

**APPROPRIATE LINKAGE FOR DRAINAGE RETENTION AREA
IN LAM TAKHONG WATERSHED, NAKHON RATCHASIMA
PROVINCE, THAILAND**

PAWEEN PANYAPHOL

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Thesis
entitled
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PROVINCE, THAILAND**

.....
Miss Paween Panyaphol
Candidate

.....
Assoc. Prof. Sura Pattanakiat,
Ph.D. (Forestry)
Major advisor

.....
Asst. Prof. Saranya Sucharitakul,
Ph.D. (Demography)
Co-advisor

.....
Prof. Banchong Mahaisavariya,
M.D., Dip. Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

.....
Assoc. Prof. Sura Pattanakiat
Program Director
Master of Science Program in
Technology of Environmental
Management
Faculty of Environment and Resource
Studies, Mahidol University

Thesis
entitled
**APPROPRIATE LINKAGE FOR DRAINAGE RETENTION AREA
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was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Science
(Technology of Environmental Management)

on
May 20, 2012

.....
Miss Paween Panyaphol
Candidate

.....
Lect. Chongrak Wachrinrat,
Ph.D. (Forestry)
Chair

.....
Assoc. Prof. Sura Pattanakiat,
Ph.D. (Forestry)
Member

.....
Asst. Prof. Saranya Sucharitakul,
Ph.D. (Demography)
Member

.....
Prof. Banchong Mahaisavariya,
M.D., Dip. Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

.....
Assoc. Prof. Kampanad Bhaktikul,
Ph.D. (Civil and Environmental Engineering)
Dean
Faculty of Environment and Resource
Studies
Mahidol University

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Paween Panyaphol

APPROPRIATE LINKAGE FOR DRAINAGE RETENTION AREA IN LAM TAKHONG WATERSHED, NAKHON RATCHASIMA PROVINCE, THAILAND

PAWEEN PANYAPHOL 5336511 ENTM/M

M.Sc. (TECHNOLOGY OF ENVIRONMENTAL MANAGEMENT)

THESIS ADVISORY COMMITTEE: SURA PATTANAKIAT, Ph.D. (FORESTRY),
SARANYA SUCHARITAKUL, Ph.D. (DEMOGRAPHY)**ABSTRACT**

The Great Flood of 2010 in the Lam Takhong Watershed, Nakhon Ratchasima province caused considerable damage to several communities, including the City of Nakhon Ratchasima. Flood retention basins are promising tools that could alleviate floods. A linkage is also an important feature of retention basins. This study aimed at investigating two types of retention basin linkages: natural linkages and artificial linkages.

In order to locate flood retention areas, this study adopted potential surface analysis (PSA) which is carried out through use of the geographic information system (GIS). Several factors are taken into account for the site selection. The basic requirements, including being non built-up areas and upstream locations, are two factors that are very essential. Other factors include slope, soil fertility, soil permeability, rock permeability, land use, distance to a major waterway, and distance to protected areas. The PSA overlays all factors with corresponding suitability scores and results in retention basin suitability. The retention basin suitability was classified into three categories: high suitability, moderate suitability, and low suitability. The study selected a continuous area of 3,515.854 *rai*, where the basic requirements are allowed, to be the suitable retention basin. The suitable retention basin can contain 14,063,414.1 cubic meters of runoff.

The suitable retention basin was imported to MIKE 11 in order to investigate the benefits of two types of linkages: natural linkages and artificial linkages. At the City of Nakhon Ratchasima, the study found that the retention basin with natural linkages can lower flood peak level by 0.207 meter or 56.71%, compared to the actual flood peak level above the bank level of the Great Flood of 2010. Natural linkages could also shorten the flood period by one day compared to the actual flood as the retention basin slows down runoff. The artificial linkages could only slightly lower flood level by 0.059 meter. This weaker flood mitigation capacity is due to its wide and straight channels, which contribute to a lack of ability to retain excessive runoff within the retention basin. Moreover, a gradual decrease in water levels in the City of Nakhon Ratchasima and a great volume of runoff draining back to the Lam Takhong River would result in a one-day longer flood period. This study suggests that a minimum of two sluice gates be adopted to better manage the capture of excessive runoff.

