where none of the values are present (XOR).

3) Conditional overlaying

Conditional overlay operations are more sophisticated in the way in which maps are overlaid. These operations comprise the selection of an area where certain preset conditions are met. Basically, two approaches are used in conditional overlaying. Two-dimensional tables are used for overlaying two maps. The operator controls the output value for each combination of values of the two maps. Conditional statements are languages modeling in GIS for maps overlay operation, which performed in a way similar to that algebraic operation. Different operators can be used (+, -, x, /, AND, OR, XOR, IF.....THEN, etc) on different operand (maps, image, etc.)

2.6.6.3 Surface operations

Rapers, (1986) mention to the surface operations share the characteristic that the values of an area surrounding a certain location (target) are evaluated in relation to specific location. This type of operation generally relates in one way or another to continuo surfaces. Slopes were calculated using a DTM (a topographic surface) whereby the elevation at a certain spot is compared with elevation data at surrounding spots. There are four types of surface operation exist:

1) Topographic functions

The surface characteristics such as slope, relief and slope forms are refer to as topography. Topographic functions are used to calculate values that describe the topography at a specific geographic location.

2) Illumination functions

An illumination function a surface is viewed as if a light source shines on the surface from a certain direction and at a certain angle. This results in sunlit and shaded area. The most common application of an illumination function refers to a process of hill shading.

3) Perspective view functions

A surface may be viewed from a different perspective than the vertical. This way of playing data is primary intended for visual inspection of the data, not for data analysis. A 3-dimensional view of spatial entities to gain a better understanding of spatial entities. Perspective views may be represented by a grid display as a common in a 3-D view of a topographic surface.

4) Interpolation

The interpolation functions describe the spatial distribution of the spatial entities. Interpolation refers to interpolation from point or lines for estimation of unknown values from existing observation at neighboring locations. The interpolation methods were depended on of desired accuracy, number and distribution of points and lines. Typical examples of interpolation are point interpolation (e.g., rainfall, spot heights) and line interpolation (e.g., contours, isolines)

2.6.6.4 Connectivity operations

The feature that distinguishes this group of operations from the previous ones is the connectivity of spatial entities (area or line). Different types of connectivity are possible: Raper, (1989) to classify the connectivity operation into five approaches as followed.

1) Contiguity function

Contiguity functions consider areas that have common characteristics. Besides specifying the characteristics the conditions for connectivity should also be given.

2) Proximity function

Proximity involves the measurement of distances from spatial features or targets. The targets could points, lines or areas. The unit distance is not limited of length, but can also be express in time, costs or any other unit. Typical of examples of proximity are determinations of buffer zones, construction of thiessen polygon and determination of travel time.

3) Spread function

Spread functions evaluate phenomena that spread with distance. Here also distance can be expressed in term of length, time or any other unit. While spreading, the attribute value of the phenomena may remain constant, decrease or increase. Given the area planed for inundation, is very easy to calculate the total acreage of flooding area and the total volume of the water in the reservoir by overlay the flood map with the DTM.

4) Seek function

Seek functions are used for determining optimum pathways using one or more specified decision rules. From a start location a route is established in a step by step manner in one or more decision rules. The process is repeated until one or all of the decision rules become inapplicable. The result is the creation of a set of linear features (a network).

5) Network function

The network functions to make an analysis of the movement resource from a location to another, through this set of interconnected linear features. Resource may be water, sediment, pollutants, etc.

2.7 THE APPLICATION OF GIS FOR SPATIAL FLOODING SIMULATION

Rahman, (1992) studied the application of geographic information systems for flood map construction in polder area of Menga-Dunagoda City, Bangaladesh. The main purpose was flood map construction in year 1988 with digital elevation model (DEM) and compared with SPOT satellite image for calculated and evaluate the effect on flood area, flood depth and flood volume. The result of comparison with SPOT image and DEM by using overlay technique to study about similarly and difference in study area. From the validation process it appeared that DEM less corrects than SPOT, but was in scope of acceptation, which it was assume from the error of spatial data that used in this study.

Silapathong, (1995) studied the application of remote sensing and GIS for flooding evaluation from high tide level factor in area of east Bangkok bank and Bang Pakong area. The main purpose of this study was demonstration of remote sensing and GIS application for effect of economic and social evaluation from flood event of high tide level factor. This study was not comparison with real flood event.

CHAPTER III

METHODOLOGY

From the study of factors that cause flooding and data inspection, including the potential of software and hardware in GIS operation. Throughout the exiting limitation, then this study can identify the parameters and methodology as follows:

3.1 MATERIALS

1. Computer Workstation O/S UNIX and GIS Arc/Info version 7.0
2. Inkjet printer HP 670C
3. Diskette 3.5 inch capacity 1.44 MB
4. Plotter A0
5. Digitizer A0
6. SPSS for window

3.2 DATA COLLECTION

1) Hourly rainfall and hourly water level from Flood Control Center (FCC) BMA, 1998.

3) Digital files of spot elevation from BMA, 1986.

4) Digital files of spot elevation from BMA, 1995.

5) Digital files of road network, canal network and political boundary from Department of Environmental Quality Promotion, 1995.

6) Flood conditional report from Flood Control Center (FCC) BMA, 1998.

7) Polder system in study area from Flood Control Center (FCC) BMA, 1997.

8 Bangkok base map scale 1 : 20,000 from Ordnance Survey Department

9) Bangkok topographic map scale 1 : 50,000 sheet number 5036 I II 5136 I III IV from Ordnance Survey Department

3.3 DATA MANAGEMENT

3.3.1 Real flood event definition.

3.3.1.1 Rainfall and water gage station in study area as table 3.1 and figure 3.1

Tables 3.1 shows detail of rainfall and water gage station in study area

No.	Code	Name
1	E00	FCC
2	E01	Klong Song Sai Tai regulation gate.
3	E02	Klong Phraya Suren regulation gate.
4	E03	Klong Saam Wa regulation gate.
5	E04	Klong Bang Buo rainfall – water gage station.
6	E05	Klong Prem Phrachakorn regulation gate.
7	E06	Klong Lam Chala rainfall – water gage station.
8	E07	Klong Saen Saep (part of Phracharuamjai road) regulation gate.
9	E08	Klong Bang Ken Mai pumps station.
10	E09	Klong Bong Khwang regulation gate.
11	E10	Bang Sue pump station.
12	E11	Klong Saen Saep (part of Bang Chan) regulation gate.
13	E12	Klong Lad Prao regulation gate.
14	E13	Klong Sam Sen Pump stations.
15	E14	Klong Chao Kun Sing rainfall-water gage station (part of Bodindecha School)
16	E15	The Wate regulation gate.
17	E16	Klong Sam Sen rainfall-water gage station (part of the victory monument)
18	E17	Klong Saen Saep rainfall-water gage station of Bang Kapi district.
19	E18	Klong Sam Sen Pump stations (part of Klong Saen Saep).
20	E19	Klong Sam Sen pump station (part of Klong Tan).
21	E20	Krung Kasem pumps station.
22	E21	Klong Phra Khanong regulation gate (part of Lad Krabang)
23	E22	Klong Phra Khanong regulation gate (part of Wat Kra Toom Sua Phla).
24	E23	Klong Sa Torn pumps station.
25	E24	Klong Phra kanong rainfall-water gage station (part of Wat kachorn Siri)
26	E25	Bang Chan water gage point.
27	E26	Pra Ram IV pumps station.
28	E27	Phra Khanong pumps station.
29	E28	Klong Jek pumps station.
30	E29	Klong Wat Trai pumps station.
31	E30	Klong Bang Ou pumps station.
32	E31	Klong Bang Na pumps station.
33	E32	Klong Bang Na rainfall-water gage station (part of Sri Nakharin road).
34	E33	Klong Sam Rong pumps station.

Source: Flood Control Center (FCC), BMA 1998

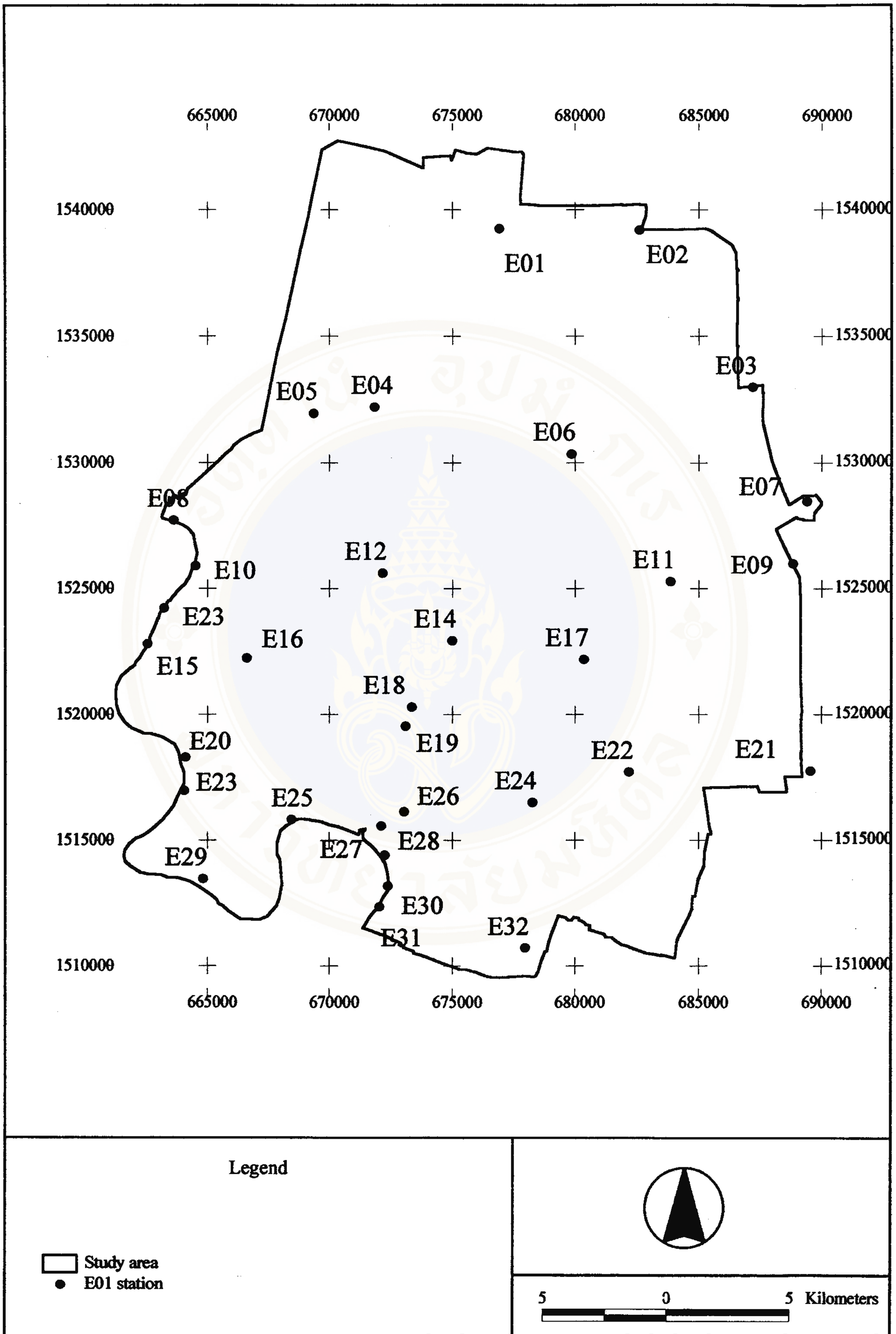


Figure 3.1 showed the rainfall and water gage station in study area

3.3.1.2 Rainfall

The criteria of rainfall is cause of flooding from the Action Plan of Flood Control, BMA (DDS, 1997) define that there is rainfall about 10 – 60 mm./day, except when the weather is abnormal it may be over 90 mm./day. This study therefore considered that criteria for samples group definition.

The collection of daily rainfall data in 33 network stations in study area from Flood Control Center (FCC) BMA, in September and October 1998 and event definition for rainfall distribution and direction analysis consists of four events as table 3.2

Table 3.2 showed daily rainfall in study area

Station	Rainfall (mm./day)			
	18-Sept.-98	19-Sept.-98	20-Sept.-98	1-Oct-98
E00	70.50	0.00	4.00	90.50
E01	103.00	0.50	2.50	4.00
E02	0.00	0.00	0.00	0.00
E03	23.00	0.00	0.50	43.00
E04	78.00	0.00	0.00	56.50
E05	46.50	0.00	0.00	1.50
E06	12.50	0.50	0.90	91.50
E07	32.50	6.50	0.00	60.00
E08	21.00	0.00	0.50	52.00
E09	21.50	14.50	0.50	70.00
E10	28.00	0.00	1.50	66.00
E11	13.00	4.00	7.00	80.50
E12	67.00	4.50	12.50	89.50
E13	36.00	0.50	7.00	63.50
E14	0.50	0.50	0.50	140.00
E15	25.50	0.00	31.50	43.50
E16	46.50	0.00	1.50	73.50
E17	42.00	74.50	21.50	122.00
E18	77.50	22.50	7.00	105.50
E19	88.50	23.50	10.50	83.50
E20	11.50	0.50	22.00	34.00
E21	28.50	36.50	12.50	188.50
E22	40.50	54.50	5.00	104.00
E23	27.00	13.50	52.00	49.50
E24	0.00	0.00	0.00	0.00
E25	35.00	21.50	32.50	64.50
E26	60.50	33.50	75.00	50.50
E27	36.00	22.00	50.00	50.50
E28	27.50	11.00	34.00	0.00
E29	16.00	6.50	25.50	71.00
E30	0.00	0.00	0.00	0.00
E31	37.00	3.00	47.50	96.50
E32	24.00	6.00	36.00	83.00
E33	36.00	0.00	66.50	56.00
Average	34.56	10.60	16.96	63.69

Source: Flood Control Center (FCC), BMA 1998

3.3.1.3 Water level

Types of water level recorded at Flood Control Center (FCC) BMA consist of average, minimum and maximum water level. Generally, the serious of flood events is concerned with the water levels. Then the maximum water level is the most effect on flood conditions and it can display flood events more implicitly.

The data collection of maximum water level in 33 network stations from FCC in September and October 1998. The maximum water level (same day with rainfall selections) use for spatial flooding simulation consist of four events as table 3.3

Table 3.3 showed the maximum water level in study area

Station	Maximum water level (m.msl.)			
	18-Sep-98	19-Sep-98	20-Sep-98	1-Oct-98
E01	0.88	0.88	0.77	0.54
E02	0.31	0.31	0.31	0.31
E03	0.95	0.98	1.02	1.00
E04	1.09	1.03	0.83	0.80
E05	1.12	1.12	0.85	0.82
E06	0.85	0.85	0.90	1.11
E07	0.79	0.74	0.90	0.90
E08	0.27	0.09	-0.18	0.02
E09	0.42	0.46	0.56	0.74
E10	-0.82	-0.78	-0.84	-0.65
E11	0.51	0.52	0.57	0.72
E12	0.80	0.75	0.55	0.74
E13	-1.97	-1.78	-1.75	-1.74
E14	3.53	3.53	3.53	-2.37
E15	0.10	-0.20	0.23	0.18
E16	0.59	0.33	0.22	0.66
E17	0.56	0.54	0.22	0.72
E18	0.12	0.37	0.06	0.14
E19	0.60	0.50	0.51	0.56
E20	-0.45	-0.62	0.06	-0.25
E21	0.47	0.51	0.51	0.53
E22	0.29	0.35	0.43	0.33
E23	-	-	-	-
E24	-0.63	-0.63	-0.63	-0.63
E25	-	-	-	-
E26	-0.18	0.01	-0.17	-0.16
E27	-1.46	-1.37	-1.46	-1.46
E28	-0.57	-0.14	-0.14	-1.56
E29	-0.57	-0.14	-0.14	-1.56
E30	-0.70	-0.70	-0.70	-0.70
E31	-0.16	-0.40	-0.41	-0.31
E32	0.14	-0.14	0.41	0.14
E33	0.18	1.42	1.33	0.02

Source: Flood Control Center (FCC), BMA 1998

3.4 GIS OPERATION

From the study of Rahman, (1992) and Silapathong, (1995) by using the Geographic Information Systems (GIS) for spatial flooding simulation. The result of study fined that the methodology in GIS operation can simulate the spatial flood condition, then this study is use the methodology as mentioned to the spatial flooding simulation as steps followed:

3.4.1 Spatial data management

3.4.1.1 Study area

Input the boundary of study area from BMA base map scale 1:20,000 into GIS process. The total area of Bangkok about 1500 square kilometer, but this study had area about 664 square kilometer that is Flood Control and Protection area in east bank of Bangkok. In the present, study area had 33-network stations of rainfall and water gage station.

3.4.1.2 Main area and sub-area

The criteria of main area and sub-area are providing depend on linking analysis of canal network system. Then input the digital files of canal network into study area as figure 3.3. The evaluate method that is linking analysis of major canal and minor canal by visual analysis of flow direction, canal intersection, slope, pumping and regulation gate. The result can be displayed in figure 3.4 consist of main area, sub-area 01 and sub-area 02. Appear that, both of sub-area 01 and sub-area 02, the canal network are absolutely separate from canal network in main area that mean the water level in canals will be effect for flooding in each area only.

3.4.1.3 Rainfall and water gage station

Input the geo-reference of 33-network stations into study area use for rainfall and water level analysis in next steps. Three steps as figure bellowed:

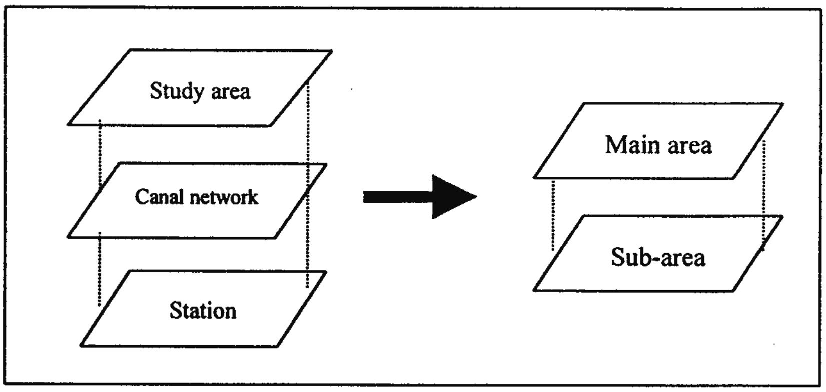


Figure 3.2 showed process of study area providing

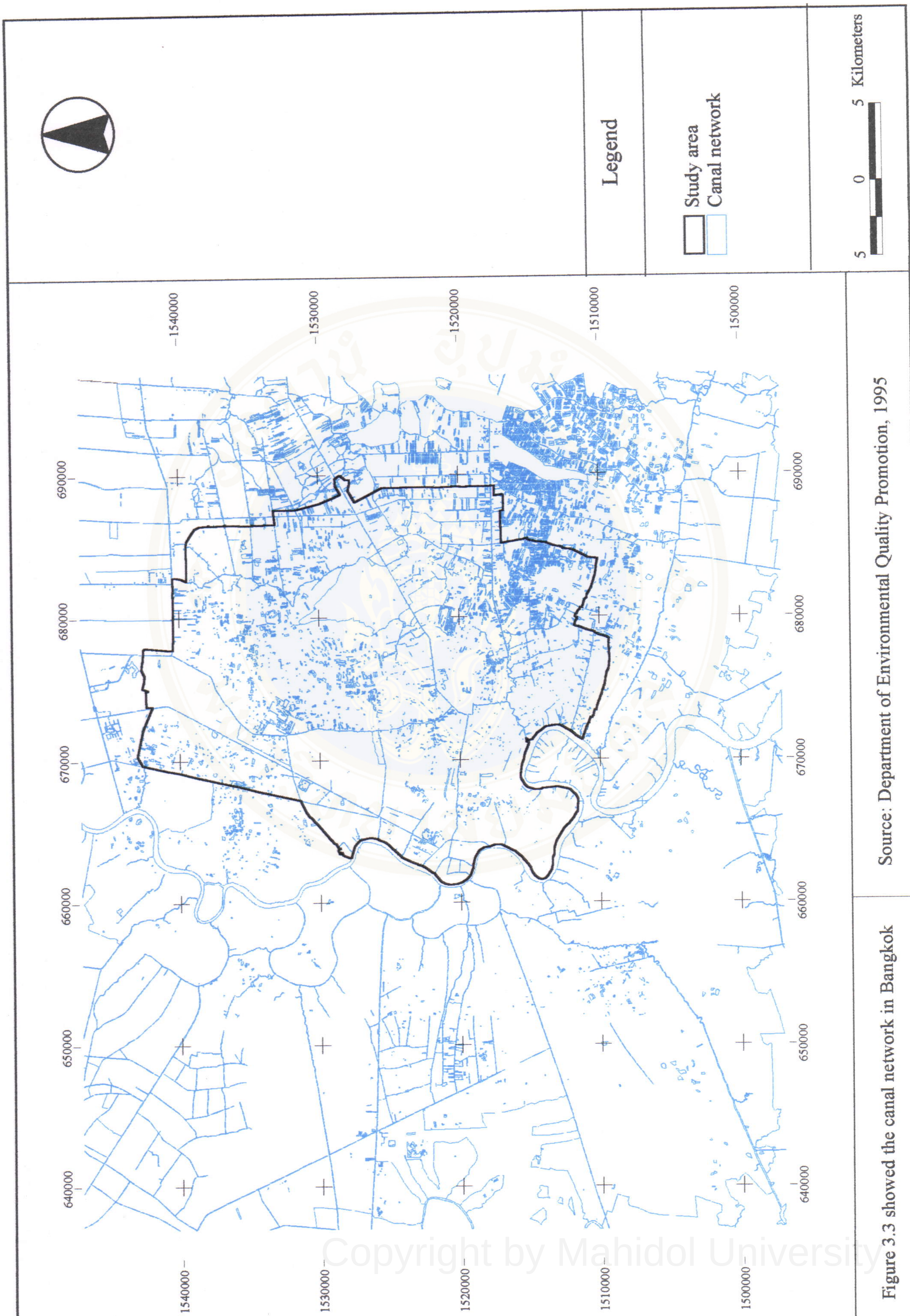


Figure 3.3 showed the canal network in Bangkok

Source: Department of Environmental Quality Promotion, 1995

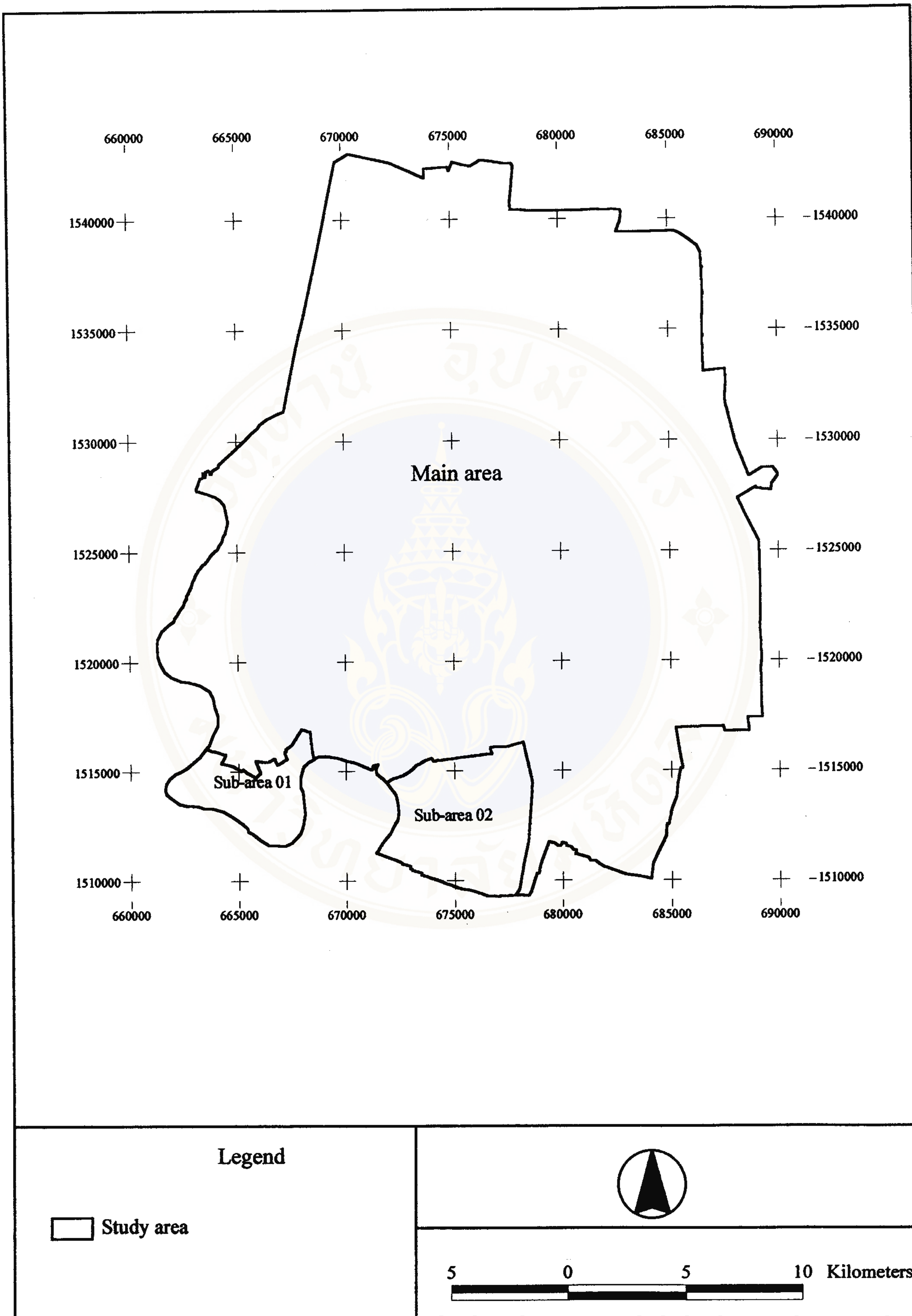


Figure 3.4 showed the main area sub-area in study area

3.4.2 Analysis process

3.4.2.1 DEM

DEM means to change displaying of spatial elevation in form of digital point (mark, 1978) as steps follow:

- Data entry of spot (ground) elevation as figure 3.7 into main area sub-area 01 and sub-area 02.
- GIS Process with *module TIN and TINLATTICE* and pixel size definition equal 20 x 20 meter and the process as figure bellowed:

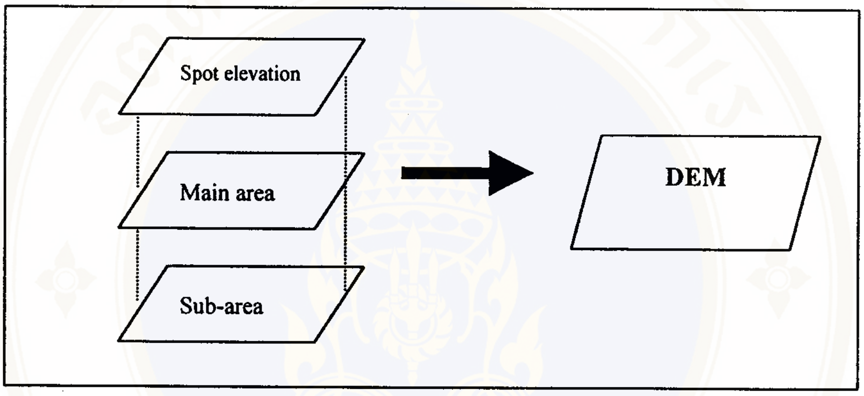


Figure 3.5 showed the process for DEM creation with spot elevation in study area

3.4.2.2 Rainfall isohyetal line.

The rainfall isohyetal line construction for displaying the rainfall distribution and direction on rainstorm day which was selected as steps follow:

- Data entry of daily rainfall into database of 32 station in study area.
- GIS process with *module spatial analysis* and *surface interpolates function for spatial interpolation* and contour intervals Reclassification. The process as figure bellowed:

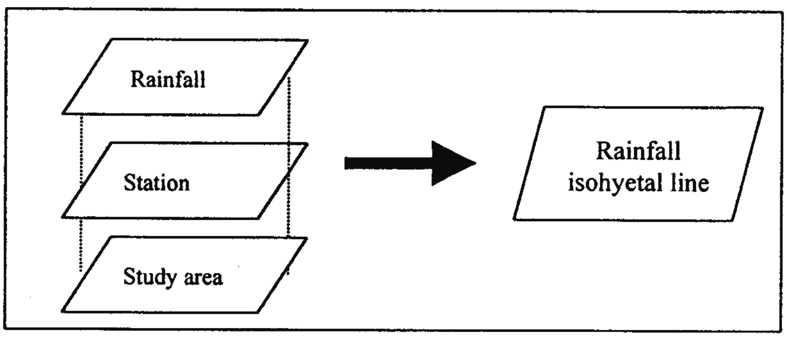


Figure 3.6 showed the construction process of rainfall isohyetal line

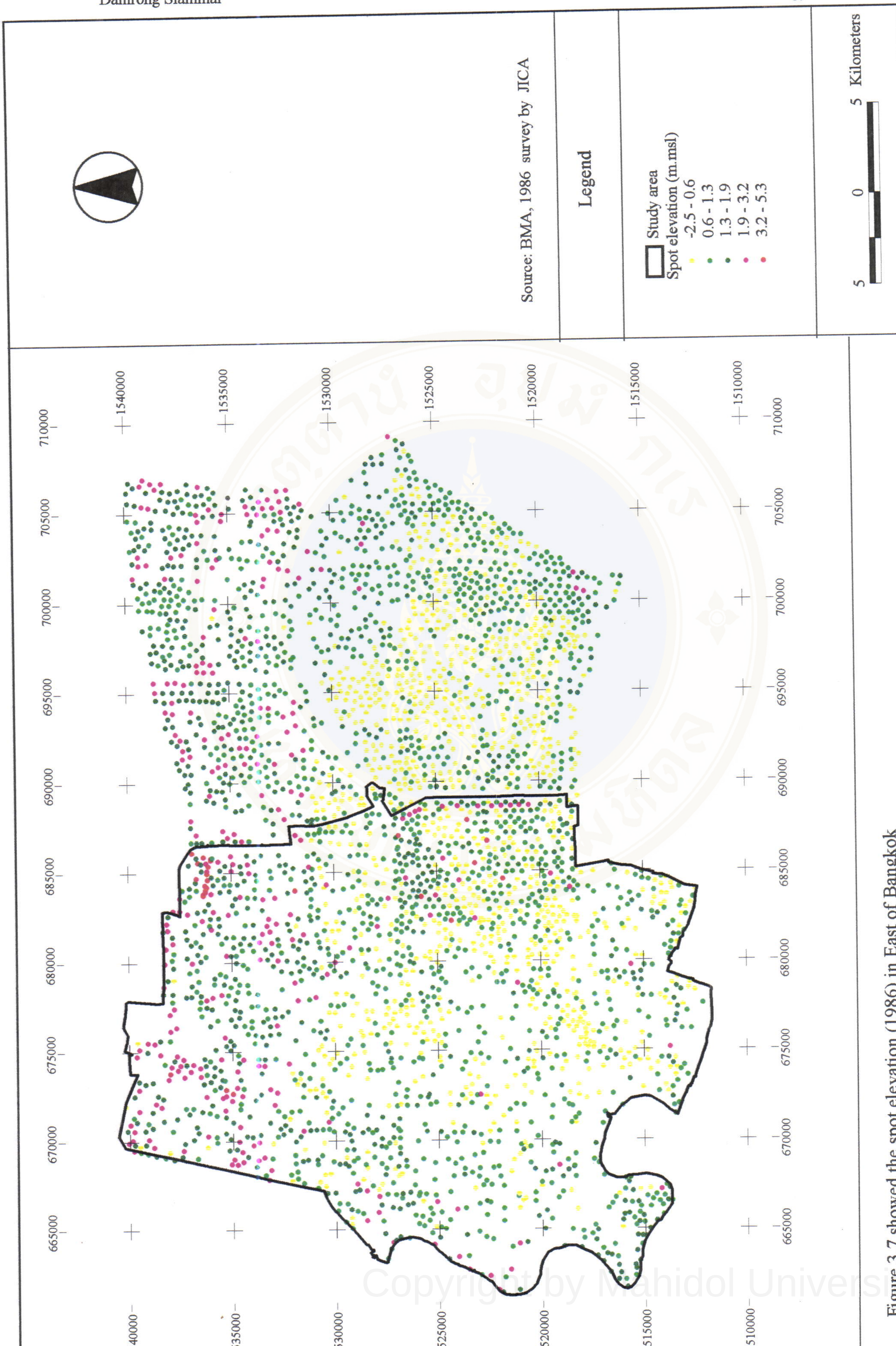


Figure 3.7 showed the spot elevation (1986) in East of Bangkok

3.4.2.3 Equivalent water level line

The construction of equivalent water level line in only part of main area because the canal network is linking together, then it can effect flooding especially in main area only. The equivalent water level line is used for spatial relation analysis between water level and topography (DEM), of which the approach is similar to creation of the isohyetal line as steps follow:

- Data entry of maximum water level into all of water gage stations in main area.

- GIS Process with *module spatial analysis* and *surface interpolates function for spatial interpolation* and contour intervals reclassification. The process as figure bellowed:

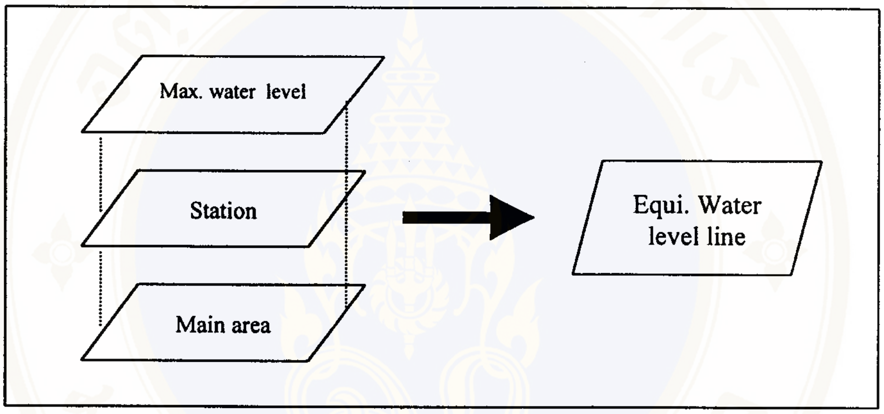


Figure 3.8 showed the construction process of equivalent water level line

3.4.3 Grid formulation

The spatial is flooding analysis by integrating between elevation and water level with overlaying technique, before overlaying both two layers. In GIS operation must be grid formulation of DEM and water level in order that GIS can calculate of flood area, flood depth and flood volume. Then these studies define pixel size 20 x 20 meter. The total grid layers and grid characteristic as table and figure bellowed

Table 3.4 showed the number of grid layers in study area

GRID LAYER		
ELEVATION	WATER LEVEL	EQUIVALENT WATER LEVEL LINE
Main area Sub-area 01 Sub-area 02	Sub-area 01 Sub-area 02	Main area

Elevation (m.msl.)

1	1.5	3	2.5
1.5	3	2.5	2
3	2.5	2	1.5
2.5	2	1.5	0.5

Water level (m.msl.)

1.1	1.1	1.1	1.1
1.1	1.1	1.1	1.1
1.1	1.1	1.1	1.1
1.1	1.1	1.1	1.1

Equivalent water level line

0.5	1	1.5	2
1	1.5	2	2.5
1.5	2	2.5	3
2	2.5	3	3.5

Figure 3.9 showed the characteristic of grid layers in study area

3.4.4 Flood simulation

3.4.4.1 Flood area analysis

Flood area analysis in main area and sub-area with grid overlaying technique between DEM and water level as figure bellowed:

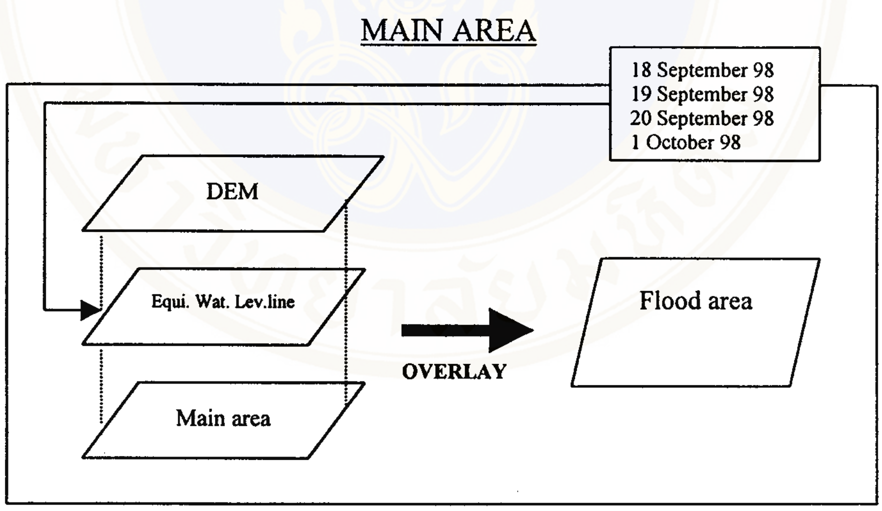


Figure 3.10 showed the construction process of flood map in main area

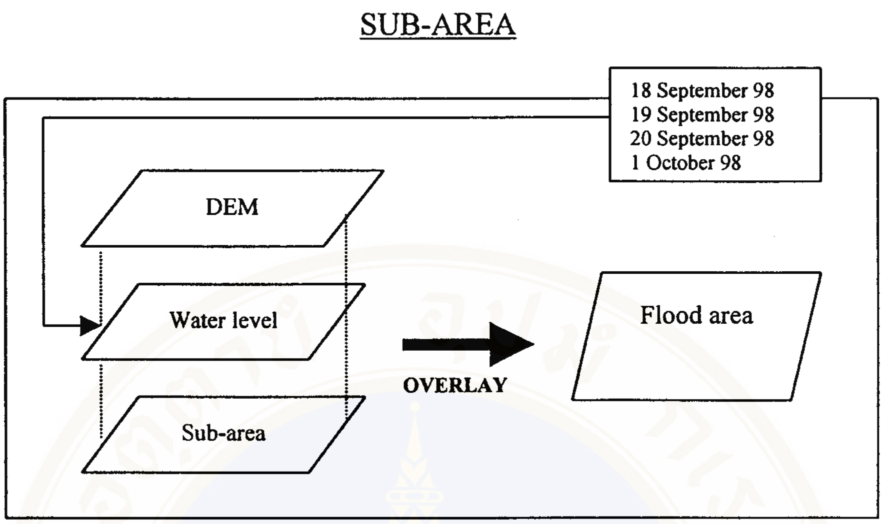


Figure 3.11 showed the construction process of flood map in sub-area

3.4.5 The equation in GIS operation

These studies there are three major steps for spatial analysis i.e flood area analysis, flood depth analysis and flood volume analysis, which there are the equations in GIS operation as followed:

3.4.5.1 Flood area analysis in GIS operation by overlaying technique as equation below:

ARC: GRID = con (elevation > water level, 1, 2)

From the equation means that if any area elevation or pixel are higher than water level then those area are non-flooded area (value = 1), where as if any area elevation are lower than water level then those area are flooded area (value = 2).

3.4.5.2 Flood depth analysis

When flood area simulation is constructed, next study is flood depth calculation in each event. The term of flood depth for this study is the value of floodwater level upper elevation in neighborhood of flooded area. Flood depth analysis within GIS process in module grid as equation bellowed:

ARC: GRID = cell value (grid_file *)

From the equation means that if any area is flooding then these areas is cell value of flood depth. In practical method we can select any of flooded area for displaying of flood depth value. The graphic can show flood area and grid for flood depth calculating as figure bellowed:

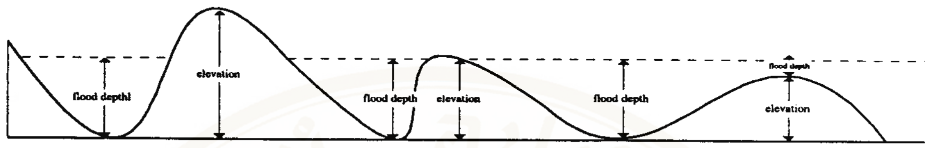


Figure 3.12 showed the characteristic of flood depth calculation

3.4.5.3 Flood volume analysis

Concept of flood volume analysis is the discharge of floodwater upper topography in neighborhood of flooded area, within GIS operation in module grid as equation bellowed:

ARC: GRID = (elevation - water level) * area

The graphic can showed the area and grid for flood volume calculating as figure bellowed:

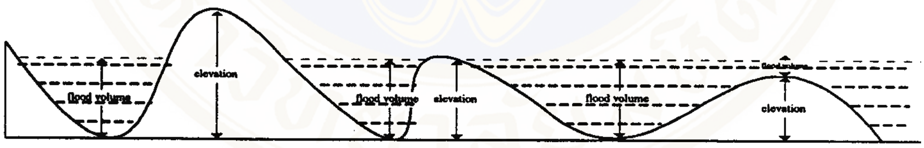


Figure 3.13 showed the characteristic of flood volume calculation

3.5 FLOOD DEPTH CALIBRATION

This study sophisticate at methodology for spatial flooding simulation in ideal conditions to test the methodology of model comparison with real events. The information for model calibration is flooded prone area from Flood Control Center (FCC), BMA 1998. The attribute of flood prone area consists of date, location, duration and depth of flooding on major and minor road and road intersection. Flood location and flood depth used for calibrate, which is same event with data for model construction.
The process in GIS for model calibration as figure bellowed

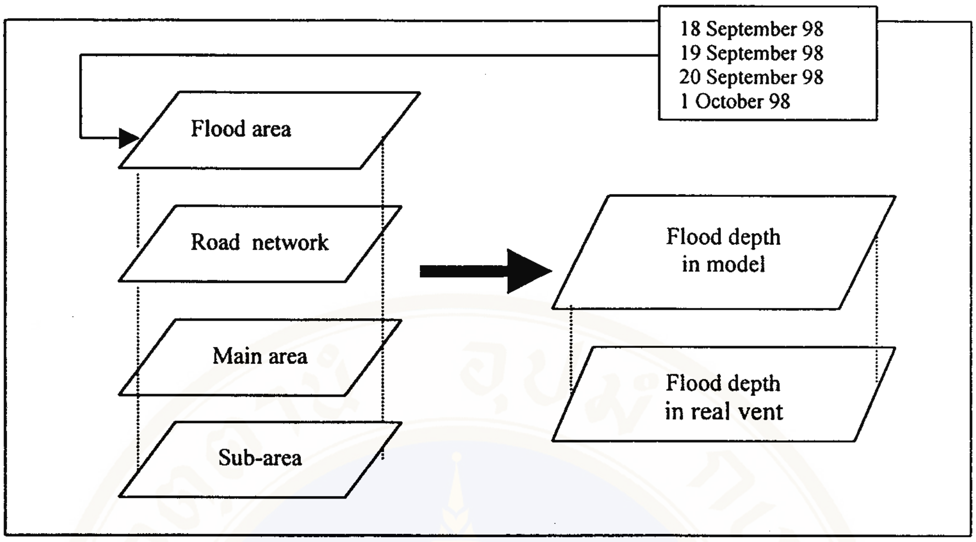


Figure 3.14 showed the process of flood depth calibration

The operation of geographical information system (GIS) as showed in figure 3.15 and all process of this study as showed in figure 3.16

3.6 HYPOTHESIS EVALUATION

The hypothesis in this study, that is: the Geographic Information System (GIS) can simulate spatial flood condition on tangible scenario and neighborhood with real situation. Then this study uses statistic method for hypothesis evaluation between interval of the mean of flood depth in real event and flood depth in model.