**KEY WORDS: RETENTION BASIN/ FLOOD/ NAKHON RATCHASIMA/ LAM
TAKHONG/ MIKE 11**

86 pages

ระบบการระบายน้ำที่เหมาะสมต่อการเป็นพื้นที่หนองน้ำ ของลุ่มน้ำลำตะคอง จังหวัดนครราชสีมา ประเทศไทย
APPROPRIATE LINKAGE FOR DRAINAGE RETENTION AREA IN LAM TAKHONG WATERSHED,
NAKHON RATCHASIMA PROVINCE, THAILAND

ปวีณ ปัญญาผล 5336511 ENTM/M

วท.ม. (เทคโนโลยีการบริหารสิ่งแวดล้อม)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์: สุระ พัฒนเกียรติ, Ph.D. (FORESTRY), ศรีธยา สุจริตกุล, Ph.D.
(DEMOGRAPHY)

บทคัดย่อ

อุทกภัยครั้งใหญ่ในปี 2553 ในลุ่มน้ำลำตะคอง ได้สร้างความเสียหายอย่างมากให้กับตัวเมืองนครราชสีมา พื้นที่หนองน้ำเป็นเครื่องมือบรรเทาอุทกภัยอย่างหนึ่ง คลองเชื่อมเป็นส่วนประกอบที่สำคัญของพื้นที่หนองน้ำ วิทยานิพนธ์นี้มีวัตถุประสงค์เพื่อศึกษาคลองเชื่อม 2 ประเภท ได้แก่ คลองเชื่อมธรรมชาติ และคลองเชื่อมที่มนุษย์สร้างขึ้น

ในการกำหนดที่ตั้งพื้นที่หนองน้ำนั้น วิทยานิพนธ์นี้ให้วิธีการ Potential Surface Analysis (PSA) ซึ่งดำเนินการผ่าน GIS โดยการนำปัจจัยต่างๆ มาพิจารณา ปัจจัยพื้นฐาน ได้แก่ การไม่เป็นพื้นที่เมือง และการอยู่ในพื้นที่เหนือน้ำของพื้นที่ป้องกันน้ำท่วม ส่วนปัจจัยอื่นๆ ได้แก่ ความลาดชัน ความอุดมสมบูรณ์ของดิน การยอมให้น้ำซึมผ่านของดิน การยอมให้น้ำซึมผ่านของหิน การใช้ประโยชน์ที่ดิน ระยะทางไปยังทางน้ำสายหลัก และระยะทางไปยังพื้นที่ป้องกันน้ำท่วม ผลที่ได้จาก PSA คือความเหมาะสมต่อการเป็นพื้นที่หนองน้ำ ซึ่งได้แบ่งออกเป็น 3 กลุ่ม ได้แก่ เหมาะสมมาก เหมาะสมปานกลาง และเหมาะสมน้อย พื้นที่หนองน้ำที่คัดเลือกเป็นพื้นที่ต่อเนื่อง ขนาด 3,515.854 ไร่ สามารถกักเก็บน้ำทำได้ 14,063,414.1 ลูกบาศก์เมตร

พื้นที่หนองน้ำที่เหมาะสมที่ได้นำเข้าสู่แบบจำลอง MIKE 11 เพื่อประเมินผลประโยชน์ที่ได้รับจากคลองเชื่อมทั้ง 2 ประเภท วิทยานิพนธ์นี้พบว่า พื้นที่หนองน้ำที่มีคลองเชื่อมธรรมชาติสามารถลดระดับน้ำท่วมสูงสุดที่ตัวเมืองนครราชสีมาได้ 0.207 เมตร หรือคิดเป็นร้อยละ 56.71 ของระดับน้ำท่วมสูงสุดเหนือระดับตลิ่งของอุทกภัยครั้งใหญ่ปี 2553 นอกจากนี้ คลองเชื่อมธรรมชาติยังสามารถลดจำนวนวันที่เกิดอุทกภัยในตัวเมืองนครราชสีมาได้หนึ่งวัน เนื่องจากน้ำท่าไหลได้ค่อยๆ ไหลออกจากพื้นที่หนองน้ำ ส่งผลให้เกิดน้ำล้นตลิ่งช้าลงหนึ่งวัน ส่วนคลองเชื่อมที่มนุษย์สร้างขึ้นนั้นพบว่าลดระดับน้ำท่วมได้เล็กน้อยเพียง 0.059 เมตร เนื่องจากช่องทางน้ำที่กว้างและเป็นเส้นตรงของคลองเชื่อมที่มนุษย์สร้างขึ้น ทำให้ความสามารถในการหน่วงน้ำท่าภายในพื้นที่หนองน้ำน้อยลง นอกจากนี้ยังทำให้น้ำท่วมยาวนานกว่าเหตุการณ์จริงหนึ่งวันด้วย วิทยานิพนธ์นี้เสนอให้มีการใช้ประตูน้ำเพื่อให้สามารถควบคุมการกักเก็บน้ำท่าส่วนเกินไว้ในพื้นที่หนองน้ำได้ดียิ่งขึ้น