This study used to test the couple design call " Paired-Samples T Test" is the method for interval of the mean or means comparison

Hypothesis for testing

H_0 : $\mu_d = 0$

H_1: $\mu_d \neq 0$ or

H_0 : flood depth in real events = flood depth in model

H_1 : flood depth in real events $\neq$ flood depth in model

Significant level

$\alpha = 0.05$ or 95 % confidence

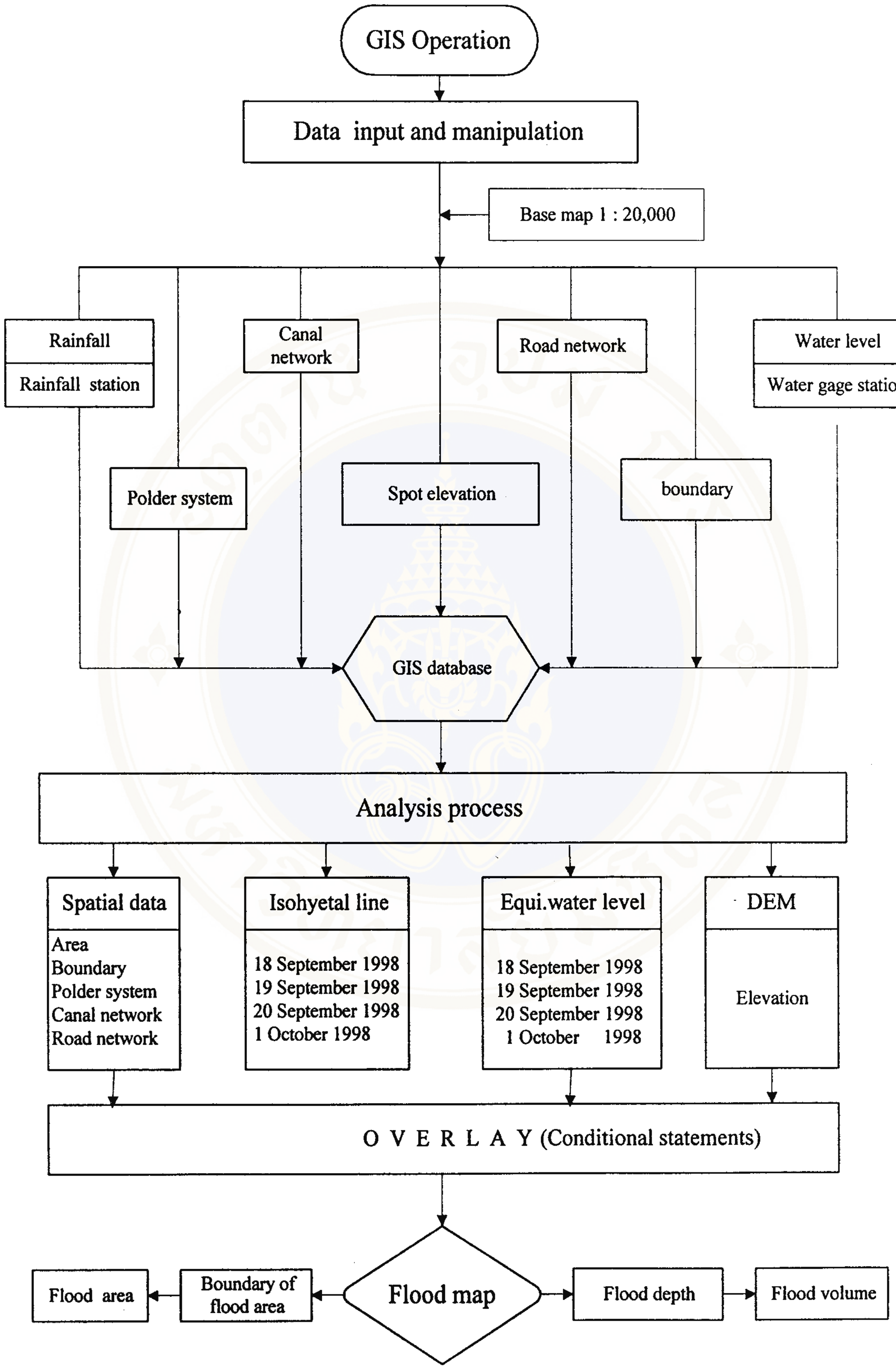


Figure 3.15 showed the process of Geographic Information Systems (GIS)

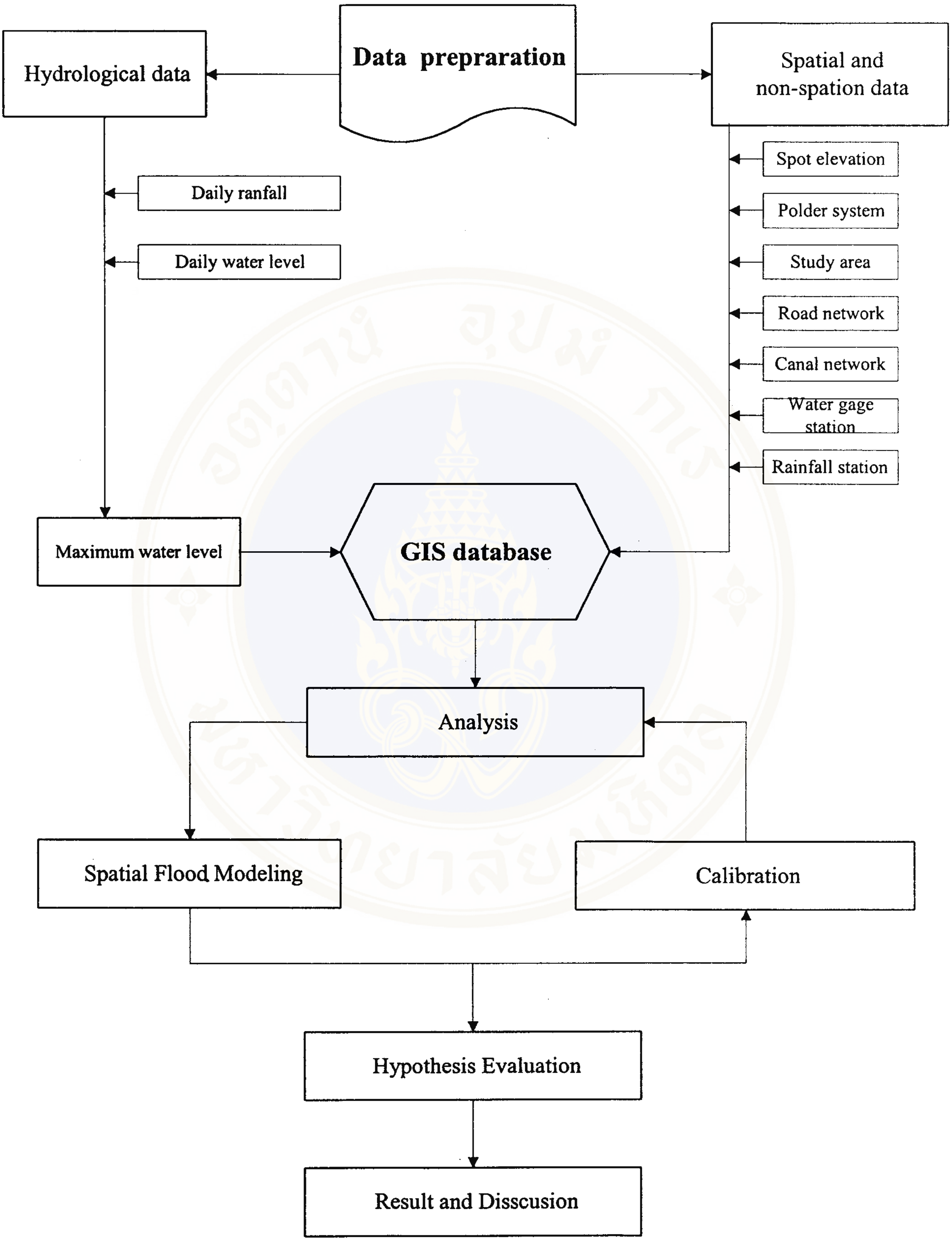


Figure 3.16 showed the process of all this study

CHAPTER IV

RESULT AND DISCUSSION

From the study factors concerning with urban flooding consists of many factors, which are mentioned in before chapters. Because of the limitations of data, budget and timing this study use factor that cause of flood condition there were rainfall, water level and geography in study area. The spatial flooding analysis with Geographical Information System (GIS) depends on conditional definition in GIS operation. The collection and analysis data throughout the result and discussion of study as followed:

4.1 RAINFALL

The data is collected with hourly rainfall in August, September and October 1998 in study area recorded by Flood Control Center (FCC), BMA, which consists of 33 network rainfall station and this area called Flood Control and Protection Area of East-Bangkok Bank. The rainstorm days selected for spatial flooding analysis are of four-day or events i.e. September 1998, 19 September 1998, 20 September 1998 and 1 October 1998. The average rainfall was 34.50 mm./day, 10.60 mm./day, 16.96 mm./day and 63.69 mm./day respectively. The distributions of daily rainfall of all four events are selected as figure 4.1. The maximum rainfall on 18 September 1998 was abouts 103 mm./day at E01 station, on 19 September 1998, about 74.50 mm./day at E17 station on 20 September 1998, about 75.00 at E26 station and 1 October 1998, about 188 mm./day at E21 station. Those rainfall data is accorded with Action Plan of Bangkok Flood Control in 1997 in order to specify the rainfall that caused of flood in normal weather about 35-90 mm./day, except in abnormal weather may be over 90 mm./day such as when there is the cyclone condition. Those rainfall is direct effect to water level in study area.

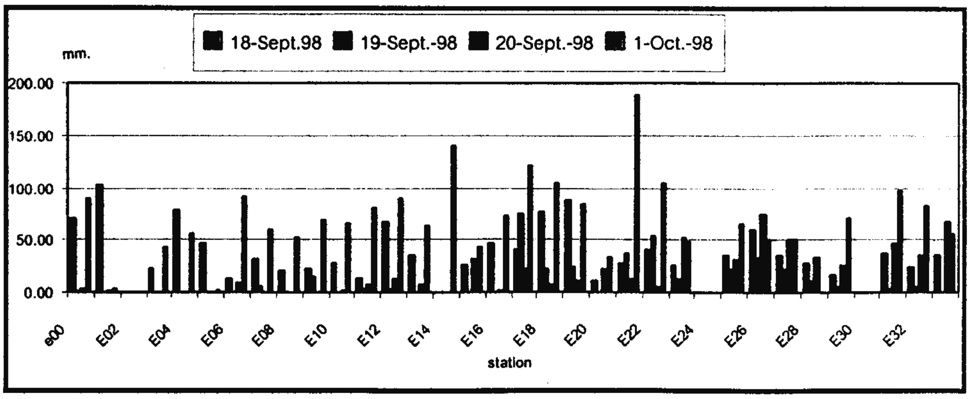


Figure 4.1 showed the distribution of daily rainfall in study area

4.2 WATER LEVEL

The data is collected with hourly water level in August, September and October 1998 in study area recorded by Flood Control Center (FCC), BMA which consists of 33 network water gage station. The characteristic of data consists of maximum, minimum and average water level. This study takes the maximum water level for spatial flooding analysis because it can show the problem of flood condition more explicitly. The maximum water level all four-event areas selected as figure 4.2. The maximum water level on 18 September 1998 at E14 station is 3.53 m.msl., 19 September 1998 at E14 station is 3.53 m.msl. 20 September 1998 at E14 station is m.msl. and 1 October 1998 at E06 station is 1.11 m.msl. The different of maximum water level depend on intensive of rainfall, period of rainy season, water pumping and regulation gate controlling in study area.

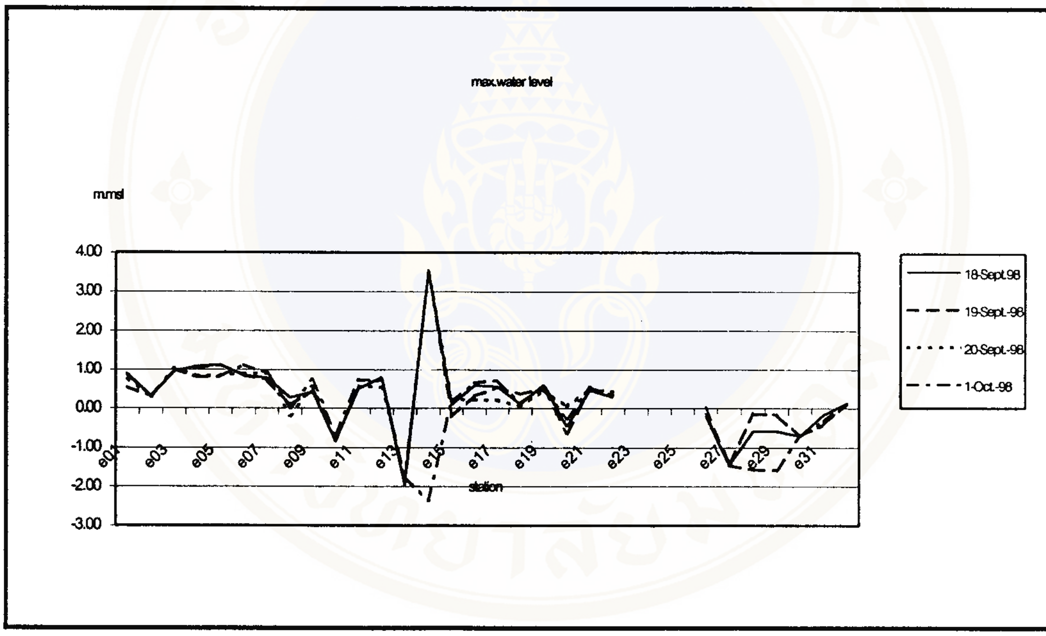
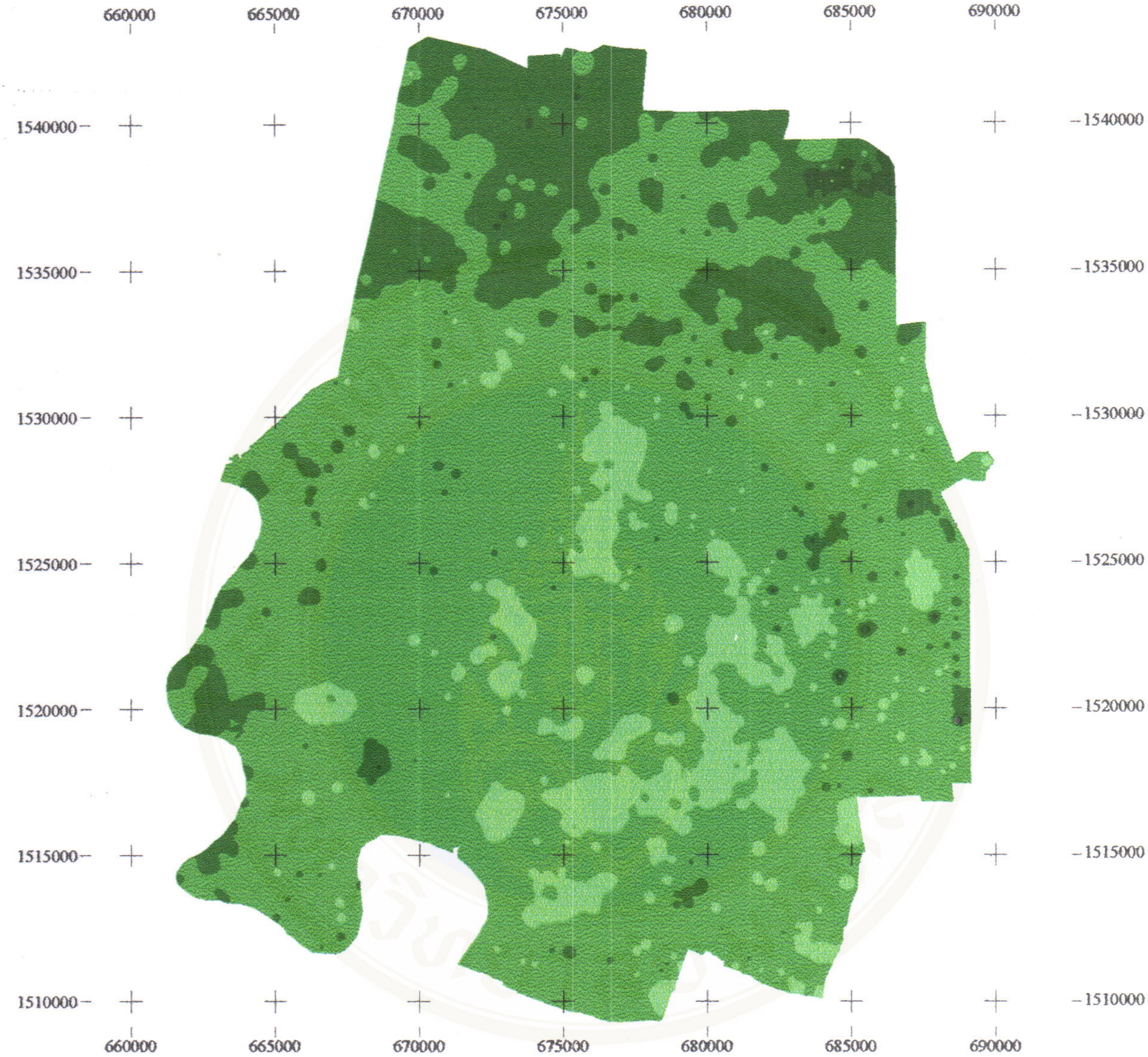


Figure 4.2 showed the maximum water level in study area

4.3 DIGITAL ELEVATION MODEL (DEM)

4.3.1 The elevation 1986

DEM means to change displaying of spatial elevation in form of digital point (mark, 1978) with Geographic Information Systems (GIS). These study uses DEM for integrate with water level for spatial flooding simulation. DEM is deriving from spot ground elevation, which surveyed in 1986 by Japanese International Cooperation Agency (JICA). The result of DEM was created with GIS process as figure 4.3 appears that most of area elevation between 0.6 to 1.7 m.msl. was about 60 % of total area which was distributed throughout study area especially part of center. The critical area means the elevation is lower than mean sea level (msl.) that is –5.1 to 0.5 m.msl. but only 10 % of total area which is distributed in



Legend

elevation (m.msl.)
- -5.1 - 0.5
- 0.6 - 1.7
- 1.8 - 2.9
- 3.0 - 5.0

5 0 5 Kilometers

Figure 4.3 showed the elevation in year 1986 center and many in east and south of study area. This area is risk to regular inundating in every year. The elevation is between 1.8 to 2.9 m.msl. and 3.0 to 5.0 m.msl., concentrating together is about 30 % of total area which was also distributed throughout study area.

4.3.2 The elevation 1995

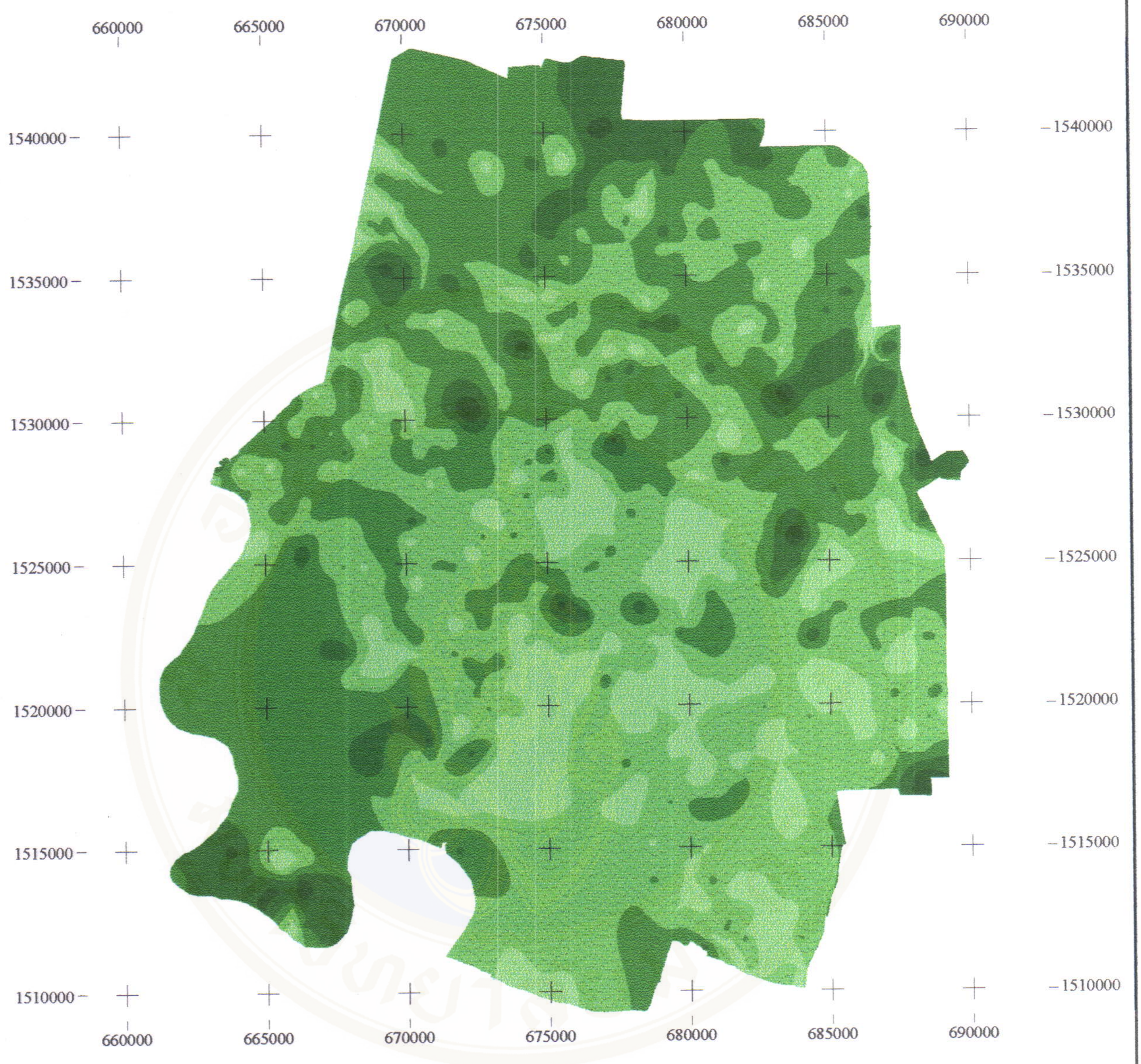
The elevations from DEM in 1995 as figure 4.4. The elevation from this figure was constructed from spot elevation, which was surveyed by Water Development Consultant ltc. (WDC), 1995. The result of DEM creation is that the interval values begun at 0.05 m.msl. and ended at 3.3 m. msl. The elevation from 0.05 to 0.8 m.msl. was almost distributed in center area. The elevation from 0.8 to 1.3 m.msl. was almost distributed in throughout of study area. The elevation from 1.3 to 1.7 m.msl. was almost distributed in north and west of study area. The elevation from 1.7 to 3.3 m.msl. was distributed in some point in study area.

The comparison of elevation in 1986 and 1995 appears that, when we considered by point per point, it was found that the elevation in some point was increased and some point was reduced. This was caused by the area development such as digging, filling and adjustment of land surface. As it did not cover all of study area, but if we considered overall area it would be found that the elevation in 1995 was a little higher than in 1986. If this assumption is real, it is contrast with the land subsidence in Bangkok since year 1986 to 1995, especially in east of Bangkok. In fact the elevation in 1995 should be lower than in 1986, because it was caused from the land subsidence.

All this error of result comparison is occurred from the source of spot elevation, which was different source. The elevation in 1986 was surveyed by Japanese International Cooperation Agency (JICA), whereas Water Development Consultant Ltc. (WDC) surveyed the elevation in 1995 in responsibility of Bangkok metropolitan Administration (BMA). From the study of spot elevation it was found that the elevation in year 1986 by JICA it was more precise than that by WDC, 1995. In addition, the base (position) of spot elevation was different. And also, the spot elevation in 1995 that uses in this study was not adjusted with the land subsidence. It causing that was the elevation in 1995 was not accorded with the real condition.

4.4 RAINFALL ISOHYETAL LINE

The data is collected with daily rainfall in August, September and October 1998 and selected with the rainstorm day causes flooding in study area. The criteria from Action Plan for solving and flood control of Bangkok specifying cause of flooding in abnormal rainfall is about 60-90 mm./day. That is reason for rainfall event selection amounts in four day i.e. 18 September 1998, 19 September 1998, 20 September 1998 and 1 October 1998. The result of rainfall isohyetal line construction within GIS operation is as figure 4.5 followed;



Source: Create from spot elevation, BMA 1995

Legend

Elevation 1995 (m.msl.)
- 0.05 - 0.8
- 0.8 - 1.3
- 1.3 - 1.7
- 1.7 - 2.3
- 2.3 - 3.3

5 0 5 Kilometers

Figure 4.4 showed the elevation 1995 in study area

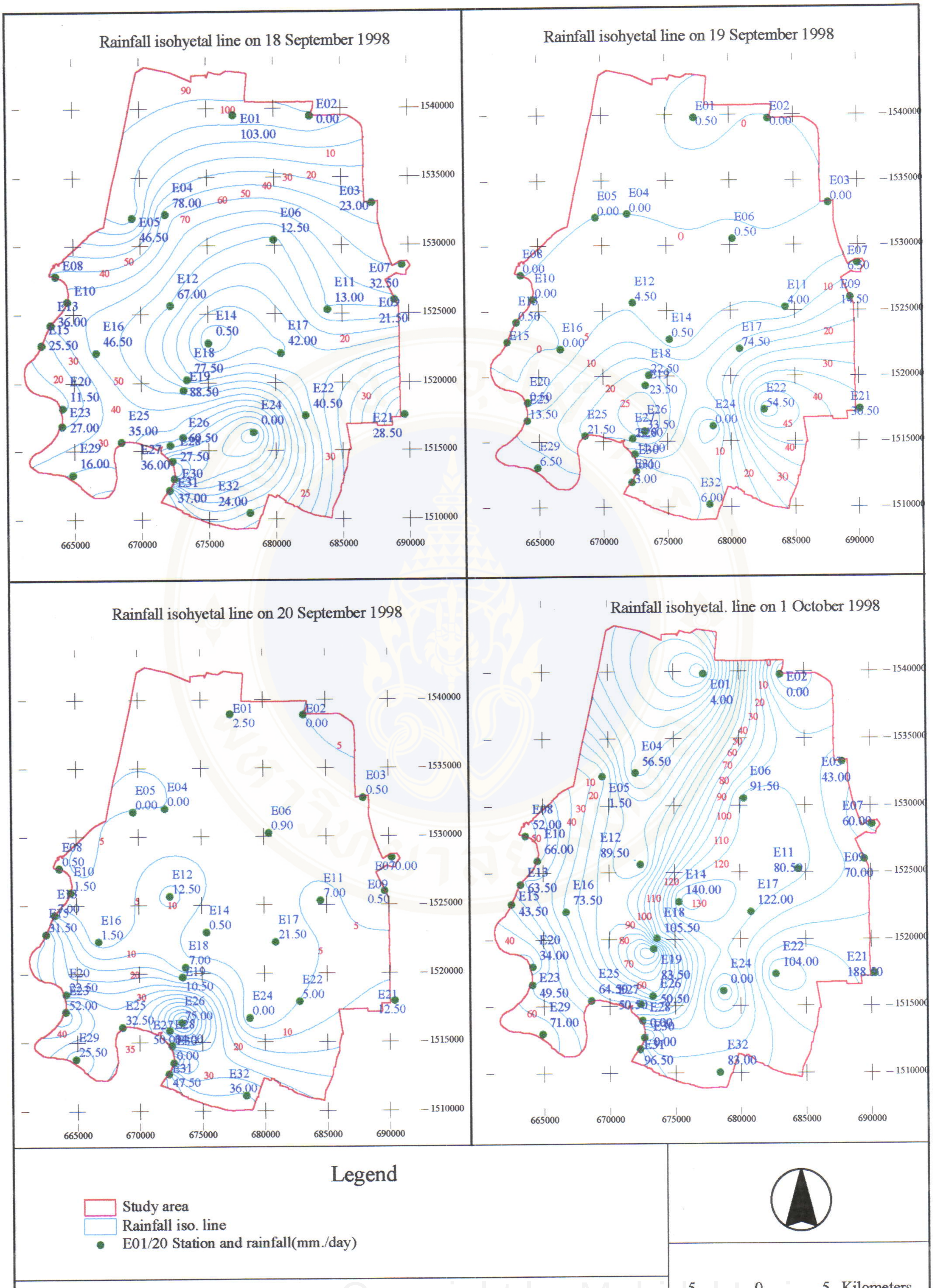


Figure 4.4 showed the rainfall isohyetal line in study area

On 18 September 1998, it is showed that rainfall distribution and direction forward to E01, E04, E12, E18, E19 and E26 station was equal to 103.00, 78.00, 67.00, 77.00, 88.50 and 60.50 mm./day respectively, notice those values over 60.mm./day. Trend of rainstorm direction is same line that is from north to south, whereas the rainfall in east and west had value and average almost similar to rainfall in this event which is around 34.56 mm./day.

On 19 September 1998, it is showed that rainfall distribution and direction forward to only E17, E22 and E21station was equal to 74.50, 54.50 and 36.50 mm./day respectively. Trend of rainstorm direction was narrow distribution in southeast and average rainfall in this event is around 10.60 mm./day.

On 20 September 1998, it is showed that rainfall distribution and direction forward to E15, E23, E26, E27, E28, E31 and E32 station was equal to 31.5, 52.00, 75.00, 50.00, 34.00, 47.50 and 36.00 mm./day respectively. Trend of rainstorm direction is in south and southwest and average rainfall this event is around 16.96 mm./day.

On 1 October 1998, it is showed that in this event had almost similar to those covered in study area especially at E17, E18, E22 and E21 station, the rainfall value over 100 mm./day is 140.00, 122.00, 105.00, 104.00 and 188.50 respectively. Trend of rainstorm direction is from center to southeast in study area. These rainfall values could be happening in cyclone condition and the average rainfall in this event, which is called as "abnormal weather period" is around 63.69 mm./day.

From the result of rainfall isoyetal line construction is all of four events shows that the rainfall distribution and direction was differed in each event due to the rainfall intensive and locate of rainfall station. That trend of rainfall isoyetal line is direct effect to water level and flood condition in study area.

4.5 EQUIVALENT WATER LEVEL LINE

The result of water level line from GIS operation in part of main area of all four events as figure 4.6 appear that the equivalent water level line on 18 September 1998, 19 September 1998 and 20 September 1998 were in nearly same form. The direction and distribution of water level line forward to E14 station, which the maximum water level of all three events was equal to 3.53 m.msl. This area was combined with is ground elevation, which little upper or lower means see level (msl), then it effects high of water level in those areas.

The water level line on 1 October 1998 was differed from first three events, because the maximum water level at E14 stations was equal to –2.37 m.msl. This value may be controlled by flood protection system such as polder system, pumping and regulation gate in study area.

When the equivalent water level line was constructed after that take it to integrate with elevation (DEM) in GIS process for spatial flooding simulation, the characteristic of equivalent water level line (m.msl.) is direct effect to flooding simulation on flood area, flood depth and flood volume.

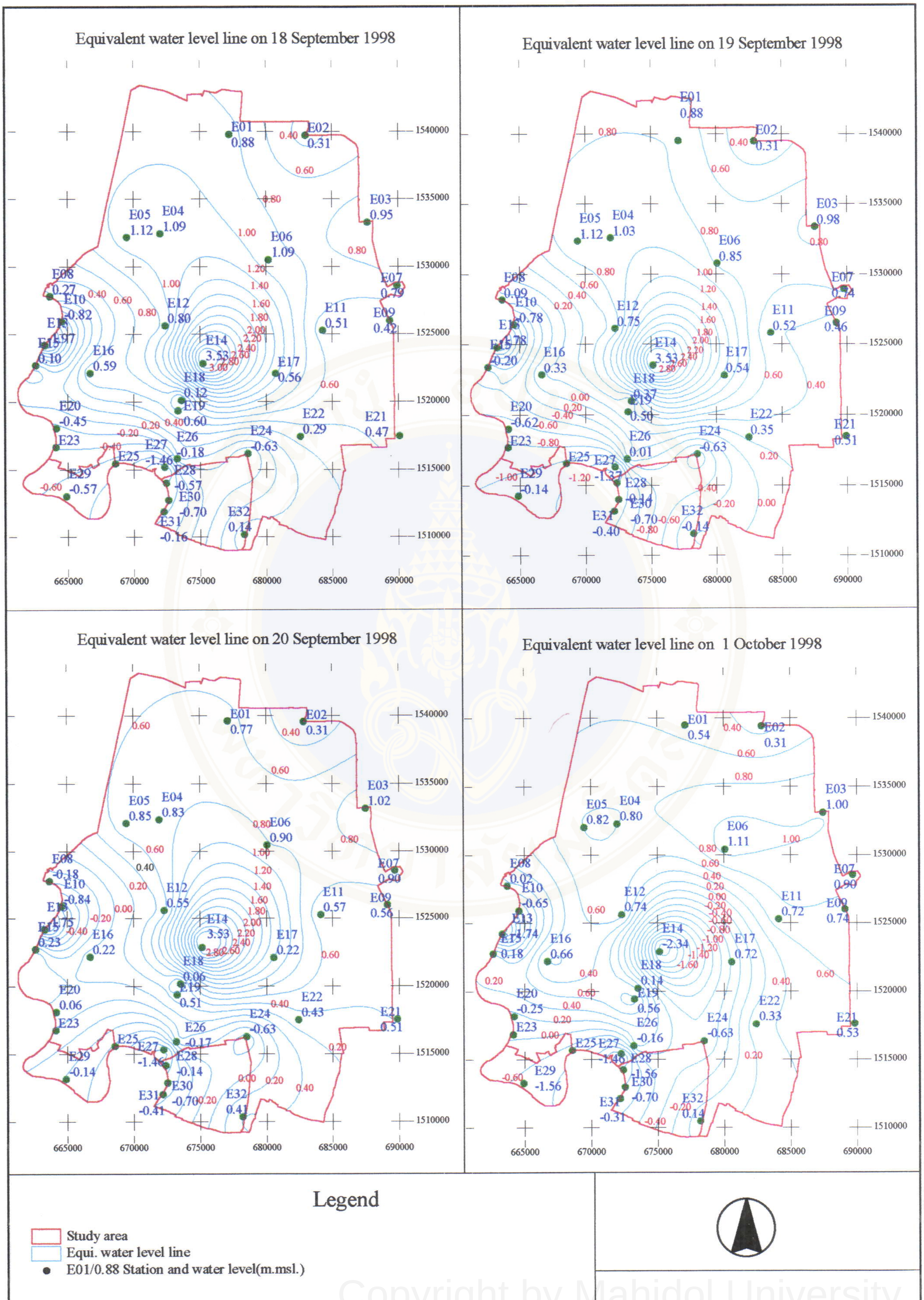


Figure 4.5 showed the equivalent water level line in study area

The maximum water level in sub-area01 and sub-area02. There were the canal networks that it was not linking in main area. In practical, selecting only a water gage station. There was a criterion for selects the station that is it was the outlet of canal system in each sub-area. From the study fined that the outlet station it was stationE29 in sub-area01 and stationE31 in sub-area02.

The maximum water level in sub-area01 at stationE29 in 18 September 1998, 19 September 1998, 20 September 1998 and 1 October 1998, there were –0.57 m.msl., –0.14 m.msl., –0.14 m.msl. and –1.56 m.msl. respectively. In sub-area 02 at station E31 there were –0.16 m.msl., –0.40 m.msl., -0.41m.msl. and -0.31m.msl respectively. After that use the maximum water level to construct the grid of maximum water level and analysis with DEM for flood area simulation in next step.

4.6 GRID ANALYSIS IN GIS OPERATION

Flooding simulation in main area consists of elevation (m.msl) and equivalent water level line (m.msl.). In sub-area 01 and sub-area 02 consists of DEM and water level layer. Flooding simulation in GIS operation by conditional definition with OVERLAY technique and grid calculation in study area as figure bellowed:

Main area

Elevation (m.msl.)

1.2	0.8	0.6	0.6
1.6	0.8	0.6	0.9
1.5	1.5	1.3	0.9
1.3	1.3	1.5	0.5

Equi. water level (m.msl.)

1.1	1.0	1.0	1.5
1.3	1.1	1.1	1.5
1.3	1.8	1.0	1.8
1.0	1.0	1.0	1.0

Flood area

1	2	2	2
1	2	2	2
1	1	1	2
1	1	1	2

Figure 4.7 showed the process of grid analysis in main area

Sub-area

Elevation (m.msl.)

1.2	0.8	0.6	0.6
1.6	0.8	0.6	0.9
1.5	1.5	1.3	0.9
1.3	1.3	1.5	0.5

Max.water level (m.msl.)

1.1	1.1	1.1	1.1
1.1	1.1	1.1	1.1
1.1	1.1	1.1	1.1
1.1	1.1	1.1	1.1

Flood area

1	2	2	2
1	2	2	2
1	1	1	2
1	1	1	2

Figure 4.8 showed the process of grid analysis in sub-area

4.7 FLOODING SIMULATION WITHIN ELEVATION 1986

The linkage between DEM and maximum water level for flood map simulation in main area and sub-areas consists of four events on 18 September 1998, 19 September 1998, 20 September 1998 and 1 October 1998. The result of flood area simulation is as figure 4.9

4.7.1 Flooded area

4.7.1.1 Main area

Flooded area in main area from the figure was difference of all four events. First three events of flooded area had nearly same value as on 18 September 1998 equal 134,310,800.00 square meters, 19 September 1998 equal 131,906,000.00 square meters, 20 September 1998 equal 114,380,800.00 square meters. Flooded area on 1 October 1998 equal 57,241,200.00 square meters.

4.7.1.2 Sub-area 01

There were no flooded areas in sub-area 01 of all four events, because they were not any areas lower than water level. The water level in sub-area 01 may be controlled by other factors that beside the point of this study.

4.7.1.3 Sub-area 02

There were parts of flooded area in sub-area 02 of all four events. Flooded area on 18 September 1998 was equal to 95,600.00 square meters, 19 September 1998 was equal to 53,200.00 square meters, 20 September 1998 was equal to 52,000.00 square meters and flooded area on 1 October 1998 was equal to 68,800.00 square meters.

The conclusion of flooded area in main area, sub-area 01 and sub-area 02 all four events is as table 4.1

Table 4.1 showed the numeric of flooded area within elevation 1986

No.	Date	Area(m^2)			
		Main area	Sub-area 01	Sub-area 02	Total
1.	18 September 1998	134,310,800.00	-	95,600.00	134,406,400.00
2.	19 September 1998	131,906,000.00	-	53,200.00	131,959,200.00
3.	20 September 1998	114,380,800.00	-	52,000.00	114,432,800.00
4.	1 October 1998	57,241,200.00	-	68,800.00	57,310,000.00

Note: The total of study area is about 664,000,000.00 square meter

From above table the numeric of flooded area appeared that first three events were nearly of flooded area. Because of rainfall and water level at represent station in study area, there were nearly same value and also the neighborhood of flood area were little upper or lower than mean sea level (msl). Then this area was risk to flooding almost every year. Flooded area on 1 October 1998 was differing from first three events because the water level at E14 station was –2.37 m.msl that lower than ground elevation. This water level may be controlled by flood control structure such as water pumping, regulation gate etc.