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CHAPTER I

INTRODUCTION

1.1 Statement of Problem

Flood is a natural phenomenon usually occurring annually in the rainy season. Flood mostly affects low-lying area along sides of watercourses called floodplain. Some steep-sloping area near waterways may also suffer from fast-moving overflows of runoff called flash flood. Floodplain is a flood-prone area formed by watercourse action that leads to sedimentation of sediments carried by that watercourse along both of its sides. Even with some flood mitigation measures, a flood plain is still vulnerable to flood.

Flood causes varying and different impacts on flooded areas, depending on various factors, e.g., relief, water levels, and velocity, leaving behind damages to properties, structures, farmlands, and lives, including those of human beings. Urbanization has led to a fast pace of urban expansion encroaching into the urban fringes and undeveloped natural areas surrounding cities. This phenomenon exacerbates flood severity as natural retention basins have been displaced by urban development, allowing for excessive runoff directly entering and inundating cities, communities, and farmland. In response, several government agencies as well as the private sector have initiated some flood mitigation measures, with one of the most prevailing measures being construction of dams. However, such measures do not alleviate flood to satisfying extent. Artificial detention or retention basins which are pools of excessive runoff water are promising tools that help alleviate or even prevent flood by capturing excessive runoff that potentially inundates cities, communities, and farmlands. His Majesty the King has initiated detention/retention facilities, called Kaem Ling, in many areas, most of them located in Chao Phraya River basin such as one in a royal park of Maung Ayutthaya District (United Nations, 1999). These

retention basins play a role in retaining some runoff water in the Chao Phraya River before reaching Bangkok, the capital city of Thailand. Other areas, however, still lack retention basins. Floodplain of Lam Takong River in Nakhon Ratchasima Province in the northeastern region of Thailand also suffers from flood caused by overflows of the Lam Takong River. The great flood of October of 2010 is known to be the most severe flood ever occurring in Maung Nakhon Ratchasima District in 50 years (Thai Rath, 2010, October 16). As with other floodplains, Lam Takhong floodplain also sees a number of dams designed for several purposes, including but not limited to, storing water for use in dry season and mitigating flood in rainy season. Evidently, those dams could not prevent the great flood of 2010 as stated. Retention basins, therefore, can be constructed and play a role in alleviating or preventing flood in the future.

Muang Nakhon Ratchasima District is the political, economic, social and educational center of Nakhon Ratchasima Province. Moreover, there are 129 villages in Muang Nakhon Ratchasima alone that are located in Lam Takong Watershed (Muang Nakhon Ratchasima Agricultural Office, n.d.). Damages caused by flood would create considerable economic loss. Therefore, preventing or alleviating future flood in this area is more than essential. Building of retention basins could be an efficient measure of alleviating flood in Muang Nakhon Ratchasima District and could complement flood mitigation schemes currently employed in the area. Locating and designing the retention basins could, however, be a great challenge. This research utilizes GIS as a tool to locate retention basins and utilizes MIKE 11 to design potential retention basins along with their linkages in Lam Takhong Watershed that could alleviate flood in Muang Nakhon Ratchasima District by simulating water flow before and after an implementation of retention basins. This study aims at comparing the capability of retention basin with natural linkages and that with artificial linkages. The hydrological model could then suggest a modified drainage pattern of Lam Takhong Watershed. Implementation of the findings would result in a greater good of all the people in Maung Nakhon Ratchasima District.