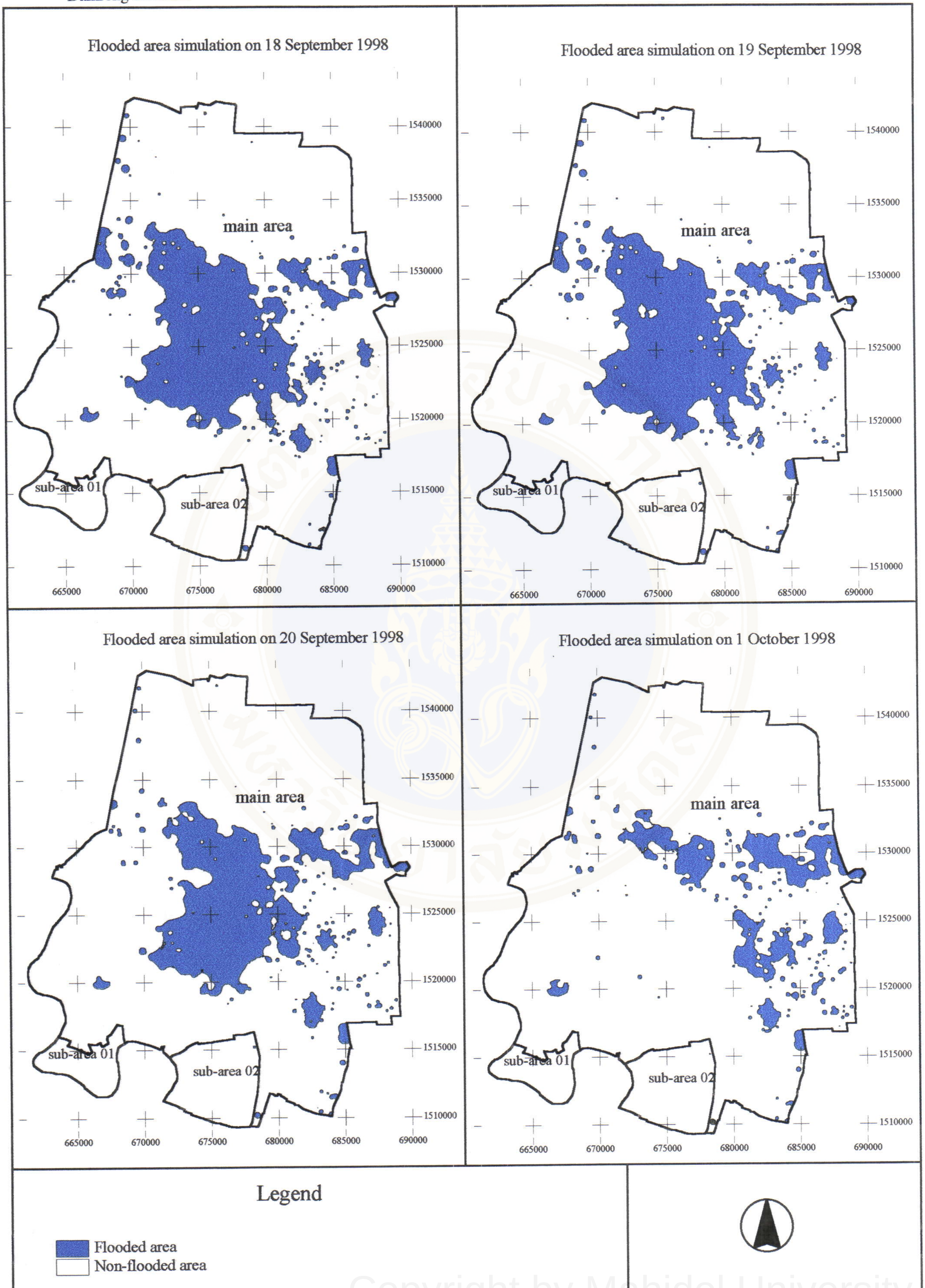


Figure 4.9 showed the flooded area simulation within elevation 1986

5 0 5 Kilometers

4.7.2 Flood volume

Concept of flood volume analysis that is the discharge of floodwater upper elevation in neighborhood of flooded area and the result of flood volume analysis within GIS process as table 4.2

Table 4.2 showed the numeric of flooded volume within elevation in year 1986

No.	Date	Flood volume(m^3)			Total
		Main area	Sub-area 01	Sub-area 02	
1.	18 September 1998	530,261.00	-	51,974.00	582,235.00
2.	19 September 1998	525,074.00	-	86,198.00	611,272.00
3.	20 September 1998	531,165.00	-	87,824.00	618,989.00
4.	1 October 1998	357,038.00	-	72,284.00	429,322.00

Note: The total of study area about 664,000,000.00 square meter

4.7.2.1 Main area

There were differences of flood volume in main area all four events. First three events of flood volume were nearly value same i.e. on 18 September 1998 was equal to 530,261.00 cubic meter, 19 September 1998 was equal to 525,074.00 cubic meter, 20 September 1998 was equal to 531,165.00 cubic meter. Flood volume on 1 October 1998 was equal to 357,038 cubic square meter.

4.7.2.2 Sub-area 01

There were no flood volume in sub-area 01 of all four events, because they were not of flooding in study area.

4.7.2.3 Sub-area 02

There were parts of flooded area in sub-area 02 of all four events. For instance flood volume on 18 September 1998 was equal to 51,974.00 cubic meters, 19 September 1998 was equal to 86,198.00 cubic meters, 20 September 1998 was equal to 87,824.00 cubic meters and flooded area on 1 October 1998 was equal to 72,284.00 cubic meters.

The quantity of flood volume depends on flooded area and flood level above elevation in each events and all this flood volume that were mentioned not conclude with the volume of water pumping in study area. Because it was only specified that how pumping influenced or effect to water level in study area.

4.7.3 Flood depth

Flood depth analysis the most important in this study, because it is used for flood depth calibration in next steps. The term of flood depth is the value of water level upper elevation at neighborhood of flooded area. In practical method in GIS operation, we can select any of flooded area for displaying of flood depth value. The calculation of flood depth within GIS process and the result of flood position and flood depth of all four events would be showed in process of model calibration in next step.

4.7.4 Flood depth calibration within elevation 1986

The information for model calibration is flooded prone area from Flood Control Center (FCC), BMA 1998. The attribute data of flood prone area consists of date, position and location, duration and depth of flooding on major and minor road and road intersection. Flood position and flood depth used for calibration, which it is same events with data (rainfall and water level) for model construction and the result of model calibration as table 4.3

Table 4.3 showed the flood depth calibration within elevation 1986

Date	Position	Flood depth(cm.)	
		Real event	model
18-Sept. 1998	Ram Kham Haeng Road -Soi 87 to Klong Saen Saep bridge -Lamsalee intersection -Ram Kham Haeng Univ. To Soi 24	 25 5-10 10-15	 57 36 52
19-Sept. 1998	Ram Kham Haeng Road -Soi 21 to Ram Kham Haeng Univ. -Lamsalee intersection	 25 25	 31 39
20-Sept. 1998	Ram Kham Haeng Road -Soi 21 to Ram Kham Haeng Univ. -Lamsalee intersection Srinakharin Road -Lamsalee intersection	 25 25 25	 27 16 16
1 Oct.1998	Ram Kham Haeng Road -Soi 8 to Ram Kham Haeng Univ. -Lamsalee intersection	 30-50 25	 - -

The flood depth comparison amount fifty-five position in real event, find that there were only eight position in model that they had data for calibration together.

From above tables appears that the position of flood depth calibrations is on the road that is Ram Kham Haeng road and Lamsalee intersection.

From flood depth calibration on 18 September 1998 in Ram Kham Haeng Road, at Soi 87 to Klong Saen Saep bridge, it appears that flood depth in model was different from real event about 32 cm. At Lamsalee intersection flood depth in model was different in real events about 26 cm. At Ram Kham Haeng University to Soi 24 flood depth in model was differently in real events about 42 cm.

Flood depth calibration on 19 September 1998 had two event in Ram Kham Haeng road which flood depth in real events were equal to all of two events i.e. 25 cm.(sidewalk level). At Soi 21 to Ram Kham Haeng University flood depth in model was different from real event about only 6 cm. whereas at Lamsalee intersection in model was different from real event about 14 cm.

Flood depth calibration on 20 September 1998 had events in Ram Kham Haeng road which flood depth in real events were equal to all of three events i.e. 25 cm.(sidewalk level). At Soi 21 to Ram Kham Haeng University, flood depth in model was very nearly from real event about only 2 cm. Whereas at Lamsalee intersection in Ram Kham Haeng road and Srinakharin road had equal value in model i.e. 16 cm., which in real event was different from model about 9 cm.

Flood depth calibration on 1 October 1998 there was no flooding in model, then there was not data for calibration.

From the result of flood depth calibration appears that there are not any positions to be exactly or matched together, but there is few position such as on 19 September 1998 that has flood depth of very near level. The results, shows that there are other variable or environmental conditions beside those in this study that effect model construction and cause that data in model is incorrect or different from real events.

4.8 ASSUMPTION OF ELEVATION SINCE YEAR 1986-1995

From below figure and define the assumption that the ground elevation was the main issue to influent for occurrence of flood events, then the change of ground elevation in study area since year 1986 to 1995 also effect flood events both in real situation and model construction That's mean the elevation in 1995 must be higher than in 1986

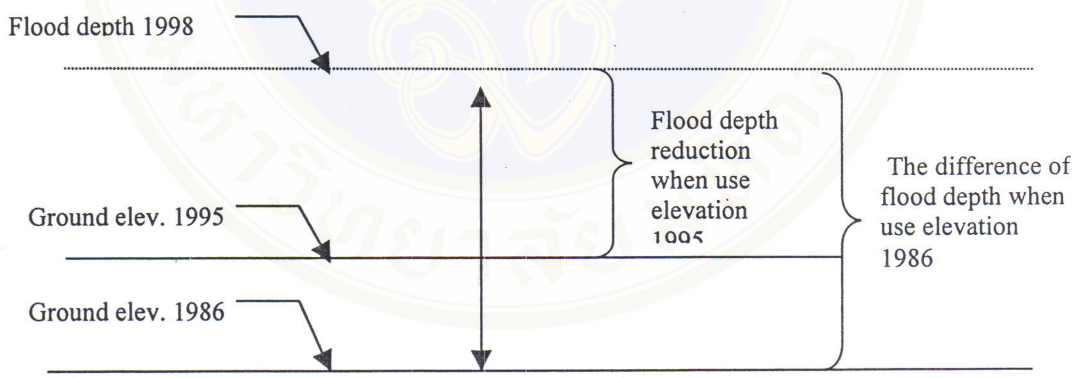


Figure 4.10 showed the assumption of elevation 1986-1995

4.9 FLOODING SIMULATION WITHIN ELEVATION 1995

The linkage between DEM in 1995 as figure 4.10 and maximum water level for flood map simulation in main area and sub-areas consists of four events i.e. 18 September 1998, 19 September 1998, 20 September 1998 and 1 October 1998. The result of flood area simulation is as figure 4.11

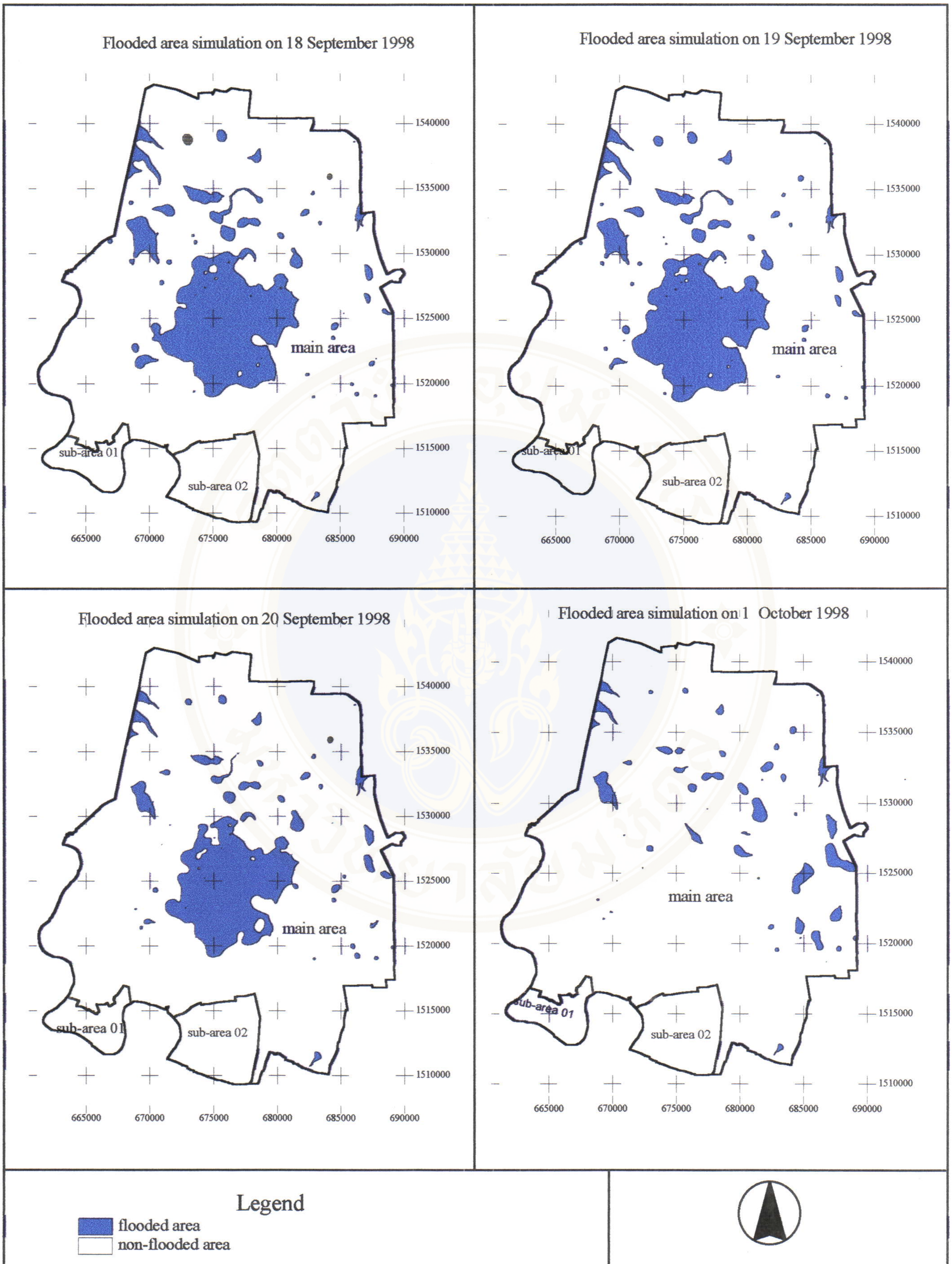


Figure 4.11 showed flooded area simulation within elevation 1995

4.9.1 Flood area

4.9.1.1 Main area

Flood area in main area from the figure had difference in all of four events. First three events of flooded area had nearly same value i.e. 18 September 1998 was equal to 95,264,000.00 square meters, 19 September 1998 was equal to 91,843,200.00 square meters, 20 September 1998 was equal to 75,585,600.00 square meters. Flooded area on 1 October 1998 was equal to 20,284,000.00 square meters.

4.9.1.2 Sub-area 01 and sub-area 02

There were no flooded areas in sub-area 01 and sub-area 02 of all four events, because there were no any area lower than water level.

The conclusion of flooded area in main area, sub-area 01 and sub-area 02 all four events is as table 4.4

Table 4.4 showed the numeric of flooded area within elevation 1995

No.	Date	Area(m^2)			
		Main area	Sub-area 01	Sub-area 02	Total
1.	18 September 1998	95,264,000.00	-	-	95,264,000.00
2.	19 September 1998	91,843,200.00	-	-	91,843,200.00
3.	20 September 1998	75,585,600.00	-	-	75,585,600.00
4.	1 October 1998	20,284,000.00	-	-	20,284,000.00

Note: The total of study area is about 664,000,000.00 square meter

From the numeric of flooded area in above table, it appears that first three events were nearly of flooded area, because of rainfall and water level at represented station in study area had nearly same value and also the neighborhood of flood area were little upper or lower than mean sea level (msl). Then this area was risk to flooding almost every year. Flooded area on 1 October 1998 was different from first three events because the water levels at E14 station was –2.37 m.msl which was lower than ground elevation. This water level may be controlled by flood control structure such as water pumping, regulation gate etc.

4.9.2 Flood volume

Concept of flood volume analysis that is the discharge of floodwater upper elevation in neighborhood of flooded area and the result of flood volume analysis within GIS process is as table 4.5

Table 4.5 showed the numeric of flooded volume within elevation 1995

No.	Date	Flood volume(m^3)			Total
		Main area	Sub-area 01	Sub-area 02	
1.	18 September 1998	422,871.00	-	-	422,871.00
2.	19 September 1998	427,421.00	-	-	427,421.00
3.	20 September 1998	422,807.00	-	-	422,807.00
4.	1 October 1998	44,886.00	-	-	44,886.00

Note: The total of study area is about 664,000,000.00 square meter

4.9.2.1 Main Area

There were differences of flood volume in main area in all of four events. First three events of flood volume had nearly same value i.e. 18 September 1998 was equal to 422,871.00 cubic meter, 19 September 1998 was equal to 427,421.00 cubic meter, 20 September 1998 was equal to 422,807.00 cubic meter. Flood volume on 1 October 1998 was equal to 44,886.00 cubic square meters.

4.9.2.2 Sub-area 01

There was no flood volume in sub-area 01 of all four events, because there were no flooding in study area.

4.9.2.3 Sub-area 02

There was no flood volume in sub-area 01 of all four events, because there were no flooding in study area.

The quantity of flood volume depends on flooded area and flood level above elevation in each event and all this flood volume that was mention was not concluded with the volume of water pumping in study area. Because it was only specified that how pumping had influence or effect to water level in study area.

4.9.3 Flood depth calibration within elevation 1995

The inspections of flood depth position within elevation in 1995 appear that they are same position with flood depth within elevation in 1986, because flood model simulation is in nearly same direction and distribution. The result of study is as table 4.6

Table 4.6 showed the flood depth calibration within elevation 1995

Date	Location	Flood depth(cm.)	
		Real event	model
18-Sept. 1998	Ram Kham Haeng Road -Soi 87 to Klong Saen Saep bridge -Lamsalee intersection -Ram Kham Haeng Univ.To Soi 24	 25 3 - 10 10 - 15	 67 27 115
19-Sept. 1998	Ram Kham Haeng Road -Soi 21 to Ram Kham Haeng Univ. -Lamsalee intersection	 25 25	 104 29
20-Sept. 1998	Ram Kham Haeng Road -Soi 21 to Ram Kham Haeng Univ. -Lamsalee intersection Srinakharin Road -Lamsalee intersection	 25 25 25	 87 14 14
1 Oct.1998	Ram Kham Haeng Road -Soi 8 to Ram Kham Haeng Univ. -Lamsalee intersection	 30-50 25	 - -

From the results of study in above table, almost position does not accord with assumption of elevation changing from 1986 to 1995 which mentions that flood depth in model within elevation in 1995 must be more nearly same as in real events.

From flood depth calibration on 18 September 1998 in Ram Kham Haeng road from Soi 87 to Klong Saen Saep Bridge and Lamsalee intersection, appears that flood depth in model was more than flood depth in real events especially from Ram Kham Haeng University to Soi 24 of which flood depth in model was different from real events about 100 cm.

Flood depth calibration on 19 September 1998 had two events in Ram Kham Haeng road of which flood depth in model was equal to all 2 events i.e. 25 cm. (sidewalk level). From Soi 21 to Ram Kham Haeng University, flood depth in model was about 80 cm. different from real event whereas at Lamsalee intersection in model was different from real event only 4 cm.

Flood depth calibration on 20 September 1998 had three events in Ram Kham Haeng Road which in model was equal to all of three events i.e. 25 cm.(sidewalk level). From Soi 21 to Ram Kham Haeng University, flood depth in model was different from real event about 60 cm. Whereas at Lamsalee intersection in Ram Kham Haeng road and Srinakharin road had same value in model i.e. 14 cm. which was different from real event only about 11 cm.

Flood depth calibration on 1 October 1998 had no flooding in model, then there are not data for calibration.

The flood depth calibration within elevation in 1995 find that there was only a position accorded with the assumption i.e. at Lamsalee intersection. Whereas the others value was contrast with it. The study showed that not only the elevation change from 1986 to 1995 which influent of flood model construction. There are others variable such as spatial variables and flood-controlled structure etc.

4.10 FLOOD MODEL COMPARISON

4.10.1 Flooded area and flood volume comparison

The result of flooded area and flood volume comparisons as tables 4.7 showed that floods area and flood depth comparison within elevation in 1986 and 1995.

The implicit difference of flooded area within the elevation in 1986 was more than all four events in 1995, which especially in main area. But in sub-area 01, there was no flooded area meantime, there was flooded area only within the elevation in 1986 in sub-area02. The result of study indicate the increasing elevation in 1986 to 1995 cuased by the urban development, finally effect to flooded area in each events.

Moreover the flood volume was implicit difference; flood volume within the elevation in 1986 was more than all four events in 1995, especially in main area. But in sub-area 01, there was no flood volume meantime there was flood volume in sub-area 02 within the elevation in 1986. It showed that the result of flood volume was occurred from single control factor. Which is change of the elevation in 1986 to 1995.

Table 4.7 showed flooded area and flood volume comparison in study area

Date	Flooded Area (m^2)					
	Within elevation in 1986			Within elevation in 1995		
	Main area	Sub-area 01	Sub-area 02	Main area	Sub-area 01	Sub-area 02
18 Sept. 98	134,310,800.00	-	95,600.00	95,264,000.00	-	-
19 Sept.98	131,906,000.00	-	53,200.00	91,843,200.00	-	-
20 Sept.98	114,380,800.00	-	52,000.00	75,585,600.00	-	-
1 Oct.98	57,241,200.00	-	68,800.00	20,284,000.00	-	-
Date	**Flood Volume (m^3)**					
	Within elevation in 1986			Within elevation in 1995		
	Main area	Sub-area 01	Sub-area 02	Main area	Sub-area 01	Sub-area 02
18 Sept. 98	530,261.00	-	51,974.00	422,871.00	-	-
19 Sept.98	525,074.00	-	86,198.00	427,421.00	-	-
20 Sept.98	531,165.00	-	87,824.00	422,807.00	-	-
1 Oct.98	357,038.00	-	72,284.00	44,886.00	-	-

4.11 FLOOD DEPTH CALIBRATION

From the assumption, if the ground elevation was really influent to flood events occurrence, then the change of ground elevation in the study area in 1986 to 1995 also effected to flood events in both real situation and model construction
It can be explained that when we use the elevation in 1995, the flood depth in model was more nearly with the flood depth in the real situation. The result of flood depth comparison is shown in tables 4.8

Table 4.8 showed flood depth calibration in study area

Date	Location	Flood depth(cm.)		
		Real event	Model	
			Elevayion1986	Elevation 1995
18-Sept. 1998	Ram Kham Haeng Road			
	-Soi 87 to Klong Saen Saep bridge	25	57	67
	-Lamsalee intersection	5-10	36	27
	-Ram Kham Haeng Uni. To Soi 24	10-15	52	115
19-Sept. 1998	Ram Kham Haeng Road			
	-Soi 21 to Ram Kham Haeng Univ.	25	31	104
	-Lamsalee intersection	25	39	29
20-Sept. 1998	Ram Kham Haeng Road			
	-Soi 21 to Ram Kham Haeng Univ.	25	27	87
	-Lamsalee intersection	25	16	14
	Srinakharin Road			
	-Lamsalee intersection	25	16	14
1 Oct.1998	Ram Kham Haeng Road			
	-Soi 8 to Ram Kham Haeng Univ.	30-50	-	-
	-Lamsalee intersection	25	-	-

From table 4.8 showed the comparison of between the flood depth in real events and in model within the elevation in 1986 and 1995 was only one position according to the assumption. At Lamsalee intersection in Ram Kham Haeng road and Srinakharin road, especially on 18 September 1998, 19 September 1998 and 20 September 1998. Besides those, it was contrast with the assumption.

From the result of flood depth calibration appeared that almost of flood depth value in model do not according to the flood depth in real event. And it was contrast with the assumption about the elevation changing in 1986 to 1995. The result showed that there were not only elevation and water level that effect to flooding in model. But also were the other variable in real condition that exept for this study which to be mentioned in next step and the positions of flood depth comparison is shown in figure 4.12

4.12 HYPOTHESIS EVALUATION

The hypothesis in this study, i.e. the Geographic Information Systems (GIS) can simulate the spatial flood condition on tangible scenario and neighborhood with real situation. This study uses statistic method for hypothesis evaluation between interval of the mean of flood depth in real event and flood depth in model that it is in same position.

This study is used to test the couple design called as " Paired-Samples T Test" is the method for interval of the mean or means comparison

Hypothesis for testing

H_0 : $\mu_d = 0$

H_1: $\mu_d \neq 0$ or

H_0 : flood depth in model = flood depth in real events

H_1 : flood depth in model ≠ flood depth in real events

Significant level

$\alpha = 0.05$ or 95 % confidence

The result of flood model simulation was integration between equivalent water level line (msl.) and elevation (msl.) in study area. with GIS operation. The elevation used in this study are two periods i.e. in 1986 and 1995, then the model comparison with real events for this study has two time. The summary of study is as table 4.9

Table 4.9 showed the summery of hypothesis evaluation

Hypothesis	Condition			Result	
	Significance level	position	Method	elevation 1986	elevation 1995
H_0 : flood depth in model = real situation H_1 : flood depth in model ≠ real situation	$\alpha = 0.05$ or 95 % confidence	55	Paired Samples T Test	Deny : H_0 Accept : H_1	Deny : H_0 Accept : H_1

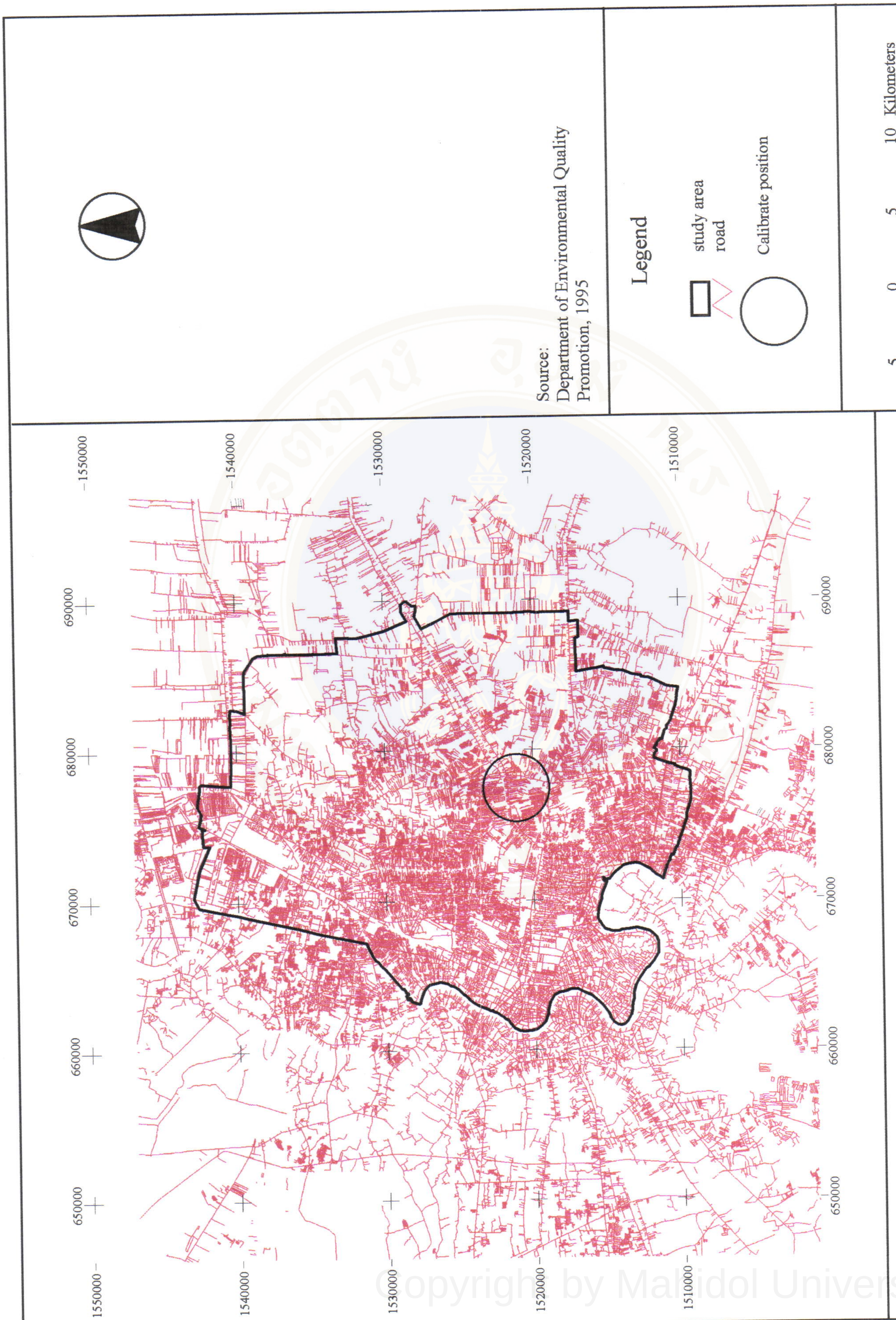


Figure 4.12 showed the position of flood depth calibration

4.12.1 Flood depth calibration within elevation 1986

Flood depth comparison in model and real events within elevation in 1986 consists of fifty-five positions and find that there was only eigth position that has exact position. The result of " paired-samples t test " appeared that it denied H_0 and accepted H_1 that meant flood depth in model was different from flood depth in real events at 0.05 significance level or 95 % confidence.

4.12.2 Flood depth calibration within elevation 1995

The flood depth comparison in model and real events within elevation in 1995 also consists of fifty-five positions and find that there was only eigth position that has exact position. The result of " paired-samples t test " appeared that denied H_0 and accepted H_1 that meant flood depth in model was different from flood depth in real events at 0.05 significance level or 95 % confidence.

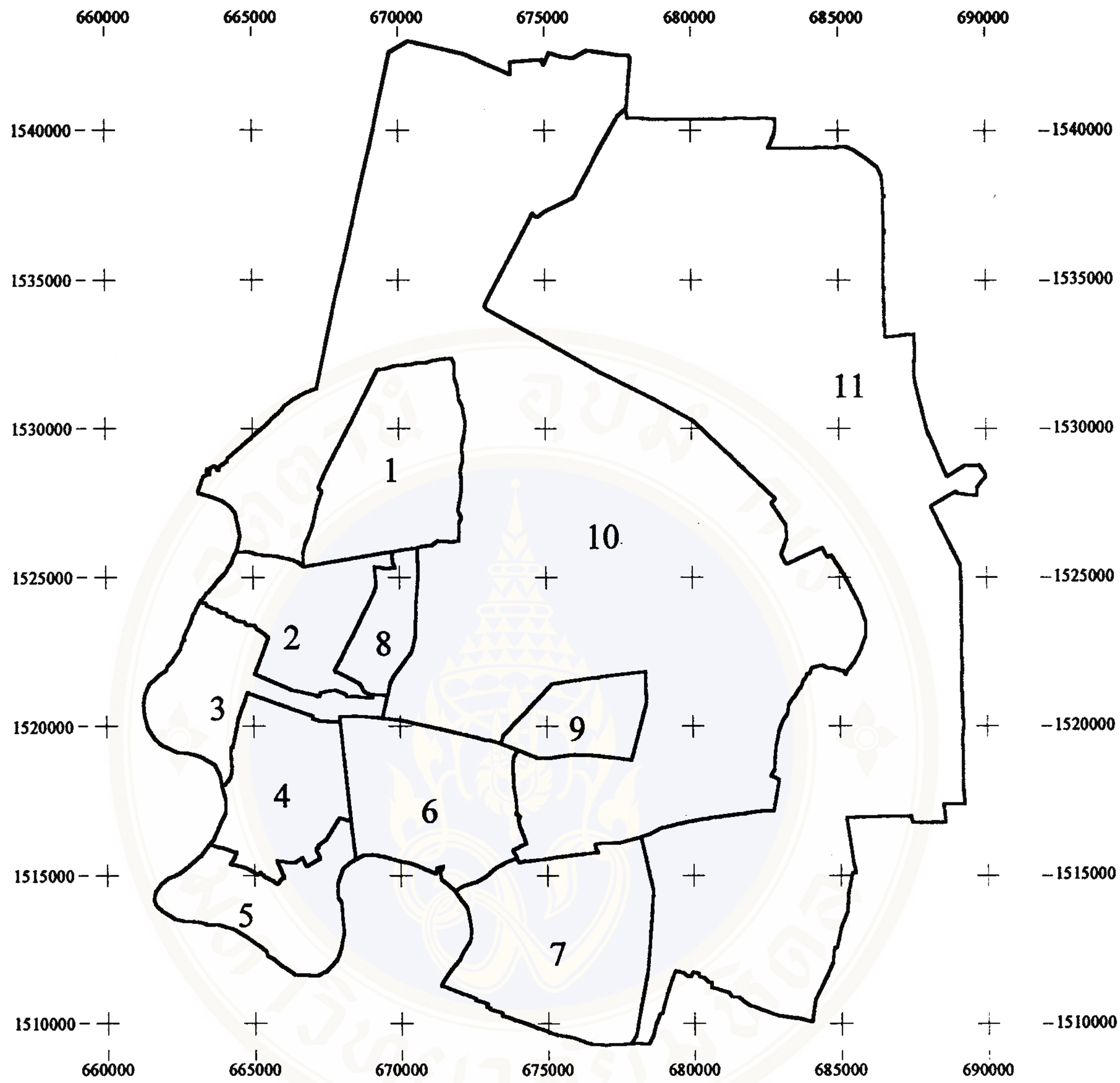
From the hypothesis evaluation with statistic method of all two cases there was different between flood depth in model and in real events. All this, there are many variables for occurrence of flood phenomenon, especially in urban area which difference in rural area. This study uses only elevation and water level for flooding simulation or in addition it is ideal condition. That means there are not any flood control structures to obstruct the waterway in klongs and canals whereas in real condition in study area there are flood control structures to obstruct the waterway in Klongs and canals such as embankment, sandbag, building and etc. In this study there is no data of embankment level and sandbag level that's above banks level of klongs and canals and compose of data and timing limitations, which it is sensitive to the result and model calibration.

The spot elevation in 1986 and 1995 it was micro scale about a spot elevation per a square kilometer which was not delicate enough when use it for flood model construction and model calibration in macro scale (point or position). Then flood depth in model was very different from real events.

Then from the result of hypothesis evaluation which summarize that the Geographic Information Systems (GIS) can simulate spatial flood condition on tangible scenario but is not absolutely correct or match with real situation, due to the major variables as followed:

1. The spot elevation (msl.) was not delicate enough because it was micro scale (one spot elevation per a square kilometer). This micro scale is appropriate in rural area, whereas it was not appropriate in urban area.
2. The real condition in study area consist of embankment and sandbag above banks level of klongs and canals whereas in model condition there were not those flood control structures.
3. Flood depth in real event (flood conditional report from FCC) is not distinguished that occurs from rainfall or floodwater from canal, whereas flood depth in model condition is only occured from floodwater.

The conditional assignment in model simulation is differed from real condition. Then this study sophisticate at methodology for spatial flooding simulation in ideal condition because the data limitations especially spot elevation is not delicate enough. In additions the other variables are not use for model simulation in this study such as polder system as figure 4.13, pumping and timing etc, It is reason that the model output was not exact with real event. However, this study is an attempt for displaying on tangible scenario of flood condition and trend of flood problem. This research is a pilot study, which is necessary to intensive study in the future.



Source: Department of Drainage and Sewerage, BMA 1996

Legend

Polder systems
1 Bangken Polder
2 Samsen Polder
3 Krungkasem Polder
4 Phraram IV Polder
5 Yannawa Polder
6 Sukhumwit Polder
7 Bangna Polder
8 Hoikwang Polder
9 Huamaak Polder
10 Middle Polder
11 King Polder

Figure 4.13 showed the exiting polder system in study area

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The main objective of this study is to simulate the spatial flooding condition with Geographic Information Systems (GIS) and to calibrate with real events. The spatial flood model is simulated by the integration between elevation and water level in study area. The study area is Flood Control and Protected Area of East Bangkok Bank, which is around 664 square kilometers

This study is design by four events of the daily rainfall and water level on 18 September 1998, 19 September 1998, 20 September 1998 and 1 October 1998. The study area is provided as main area and sub-area 01 and sub area 02. The criterion of area is provided on the linking of canal network system in study area, the integration between elevation (m.msl.) and equivalent water level line (m.msl.) in GIS operation for analysis of flood area, flood depth and flood volume. Flood depth analysis in model simulation is used for flood depth calibration with real events. The elevation in1986 and 1995 is used for flood model simulation in this study.

The elevation in 1986 and 1995 were different depending upon the different source teams and the delicate of spot elevation. The spot elevation in 1986 was surveyed by JICA, which it was more precise than in 1995, by WDC. The spot elevation in 1995 was not adjusted with land subsidence in study area. Those limitations effected the result of this study.

The result of flooded area is implicit differently within the elevation in 1986 was more than all four events in 1995, which especially in main area. But in sub-area 01, there was no flood area, whereas there was flooded area only within the elevation in 1986 in sub-area02. The study result indicate the increasing of elevation in 1986 to 1995 caused from the urban development, finally it effected flooded area in each events. The result of flood volume is also implicit differently. Flood volume within the elevation in 1986 was more than all four events in 1995, especially in main area. But in sub-area 01, there was no flood volume whereas there was flood volume in sub-area 02 within the elevation in 1986. It showed that the result of flood volume was occurred from single control factor. Which is change of the elevation in 1986 to 1995.

From the assumption, the ground elevation was really influent to flood events occurrence. Then the change of ground elevation in the study area in 1986 to 1995 also effected flood events both in real situation and model construction. It can be explained that when we use the elevation in 1995, the flood depth in model was very close to the flood depth in the real situation. The result of model comparison between the flood depth in real events and in model within the elevation in 1986 and 1995 had only one position to accord to the assumption. Besides those, other positions were contrast with the assumption. The result showed that there were not only elevation and water level that effected flooding in model, but there were the other variables in real condition outside of this study too.

The hypothesis in this study, i.e. the Geographic Information Systems (GIS) can simulate the spatial flood condition on tangible scenario and neighborhood with real situation. This study uses statistic method " Paired-Samples T Test" for hypothesis evaluation between interval of the mean of flood depth in real event and flood depth in model that is in the same position.

The result of hypothesis evaluation of flood depth comparison in model and real events within elevation in 1986 and 1995 consists of fifty-five positions and found there was only eight positions that had exact position. The hypothesis evaluation appeared that it denied H_0 and accepted H_1 that meant flood depth in model was different from flood depth in real events at 0.05 significance level or 95 % confidence.

Then from the result of hypothesis evaluation which summarize that the Geographic Information Systems (GIS) can simulate spatial flood condition on tangible scenario but is not absolutely correct or match with real situation, due to the major variables as followed; First, the spot elevation (msl.) is not delicate enough. Second, in real condition in study area consist of embankment and sandbag above banks level of klongs and canals whereas in model condition there are not those flood control structures. Finally, Flood depth in real event, which is not distinguished, is occured from rainfall or floodwater from canal, whereas the flood depth in model condition is only occurred from floodwater.

In fact this study is an attempt to display a tangible scenario of flood condition and trend of flood problem. This research is a pilot study, which requires a more intensive study in the future.

5.2 RECOMMENDATION

The main objective for this studies i.e. the simulation of spatial flooding condition on tangible scenario in GIS process. This study is not including the management plan for flood control and protection. However, the application of the result in this study for Flood Control and Protected Area of BMA can solve only in general trend of flood problem. It means that this application can be used for management and planning in macro area (all area). However, it can not be used in micro area (point or position), because from the flood depth calibration, it was much more error from real events.

Then, these studies look alike the pilot study for spatial flooding simulation due to the data limitations, especially ground elevation. The recommendations for further study should concern with variables and data for more completion as followed:

5.2.1 The spot elevation

The spot elevation in 1986 and 1995 are the major problem because it can effect to the study result. The result of data analysis, flood model construction and flood model calibration showed that it was much more error from real events. All of this was occur from the delicacy and correction of spot elevation database. The spot elevation in 1986 was more delicate than in 1995. Next study should be investigating the spot elevation in present data together with more delicate information. In addition, the spot elevation should be calibrated with land subsidence, because the land subsidence occurs continuously in study area. Then, the type of elevation should be check and distinguish i.e. ground or road elevation. If the study is reformed in interval of time, the spot elevation must be all the same series and came from the same source of data. And the amounts of spot elevation have to be equal in order to reduce the difference of the study output.

5.2.2 The variables

Because of data limitations, in this study was able to use the variables only rainfall, water level and elevation for the spatial flooding simulation. Then it was effect to the result, which was error with real events. Next study should use the other variables that concern with flood occurring.

First, the study area is a big city area or the metropolitan of Thailand (Bangkok). Due to a complexity of the city and rapidity development, there are many structures to construct for city life, those structure is influent to an occurring of flood condition in all direct and indirect effects. The study area should select as sub-area follows by the existing polder systems and in addition we can study to more intensive level.

Second, the study should use the variable about a time relation between rainfall and water level. It is very important for flood condition in real event and model simulation. Thus they must be considered together.

Third, the volume of water pumping in each polder is effect to water level in canal. It can effected to flood area, flood volume and flood depth that should be considered in next study.

Fourth, the canal in study area have embankment and sandbag above bank level so that the next study should take these variables for relation analysis with water level and bank level together.

Fifth, flooding in the Complex City is also concern with behavior of drainage and hydrodynamic systems. The mathematics model is an alternative method that suit and to enhance the flooding behavior simulating which can be simulated very close to the real events, then integrate the results Geographic Information systems.

5.2.3 The comparison data

The comparison data in this study is Flood Conditional Report from FCC, BMA. It uses for the flood depth calibration in same position of flood model with real events and the output in numeric a data. It can not be utilized in spatial condition, next study should be compared by using the satellite image approach in visualizing flood area distribution and flood area direction.

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APPENDIX : A

RAINFALL

Rainfall at E14 station
on 18 September 1998

TM	MN_RF	HR_RF	TH_RF	SX_RF	AC_RF
00:00	0.00	0.00	0.00	0.00	0.00
00:15	0.00	0.00	0.00	0.00	0.00
00:30	0.00	0.00	0.00	0.00	0.00
00:45	0.00	0.00	0.00	0.00	0.00
01:00	0.00	0.00	0.00	0.00	0.00
01:15	0.00	0.00	0.00	0.00	0.00
01:30	0.00	0.00	0.00	0.00	0.00
01:45	0.00	0.00	0.00	0.00	0.00
02:00	0.00	0.00	0.00	0.00	0.00
02:15	0.00	0.00	0.00	0.00	0.00
02:30	0.00	0.00	0.00	0.00	0.00
02:45	0.00	0.00	0.00	0.00	0.00
03:00	0.00	0.00	0.00	0.00	0.00
03:15	0.00	0.00	0.00	0.00	0.00
03:30	0.00	0.00	0.00	0.00	0.00
03:45	0.00	0.00	0.00	0.00	0.00
04:00	0.00	0.00	0.00	0.00	0.00
04:15	0.00	0.00	0.00	0.00	0.00
04:30	0.00	0.00	0.00	0.00	0.00
04:45	0.00	0.00	0.00	0.00	0.00
05:00	0.00	0.00	0.00	0.00	0.00
05:15	0.00	0.00	0.00	0.00	0.00
05:30	0.00	0.00	0.00	0.00	0.00
05:45	0.00	0.00	0.00	0.00	0.00
06:00	0.00	0.00	0.00	0.00	0.00
06:15	0.00	0.00	0.00	0.00	0.00
06:30	0.00	0.00	0.00	0.00	0.00
06:45	0.00	0.00	0.00	0.00	0.00
07:00	0.00	0.00	0.00	0.00	0.00
07:15	0.00	0.00	0.00	0.00	0.00
07:30	0.00	0.00	0.00	0.00	0.00
07:45	0.00	0.00	0.00	0.00	0.00
08:00	0.00	0.00	0.00	0.00	0.00
08:15	0.00	0.00	0.00	0.00	0.00
08:30	0.00	0.00	0.00	0.00	0.00
08:45	0.00	0.00	0.00	0.00	0.00
09:00	0.00	0.00	0.00	0.00	0.00
09:15	0.00	0.00	0.00	0.00	0.00
09:30	0.00	0.00	0.00	0.00	0.00
09:45	0.00	0.00	0.00	0.00	0.00
10:00	0.00	0.00	0.00	0.00	0.00
10:15	0.00	0.00	0.00	0.00	0.00
10:30	0.00	0.00	0.00	0.00	0.00
10:45	0.00	0.00	0.00	0.00	0.00
11:00	0.00	0.00	0.00	0.00	0.00
11:15	0.00	0.00	0.00	0.00	0.00
11:30	0.00	0.00	0.00	0.00	0.00
11:45	0.00	0.00	0.00	0.00	0.00
12:00	0.00	0.00	0.00	0.00	0.00
12:15	0.00	0.00	0.00	0.00	0.00
12:30	0.00	0.00	0.00	0.00	0.00
12:45	0.00	0.00	0.00	0.00	0.00
13:00	0.00	0.00	0.00	0.00	0.00
13:15	0.00	0.00	0.00	0.00	0.00
13:30	0.00	0.00	0.00	0.00	0.00
13:45	0.50	0.50	0.50	0.50	0.50
14:00	0.00	0.50	0.50	0.50	0.50
14:15	0.00	0.50	0.50	0.50	0.50
14:30	0.00	0.50	0.50	0.50	0.50
14:45	0.00	0.00	0.50	0.50	0.50
15:00	0.00	0.00	0.50	0.50	0.50
15:15	0.00	0.00	0.50	0.50	0.50
15:30	0.00	0.00	0.50	0.50	0.50
15:45	0.00	0.00	0.50	0.50	0.50
16:00	0.00	0.00	0.50	0.50	0.50
16:15	0.00	0.00	0.50	0.50	0.50
16:30	0.00	0.00	0.50	0.50	0.50
16:45	0.00	0.00	0.00	0.50	0.50
17:00	0.00	0.00	0.00	0.50	0.50
17:15	0.00	0.00	0.00	0.50	0.50
17:30	0.00	0.00	0.00	0.50	0.50
17:45	0.00	0.00	0.00	0.50	0.50
18:00	0.00	0.00	0.00	0.50	0.50
18:15	0.00	0.00	0.00	0.50	0.50
18:30	0.00	0.00	0.00	0.50	0.50
18:45	0.00	0.00	0.00	0.50	0.50
19:00	0.00	0.00	0.00	0.50	0.50
19:15	0.00	0.00	0.00	0.50	0.50
19:30	0.00	0.00	0.00	0.50	0.50
19:45	0.00	0.00	0.00	0.00	0.50
20:00	0.00	0.00	0.00	0.00	0.50
20:15	0.00	0.00	0.00	0.00	0.50
20:30	0.00	0.00	0.00	0.00	0.50
20:45	0.00	0.00	0.00	0.00	0.50
21:00	0.00	0.00	0.00	0.00	0.50
21:15	0.00	0.00	0.00	0.00	0.50
21:30	0.00	0.00	0.00	0.00	0.50
21:45	0.00	0.00	0.00	0.00	0.50
22:00	0.00	0.00	0.00	0.00	0.50
22:15	0.00	0.00	0.00	0.00	0.50
22:30	0.00	0.00	0.00	0.00	0.50
22:45	0.00	0.00	0.00	0.00	0.50
23:00	0.00	0.00	0.00	0.00	0.50
23:15	0.00	0.00	0.00	0.00	0.50
23:30	0.00	0.00	0.00	0.00	0.50
23:45	0.00	0.00	0.00	0.00	0.50
Max.	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
Min.	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Sum.	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**

Rainfall at E14 station
on 19 September 1998

TM	MN_RF	HR_RF	TH_RF	SX_RF	AC_RF
00:00	0.00	0.00	0.00	0.00	0.50
00:15	0.00	0.00	0.00	0.00	0.50
00:30	0.00	0.00	0.00	0.00	0.50
00:45	0.00	0.00	0.00	0.00	0.50
01:00	0.00	0.00	0.00	0.00	0.50
01:15	0.00	0.00	0.00	0.00	0.50
01:30	0.00	0.00	0.00	0.00	0.50
01:45	0.00	0.00	0.00	0.00	0.50
02:00	0.00	0.00	0.00	0.00	0.50
02:15	0.00	0.00	0.00	0.00	0.50
02:30	0.00	0.00	0.00	0.00	0.50
02:45	0.00	0.00	0.00	0.00	0.50
03:00	0.00	0.00	0.00	0.00	0.50
03:15	0.00	0.00	0.00	0.00	0.50
03:30	0.00	0.00	0.00	0.00	0.50
03:45	0.00	0.00	0.00	0.00	0.50
04:00	0.00	0.00	0.00	0.00	0.50
04:15	0.00	0.00	0.00	0.00	0.50
04:30	0.00	0.00	0.00	0.00	0.50
04:45	0.00	0.00	0.00	0.00	0.50
05:00	0.00	0.00	0.00	0.00	0.50
05:15	0.00	0.00	0.00	0.00	0.50
05:30	0.00	0.00	0.00	0.00	0.50
05:45	0.00	0.00	0.00	0.00	0.50
06:00	0.00	0.00	0.00	0.00	0.50
06:15	0.00	0.00	0.00	0.00	0.50
06:30	0.00	0.00	0.00	0.00	0.50
06:45	0.00	0.00	0.00	0.00	0.50
07:00	0.00	0.00	0.00	0.00	0.50
07:15	0.00	0.00	0.00	0.00	0.50
07:30	0.00	0.00	0.00	0.00	0.50
07:45	0.00	0.00	0.00	0.00	0.50
08:00	0.00	0.00	0.00	0.00	0.50
08:15	0.00	0.00	0.00	0.00	0.50
08:30	0.00	0.00	0.00	0.00	0.50
08:45	0.00	0.00	0.00	0.00	0.50
09:00	0.00	0.00	0.00	0.00	0.50
09:15	0.00	0.00	0.00	0.00	0.50
09:30	0.00	0.00	0.00	0.00	0.50
09:45	0.00	0.00	0.00	0.00	0.50
10:00	0.00	0.00	0.00	0.00	0.50
10:15	0.00	0.00	0.00	0.00	0.50
10:30	0.00	0.00	0.00	0.00	0.50
10:45	0.00	0.00	0.00	0.00	0.50
11:00	0.00	0.00	0.00	0.00	0.50
11:15	0.00	0.00	0.00	0.00	0.50
11:30	0.00	0.00	0.00	0.00	0.50
11:45	0.00	0.00	0.00	0.00	0.50
12:00	0.00	0.00	0.00	0.00	0.50
12:15	0.00	0.00	0.00	0.00	0.50
12:30	0.00	0.00	0.00	0.00	0.50
12:45	0.00	0.00	0.00	0.00	0.50
13:00	0.00	0.00	0.00	0.00	0.50
13:15	0.00	0.00	0.00	0.00	0.50
13:30	0.00	0.00	0.00	0.00	0.50
13:45	0.00	0.00	0.00	0.00	0.00
14:00	0.00	0.00	0.00	0.00	0.00
14:15	0.00	0.00	0.00	0.00	0.00
14:30	0.00	0.00	0.00	0.00	0.00
14:45	0.00	0.00	0.00	0.00	0.00
15:00	0.00	0.00	0.00	0.00	0.00
15:15	0.00	0.00	0.00	0.00	0.00
15:30	0.00	0.00	0.00	0.00	0.00
15:45	0.00	0.00	0.00	0.00	0.00
16:00	0.00	0.00	0.00	0.00	0.00
16:15	0.00	0.00	0.00	0.00	0.00
16:30	0.00	0.00	0.00	0.00	0.00
16:45	0.00	0.00	0.00	0.00	0.00
17:00	0.00	0.00	0.00	0.00	0.00
17:15	0.00	0.00	0.00	0.00	0.00
17:30	0.00	0.00	0.00	0.00	0.00
17:45	0.00	0.00	0.00	0.00	0.00
18:00	0.00	0.00	0.00	0.00	0.00
18:15	0.00	0.00	0.00	0.00	0.00
18:30	0.50	0.50	0.50	0.50	0.50
18:45	0.00	0.50	0.50	0.50	0.50
19:00	0.00	0.50	0.50	0.50	0.50
19:15	0.00	0.50	0.50	0.50	0.50
19:30	0.00	0.00	0.50	0.50	0.50
19:45	0.00	0.00	0.50	0.50	0.50
20:00	0.00	0.00	0.50	0.50	0.50
20:15	0.00	0.00	0.50	0.50	0.50
20:30	0.00	0.00	0.50	0.50	0.50
20:45	0.00	0.00	0.50	0.50	0.50
21:00	0.00	0.00	0.50	0.50	0.50
21:15	0.00	0.00	0.50	0.50	0.50
21:30	0.00	0.00	0.00	0.50	0.50
21:45	0.00	0.00	0.00	0.50	0.50
22:00	0.00	0.00	0.00	0.50	0.50
22:15	0.00	0.00	0.00	0.50	0.50
22:30	0.00	0.00	0.00	0.50	0.50
22:45	0.00	0.00	0.00	0.50	0.50
23:00	0.00	0.00	0.00	0.50	0.50
23:15	0.00	0.00	0.00	0.50	0.50
23:30	0.00	0.00	0.00	0.50	0.50
23:45	0.00	0.00	0.00	0.50	0.50
Max.	0.50	0.50	0.50	0.50	0.50
Min.	0.00	0.00	0.00	0.00	0.00
Sum.	0.50	0.50	0.50	0.50	0.50

Rainfall at E14 Station
on 20 September 1998

TM	MN_RF	HR_RF	TH_RF	SX_RF	AC_RF
00:00	0.00	0.00	0.00	0.50	0.50
00:15	0.00	0.00	0.00	0.50	0.50
00:30	0.00	0.00	0.00	0.00	0.50
00:45	0.00	0.00	0.00	0.00	0.50
01:00	0.00	0.00	0.00	0.00	0.50
01:15	0.00	0.00	0.00	0.00	0.50
01:30	0.00	0.00	0.00	0.00	0.50
01:45	0.00	0.00	0.00	0.00	0.50
02:00	0.00	0.00	0.00	0.00	0.50
02:15	0.00	0.00	0.00	0.00	0.50
02:30	0.00	0.00	0.00	0.00	0.50
02:45	0.00	0.00	0.00	0.00	0.50
03:00	0.00	0.00	0.00	0.00	0.50
03:15	0.00	0.00	0.00	0.00	0.50
03:30	0.00	0.00	0.00	0.00	0.50
03:45	0.00	0.00	0.00	0.00	0.50
04:00	0.00	0.00	0.00	0.00	0.50
04:15	0.00	0.00	0.00	0.00	0.50
04:30	0.00	0.00	0.00	0.00	0.50
04:45	0.00	0.00	0.00	0.00	0.50
05:00	0.00	0.00	0.00	0.00	0.50
05:15	0.00	0.00	0.00	0.00	0.50
05:30	0.00	0.00	0.00	0.00	0.50
05:45	0.00	0.00	0.00	0.00	0.50
06:00	0.00	0.00	0.00	0.00	0.50
06:15	0.00	0.00	0.00	0.00	0.50
06:30	0.00	0.00	0.00	0.00	0.50
06:45	0.00	0.00	0.00	0.00	0.50
07:00	0.00	0.00	0.00	0.00	0.50
07:15	0.00	0.00	0.00	0.00	0.50
07:30	0.00	0.00	0.00	0.00	0.50
07:45	0.00	0.00	0.00	0.00	0.50
08:00	0.00	0.00	0.00	0.00	0.50
08:15	0.00	0.00	0.00	0.00	0.50
08:30	0.00	0.00	0.00	0.00	0.50
08:45	0.00	0.00	0.00	0.00	0.50
09:00	0.00	0.00	0.00	0.00	0.50
09:15	0.00	0.00	0.00	0.00	0.50
09:30	0.00	0.00	0.00	0.00	0.50
09:45	0.00	0.00	0.00	0.00	0.50
10:00	0.00	0.00	0.00	0.00	0.50
10:15	0.00	0.00	0.00	0.00	0.50
10:30	0.00	0.00	0.00	0.00	0.50
10:45	0.00	0.00	0.00	0.00	0.50
11:00	0.00	0.00	0.00	0.00	0.50
11:15	0.00	0.00	0.00	0.00	0.50
11:30	0.00	0.00	0.00	0.00	0.50
11:45	0.00	0.00	0.00	0.00	0.50
12:00	0.00	0.00	0.00	0.00	0.50
12:15	0.00	0.00	0.00	0.00	0.50
12:30	0.00	0.00	0.00	0.00	0.50
12:45	0.00	0.00	0.00	0.00	0.50
13:00	0.00	0.00	0.00	0.00	0.50
13:15	0.50	0.50	0.50	0.50	1.00
13:30	0.00	0.50	0.50	0.50	1.00
13:45	0.00	0.50	0.50	0.50	1.00
14:00	0.00	0.50	0.50	0.50	1.00
14:15	0.00	0.00	0.50	0.50	1.00
14:30	0.00	0.00	0.50	0.50	1.00
14:45	0.00	0.00	0.50	0.50	1.00
15:00	0.00	0.00	0.50	0.50	1.00
15:15	0.00	0.00	0.50	0.50	1.00
15:30	0.00	0.00	0.50	0.50	1.00
15:45	0.00	0.00	0.50	0.50	1.00
16:00	0.00	0.00	0.50	0.50	1.00
16:15	0.00	0.00	0.00	0.50	1.00
16:30	0.00	0.00	0.00	0.50	1.00
16:45	0.00	0.00	0.00	0.50	1.00
17:00	0.00	0.00	0.00	0.50	1.00
17:15	0.00	0.00	0.00	0.50	1.00
17:30	0.00	0.00	0.00	0.50	1.00
17:45	0.00	0.00	0.00	0.50	1.00
18:00	0.00	0.00	0.00	0.50	1.00
18:15	0.00	0.00	0.00	0.50	1.00
18:30	0.00	0.00	0.00	0.50	0.50
18:45	0.00	0.00	0.00	0.50	0.50
19:00	0.00	0.00	0.00	0.50	0.50
19:15	0.00	0.00	0.00	0.00	0.50
19:30	0.00	0.00	0.00	0.00	0.50
19:45	0.00	0.00	0.00	0.00	0.50
20:00	0.00	0.00	0.00	0.00	0.50
20:15	0.00	0.00	0.00	0.00	0.50
20:30	0.00	0.00	0.00	0.00	0.50
20:45	0.00	0.00	0.00	0.00	0.50
21:00	0.00	0.00	0.00	0.00	0.50
21:15	0.00	0.00	0.00	0.00	0.50
21:30	0.00	0.00	0.00	0.00	0.50
21:45	0.00	0.00	0.00	0.00	0.50
22:00	0.00	0.00	0.00	0.00	0.50
22:15	0.00	0.00	0.00	0.00	0.50
22:30	0.00	0.00	0.00	0.00	0.50
22:45	0.00	0.00	0.00	0.00	0.50
23:00	0.00	0.00	0.00	0.00	0.50
23:15	0.00	0.00	0.00	0.00	0.50
23:30	0.00	0.00	0.00	0.00	0.50
23:45	0.00	0.00	0.00	0.00	0.50
Max.	**0.50**	**0.50**	**0.50**	**0.50**	**1.00**
Min.	**0.00**	**0.00**	**0.00**	**0.00**	**0.50**
Sum.	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**

Rainfall at E14 station
on 1 October 1998

TM	MN_RF	HR_RF	TH_RF	SX_RF	AC_RF
00:00	0.00	0.00	0.00	0.00	37.00
00:15	0.00	0.00	0.00	0.00	37.00
00:30	0.00	0.00	0.00	0.00	37.00
00:45	0.00	0.00	0.00	0.00	37.00
01:00	0.00	0.00	0.00	0.00	37.00
01:15	0.00	0.00	0.00	0.00	37.00
01:30	0.00	0.00	0.00	0.00	37.00
01:45	0.00	0.00	0.00	0.00	37.00
02:00	0.00	0.00	0.00	0.00	37.00
02:15	0.00	0.00	0.00	0.00	37.00
02:30	0.00	0.00	0.00	0.00	37.00
02:45	0.00	0.00	0.00	0.00	37.00
03:00	0.00	0.00	0.00	0.00	37.00
03:15	0.00	0.00	0.00	0.00	37.00
03:30	0.00	0.00	0.00	0.00	37.00
03:45	0.00	0.00	0.00	0.00	37.00
04:00	0.00	0.00	0.00	0.00	37.00
04:15	0.00	0.00	0.00	0.00	37.00
04:30	0.00	0.00	0.00	0.00	37.00
04:45	0.00	0.00	0.00	0.00	37.00
05:00	0.00	0.00	0.00	0.00	37.00
05:15	0.00	0.00	0.00	0.00	37.00
05:30	0.00	0.00	0.00	0.00	37.00
05:45	0.00	0.00	0.00	0.00	37.00
06:00	0.00	0.00	0.00	0.00	37.00
06:15	0.00	0.00	0.00	0.00	37.00
06:30	0.00	0.00	0.00	0.00	37.00
06:45	0.00	0.00	0.00	0.00	37.00
07:00	0.00	0.00	0.00	0.00	37.00
07:15	0.00	0.00	0.00	0.00	37.00
07:30	0.00	0.00	0.00	0.00	37.00
07:45	0.00	0.00	0.00	0.00	37.00
08:00	0.00	0.00	0.00	0.00	37.00
08:15	0.00	0.00	0.00	0.00	37.00
08:30	0.00	0.00	0.00	0.00	37.00
08:45	0.00	0.00	0.00	0.00	37.00
09:00	0.00	0.00	0.00	0.00	37.00
09:15	0.00	0.00	0.00	0.00	37.00
09:30	0.00	0.00	0.00	0.00	37.00
09:45	0.00	0.00	0.00	0.00	37.00
10:00	0.50	0.50	0.50	0.50	37.50
10:15	0.00	0.50	0.50	0.50	35.50
10:30	0.00	0.50	0.50	0.50	28.50
10:45	0.00	0.50	0.50	0.50	28.50
11:00	0.00	0.00	0.50	0.50	28.50
11:15	0.00	0.00	0.50	0.50	2.00
11:30	0.00	0.00	0.50	0.50	2.00
11:45	0.00	0.00	0.50	0.50	1.00
12:00	0.00	0.00	0.50	0.50	1.00
12:15	0.00	0.00	0.50	0.50	1.00
12:30	0.00	0.00	0.50	0.50	1.00
12:45	0.00	0.00	0.50	0.50	1.00
13:00	0.00	0.00	0.00	0.50	0.50
13:15	0.00	0.00	0.00	0.50	0.50
13:30	0.00	0.00	0.00	0.50	0.50
13:45	0.00	0.00	0.00	0.50	0.50
14:00	0.00	0.00	0.00	0.50	0.50
14:15	0.00	0.00	0.00	0.50	0.50
14:30	0.00	0.00	0.00	0.50	0.50
14:45	0.00	0.00	0.00	0.50	0.50
15:00	0.00	0.00	0.00	0.50	0.50
15:15	0.00	0.00	0.00	0.50	0.50
15:30	0.00	0.00	0.00	0.50	0.50
15:45	0.00	0.00	0.00	0.50	0.50
16:00	0.00	0.00	0.00	0.00	0.50
16:15	0.00	0.00	0.00	0.00	0.50
16:30	0.00	0.00	0.00	0.00	0.50
16:45	0.00	0.00	0.00	0.00	0.50
17:00	0.00	0.00	0.00	0.00	0.50
17:15	0.00	0.00	0.00	0.00	0.50
17:30	0.00	0.00	0.00	0.00	0.50
17:45	0.00	0.00	0.00	0.00	0.50
18:00	0.00	0.00	0.00	0.00	0.50
18:15	0.00	0.00	0.00	0.00	0.50
18:30	0.00	0.00	0.00	0.00	0.50
18:45	0.00	0.00	0.00	0.00	0.50
19:00	0.00	0.00	0.00	0.00	0.50
19:15	50.50	50.50	50.50	50.50	51.00
19:30	0.00	50.50	50.50	50.50	51.00
19:45	0.00	50.50	50.50	50.50	51.00
20:00	0.00	50.50	50.50	50.50	51.00
20:15	52.00	52.00	102.50	102.50	103.00
20:30	0.00	52.00	102.50	102.50	103.00
20:45	0.00	52.00	102.50	102.50	103.00
21:00	0.00	52.00	102.50	102.50	103.00
21:15	10.00	10.00	112.50	112.50	113.00
21:30	0.00	10.00	112.50	112.50	113.00
21:45	0.00	10.00	112.50	112.50	113.00
22:00	23.00	33.00	135.50	135.50	136.00
22:15	0.50	23.50	85.50	136.00	136.50
22:30	0.00	23.50	85.50	136.00	136.50
22:45	0.00	23.50	85.50	136.00	136.50
23:00	0.00	0.50	85.50	136.00	136.50
23:15	3.50	3.50	37.00	139.50	140.00
23:30	0.00	3.50	37.00	139.50	140.00
23:45	0.00	3.50	37.00	139.50	140.00
Max.	**52.00**	**52.00**	**135.50**	**139.50**	**140.00**
Min.	**0.00**	**0.00**	**0.00**	**0.00**	**0.50**
Sum.	**140.00**	**140.00**	**140.00**	**140.00**	**140.00**

APPENDIX : B

WATER LEVEL

Water level at E14 station
on 18 September 1998

TM	WI_BMA	O_BM	WI_MSL	WO_MSL
00:00	38.56	34.83	3.53	-0.20
01:00	38.56	34.84	3.53	-0.19
02:00	38.56	34.84	3.53	-0.19
03:00	38.56	34.84	3.53	-0.19
04:00	38.56	34.84	3.53	-0.19
05:00	38.56	34.84	3.53	-0.19
06:00	38.56	34.85	3.53	-0.18
07:00	38.56	34.85	3.53	-0.18
08:00	38.56	34.85	3.53	-0.18
09:00	38.56	34.85	3.53	-0.18
10:00	38.56	34.85	3.53	-0.18
11:00	38.56	34.85	3.53	-0.18
12:00	38.56	34.85	3.53	-0.18
13:00	38.56	34.84	3.53	-0.19
14:00	38.56	34.84	3.53	-0.19
15:00	38.56	34.84	3.53	-0.19
16:00	38.56	34.84	3.53	-0.19
17:00	38.56	34.84	3.53	-0.19
18:00	38.56	34.84	3.53	-0.19
19:00	38.56	34.84	3.53	-0.19
20:00	38.56	34.84	3.53	-0.19
21:00	38.56	34.85	3.53	-0.18
22:00	38.56	34.86	3.53	-0.17
23:00	38.56	34.86	3.53	-0.17
Max.	**38.56**	**34.86**	**3.53**	**-0.17**
Min.	**38.56**	**34.83**	**3.53**	**-0.20**
Ave.	**38.56**	**34.84**	**3.53**	**-0.19**

Water level at E14 station
on 19 September 1998

TM	WI_BMA	O_BM	WI_MSL	WO_MSL
00:00	38.56	34.86	3.53	-0.17
01:00	38.56	34.86	3.53	-0.17
02:00	38.56	34.86	3.53	-0.17
03:00	38.56	34.86	3.53	-0.17
04:00	38.56	34.87	3.53	-0.16
05:00	38.56	34.87	3.53	-0.16
06:00	38.56	34.87	3.53	-0.16
07:00	38.56	34.87	3.53	-0.16
08:00	38.56	34.87	3.53	-0.16
09:00	38.56	34.87	3.53	-0.16
10:00	38.56	34.87	3.53	-0.16
11:00	38.56	34.87	3.53	-0.16
12:00	38.56	34.87	3.53	-0.16
13:00	38.56	34.87	3.53	-0.16
14:00	38.56	34.86	3.53	-0.17
15:00	38.56	34.86	3.53	-0.17
16:00	38.56	34.86	3.53	-0.17
17:00	38.56	34.86	3.53	-0.17
18:00	38.56	34.86	3.53	-0.17
19:00	38.56	34.86	3.53	-0.17
20:00	38.56	34.89	3.53	-0.14
21:00	38.56	34.91	3.53	-0.12
22:00	38.56	34.93	3.53	-0.10
23:00	38.56	34.93	3.53	-0.10
Max.	**38.56**	**34.93**	**3.53**	**-0.10**
Min.	**38.56**	**34.86**	**3.53**	**-0.17**
Ave.	**38.56**	**34.87**	**3.53**	**-0.16**

Water level at E14 station
on 20 September 1998

TM	WI_BMA	O_BM	WI_MSL	WO_MSL
00:00	38.56	34.93	3.53	-0.10
01:00	38.56	34.93	3.53	-0.10
02:00	38.56	34.94	3.53	-0.09
03:00	38.56	34.94	3.53	-0.09
04:00	38.56	34.94	3.53	-0.09
05:00	38.56	34.94	3.53	-0.09
06:00	38.56	34.94	3.53	-0.09
07:00	38.56	34.95	3.53	-0.08
08:00	38.56	34.95	3.53	-0.08
09:00	38.56	34.95	3.53	-0.08
10:00	38.56	34.95	3.53	-0.08
11:00	38.56	34.95	3.53	-0.08
12:00	38.56	34.95	3.53	-0.08
13:00	38.56	34.95	3.53	-0.08
14:00	38.56	34.95	3.53	-0.08
15:00	38.56	34.93	3.53	-0.10
16:00	38.56	34.93	3.53	-0.10
17:00	38.56	34.93	3.53	-0.10
18:00	38.56	34.93	3.53	-0.10
19:00	38.56	34.93	3.53	-0.10
20:00	38.56	34.96	3.53	-0.07
21:00	38.56	34.99	3.53	-0.04
22:00	38.56	35.01	3.53	-0.02
23:00	38.56	35.01	3.53	-0.02
Max.	**38.56**	**35.01**	**3.53**	**-0.02**
Min.	**38.56**	**34.93**	**3.53**	**-0.10**
Ave.	**38.56**	**34.95**	**3.53**	**-0.08**

Water level at E14 station
on 1 October 1998

TM	WI_BMA	O_BM	WI_MSL	WO_MSL
00:00	32.17	34.93	-2.86	-0.10
01:00	32.17	34.93	-2.86	-0.10
02:00	32.16	34.93	-2.87	-0.10
03:00	32.17	34.93	-2.86	-0.10
04:00	32.17	34.93	-2.86	-0.10
05:00	32.17	34.93	-2.86	-0.10
06:00	32.16	34.93	-2.87	-0.10
07:00	32.17	34.88	-2.86	-0.15
08:00	32.16	34.80	-2.87	-0.23
09:00	32.16	34.77	-2.87	-0.26
10:00	32.16	34.77	-2.87	-0.26
11:00	32.16	34.77	-2.87	-0.26
12:00	32.16	34.77	-2.87	-0.26
13:00	32.16	34.77	-2.87	-0.26
14:00	32.17	34.78	-2.86	-0.25
15:00	32.16	34.79	-2.87	-0.24
16:00	32.17	34.79	-2.86	-0.24
17:00	32.16	34.80	-2.87	-0.23
18:00	32.17	34.80	-2.86	-0.23
19:00	32.17	34.81	-2.86	-0.22
20:00	32.16	34.82	-2.87	-0.21
21:00	32.16	34.83	-2.87	-0.20
22:00	32.16	34.84	-2.87	-0.19
23:00	32.66	34.85	-2.37	-0.18
Max.	**32.66**	**34.93**	**-2.37**	**-0.10**
Min.	**32.16**	**34.77**	**-2.87**	**-0.26**
Ave.	**32.18**	**34.84**	**-2.84**	**-0.19**

APPENDIX : C

FLOOD PRONE AREA

Flood prone area in Bangkok
(Bangkapi boundary)

No.	Flood prone area	Temporary solution	Permanent solution	Note
1.	Soi Lad Phrao 150	Install 2 Pumping Size 10”		E
2.	Four junction, Bangkapi	Install 1 Pumping Size 12”		E
3.	Soi Ramkham Haeng 21	Install 1 Pumping Size 6” and 2 Pumping Size 10”		C,E
4.	Happy Land Road	Install 1 Pumping Size 10”		C,E
5.	Lad Phrao Road at Klong Yaw Poun bridge	Install 1 Pumping Size 10” 1 Pumping Size 12”		E
6.	Roum Choke Village, Soi Lad Phrao 130	Install 2 Pumping Size 4”		C,E
7.	Soun Son Village	Install 1 Pumping Size 8”		E
8.	Happy Land Village	Install 1 Pumping Size 6”		C,E
9.	Soi Ramkham Haeng 39	Install 1 Pumping Size 4” and 1 Pumping Size 8”		C,D,E
10	Soi Lad Phrao 113	Install 1 Pumping Size 6”		E
11.	Soi Lad Phrao 115	Install 1 Pumping Size 6”		C,E
12.	Soi Siri Thaworn, junction of Soi Ramkam Heang 24	Install 1 Pumping Size 6”		B,C,E
13.	Soi Phuong Siri	Install 1 Pumping Size 4” and 1 Pumping Size 6”		E

Flood prone area in Bangkok (continued)
(Bangkapi boundary)

No.	Flood prone area	Temporary solution	Permanent solution	Note
14	Soi Lad Prao 122	Install 2 Pumping Size 8"		E
15	Three junction, Bangkapi	Install 1 Pumping Size 6" and 1 Pumping Size 8"		E
16	Tharn Thip Village, Public Health 3	Install 2 Pumping Size 8"		C,E
17	Thiu Son Village, Soi Lad Prao 87	Install 1 Pumping Size 10"		C,E

Source: Department of Drainage and Sewerage, BMA 1998

Note:
- A : a dirty drain
- B : the drain not link with main drain and system
- C : the drain system is small size
- D : the road is not a drain
- E : low-land area

APPENDIX : D

FLOOD CONDITIONAL REPORT

Flood conditional report

Date	District	Location	Flood depth (cm.)	Time of flooding		Rainfall (mm.)
				Flood	Dry	
18 Sept. 98	Bang Kapi	outward bound of Ram Kham Haeng Road				
		- Soi Ram. 87 to the Saen Saep Bridge	25	13.35	17.25	
		- Lamsalee intrsection to Mobil filling station	5-10			
		- Front of Ram Kham Haeng Univ. to Soi 24	10-15	13.35	18.40	
18 Sept. 98	Din Daeng	inward bound of Din Daeng Road from Phracha Songkhlou intersection to Din Daeng intersection	25	14.25	18.00	
18 Sept. 98	Ratcha Thewi	Phraram VI Road from Tog Chai intersection to Sri Ayuthaya intersection	10-15	14.35	15.45	
18 Sept. 98	Wattana	Sukhumvit Road from Soi 43-53	25	14.40	16.55	
		- inward bound Soi 62 to 101/1	5-10	14.50	16.15	
18 Sept. 98	Huai Khwang	Phet Buri Road-Asoke to Monalisa - Klong Bang Kapi to Soon Vijai-Phornpet Massage	25	14.50	18.20	
18 Sept. 98	Din Dang	Phracha Songkhlou Road from Din Daeng intersection – front of Din Daeng market	25	14.55	18.00	
18 Sept. 98	Din Daeng	Soi 23-27, Phracha Songkhlou Road	25	14.55	19.20	
18 Sept. 98	Dusit	Yommarat intersection to Sa Nam Nanglerng, Phissanuloke Road	25	14.55	16.15	
18 Sept. 98	Chattu Chag	Phahon Yothin Road - Sena intersection to Kaset Junction	25	14.55	18.10	
18 Sept. 98	Phaya Thai	- Out ward bound Soi Ratchakru to Bang Su police station	15-20	15.00	21.25	
18 Sept. 98	Phaya Thai	- Front of Old Transport Co.ltc.	5-20	15.00	17.00	
		- Front of TV 5		15.00	21.00	
18 Sept. 98	Ratcha Thewi	Mitsamphan intersection to Asoke overpass, Phet Buri Road	25	14.55	17.00	
		- Soi 37, Phet Buri Road	10	15.23	17.00	
		Ratchada Road – front of Bangkok Bank to Lad Phrao intersection	20-25	15.00	23.45	
		- Ratchada intersection cut of Lad Phrao to Klong Nam Keaw	20-25	15.05	01.00	
18 Sept. 98	Ratcha Thewi	Front of Department of Livestock development, Phayathai Road	25	15.45	18.30	
19 Sept. 98	Bang Kapi	Soi 21 to Front of Ramkham Haeng Univ., Ramkham Haeng Road	25	18.40	21.30	74.50
		Lamsalee intersection	25	18.40	23.15	74.50

Flood conditional report (continued)

Date	District	Location	Flood depth (cm.)	Time of flooding		Rainfall mm.
				flood	dry	
19 Sept. 98	Phra Khanong	Front of Bang Chag Market to Sukhumvit 62 intersection , Sukhumvit Road	25	19.30	20.30	
20 Sept. 98	Wattana	Front of Bang Chag Market to Sukhumvit 101/1 intersection , Sukhumvit Road	5-10	13.00	15.00	
20 Sept. 98	Bang Kapi	Lamsalee intersection, Ramkham Haeng Road	25	12.50	15.15	
20 Sept. 98	Samphanthawong	Phadung Dao intersection to More Mee intersection, Charoen Krung Road	25	17.35	20.10	
20 Sept. 98	Wattana	Front of Bang Chag Market to Sukhumvit 101/1 intersection , Sukhumvit Road	10-15	18.00	19.30	
20 Sept. 98	Bang Rak	Part of under the express way, Surawong Road	5-10	18.00	20.30	
20 Sept. 98	Bang Rak	Middle of Soi, Naret Road	25	18.10	20.30	
20 Sept. 98	Pathumwan	From Phatumwan inersection, Phraran I Road	5-10	18.15	21.40	
20 Sept. 98	Ratcha Thewi	Front of Phra Chae Chen market to Highways Department, Phraram VI Road	5	18.15	20.40	
20 Sept. 98	Sathon	Front of Kitti Phanich School, Saint Louis 3 Road	25	18.45	19.50	
20 Sept. 98	Bang Kapi	Soi 21 to Front of Ramkham Haeng Univ., Ramkham Haeng Road	25	04.45	09.45	
20 Sept. 98	Bang Kapi	Lamsalee intersection, Srinakarin Road	25	05.00	07.30	
1 Oct. 98	Bang Kapi	Lamsalee intersection	25	19.00	06.00	
1 Oct. 98	Bang Kapi	From front of Univ. to Soi 8 and opposite, Ramkham Haeng Road	30-50	19.00		
1 Oct. 98	Bang Kapi	Bang Kapi intersection to Soi 80, Lad Phrao	25	19.00		
1 Oct. 98	Bang Kapi	Asoke intersection to Soi Soon Vijai, Phet Buri Road	25	19.00	03.00	
1 Oct. 98	Dusit	Nearly of Savankaloke intersection, Phissanuloke Road	5-10	19.15	20.00	
1 Oct. 98	Dusit	At equestrial statue, Sri Ayuttaya Road	10-15	19.20	21.00	
1 Oct. 98	Ratcha Thewi	Tog Chai intersection to Phet Buri road, Phraram VI Road	20	19.20	23.30	
1 Oct. 98	Ratcha Thewi	Na Na intersection to Asoke, Phet Buri Road	10-15	19.20	02.35	

Flood Conditional Report (continued)

Date	District	Location	Flood depth (cm.)	Time of flooding		Rainfall mm.
				Flood	Dry	
1 Oct. 98	Ratcha Thewi	From railway to Phet Buri road, Phaya Thai Road	25	19.30	23.00	
1 Oct. 98	Phaya Thai	Sapan Kwao intersection to TV 5, Phahon Yothin Road	25	19.20	04.00	
1 Oct. 98	Din Daeng	From Prom Pan intersection to Fatima intersection , Phracha Songkhlou Road	25	19.30	00.30	
1 Oct. 98	Din Daeng	Soi 23 to Sutti San intersection, Phracha Songkhlou Road	25	19.30	01.00	
1 Oct. 98	Sathorn	Front of Kitti Phanich School, Saint Louis Road	25	20.10	23.30	
1 Oct. 98	Sathorn	Thanon Chan intersection, Sathuphradit Road	5-10	20.10	23.00	
1 Oct. 98	Sathorn	Suan Ploo Road	25	20.20	23.30	
1 Oct. 98	Klong Thoei	From Soi 43-53, Sukhumvit Road	25	20.20	22.30	
1 Oct. 98	Samphan thawong	From Plaeng Nam road to 3 junction, Charoen Krung Road	25	20.20	23.15	
1 Oct. 98	Phrawet	From Klong Tha Chang to ห้างZee Con Square, Sri Nakarin Road	25	20.25	22.30	
1 Oct. 98	Bang Na	Bang Na intersection, Sukhumvit Road	10-20	20.30	02.30	
1 Oct. 98	Phra Khanong	Front of Phra Khanong police station to Soi 101/1, Sukhumvit Road	20-30	20.30	02.30	
1 Oct. 98	Chattu Chag	From Ratchada-Lad Phrao to Klong Bang Nam Keaw, Ratchada Phisek Road	25	22.00	23.25	

Source: Flood Control Center (FCC), BMA 1998

APPENDIX : E

DATA FOR HYPOTHESIS EVALUATION

Data for hypothesis evaluation

postion	flood depth(cm.) real event 1998	model (elev.1986)	model (elev.1995)
1	25	57	67
2	10	36	27
3	15	52	115
4	25	0	0
5	15	0	0
6	25	0	0
7	10	0	0
8	25	0	0
9	25	0	0
10	25	0	0
11	25	0	0
12	15	0	0
13	20	0	0
14	20	0	0
15	25	0	0
16	10	0	0
17	17	0	0
18	18	0	0
19	19	0	0
20	25	31	104
21	25	39	29
22	25	16	14
23	10	0	0
24	25	0	0
25	25	0	0
26	15	0	0
27	10	0	0
28	25	0	0
29	10	0	0
30	10	0	0
31	5	0	0
32	50	0	0
33	25	27	87
34	25	16	14
35	25	0	0
36	50	0	0
37	25	0	0
38	25	0	0
39	10	0	0
40	15	0	0
41	20	0	0
42	15	0	0
43	25	0	0
44	25	0	0
45	25	0	0
46	25	0	0
47	25	0	0
48	10	0	0
49	25	0	0
50	25	0	0
51	25	0	0
52	25	0	0
53	20	0	0
54	30	0	0
55	25	0	0

APPENDIX : F

PAIRED SAMPLES T TEST ANALYSIS

Paired Samples Statistics

		mean	n	std. deviation	std error mean
Pair 1	model (1986)	4.9818	55	13.3382	1.7985
	Real	21.7273	55	8.4007	1.1328

Paired Samples Correlation

		n	correlation	sig
Pair 1	model (1986 Real	55	-0.027	0.845

Paired Samples Test

	Paired Difference					t	df	sig (2-tailed)
	mean	std. deviation	std error mean	95% confidence interval of the difference				
				lower	upper			
Pair 1 model(1986) -Real	-16.7455	15.9539	2.1512	-21.0584	-12.4325	-7.784	54	0.000

Paired samples T test analysis

Paired Samples Statistics

	mean	n	std. deviation	std error mean
Pair 1 model (1995	8.3091	55	25.1896	3.3966
real	21.7273	55	8.4007	1.1328

Paired Samples Correlation

	n	correlation	sig
Pair 1 model (1995 Real	55	-0.005	0.97

Paired Samples Test

	Paired Difference					t	df	sig (2-tailed)
	mean	std. deviation	std error mean	95% confidence interval of the difference				
				lower	upper			
Pair 1 model(1995) -Real	-13.4182	26.5948	3.586	-20.6078	-6.2286	-3.742	54	0.000

BIOGRAPHY

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