1.2 Objectives

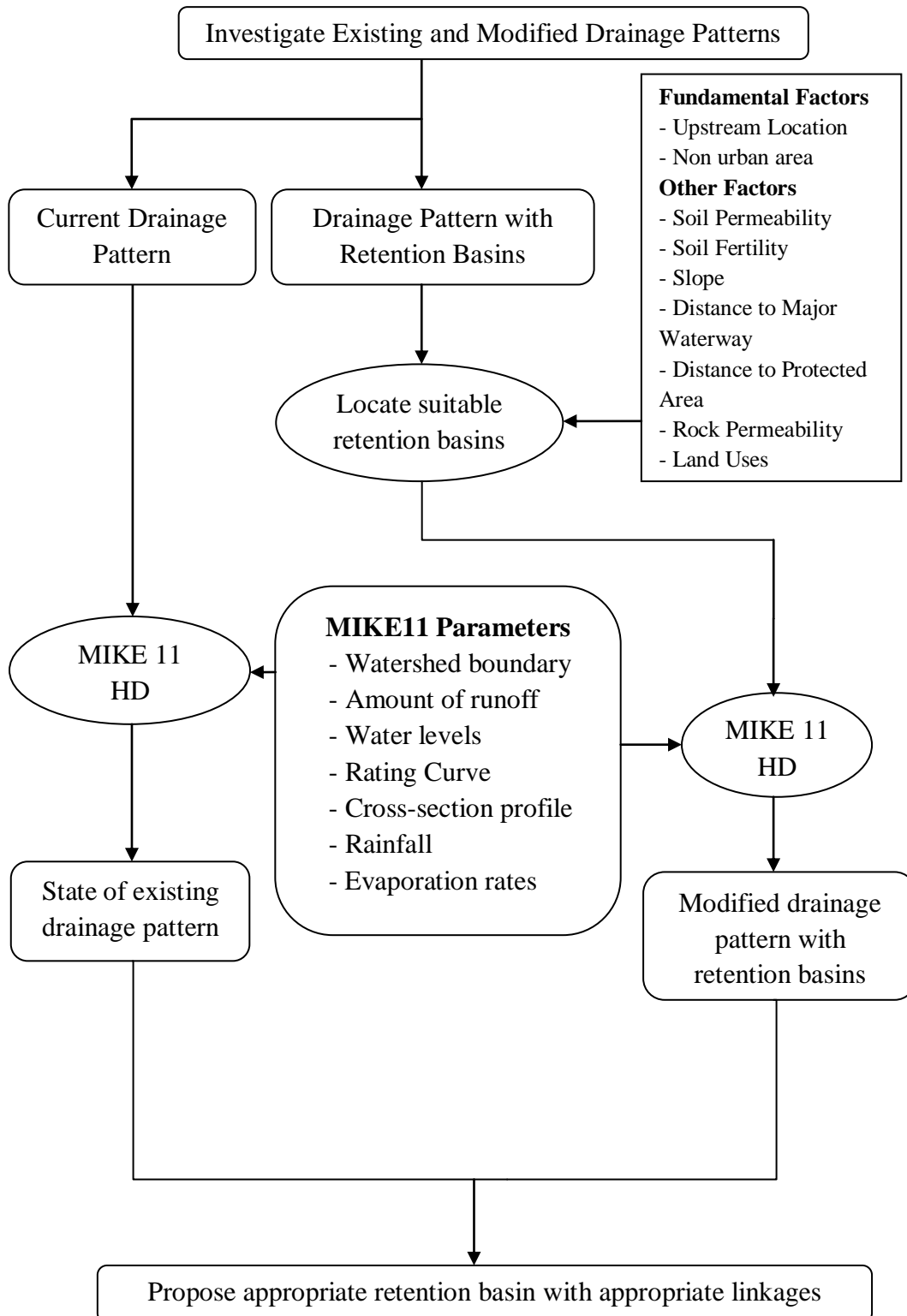
- 1) To identify the state of drainage pattern in Lam Takhong Watershed, Nakhon Ratchasima Province
- 2) To classify appropriate retention areas using potential surface analysis
- 3) To compare the benefits of retention basin with natural linkages and that with artificial linkages

1.3 Scope of the Study

This study aims at proposing a modified drainage pattern with retention basins designed to mitigate flood in Muang Nakhon Ratchasima District. In order to reach that goal, the study needs to analyze existing drainage pattern and its capacity – how much water all watercourses can hold without flooding – using a hydrological model, MIKE11 Hydrodynamic and Rainfall-Runoff. Potential Surface Analysis (PSA) is used to assess land suitability for retention basin and classify lands into three classes: most suitable, moderately suitable, and least suitable. Areas classified as “most suitable” are then selected and used to simulate hydrological flow in Lam Takhong Watershed. The hydrological simulation is done through MIKE 11. By doing so, the study compares two types of linkages: natural linkages and artificial linkages. Either of the two types of linkages would then be proposed based on their capability of flood mitigation.

The protected area of this study is the City of Nakhon Ratchasima, which is located in Lam Takhong Watershed. The study area of this study is the Lam Takhong Watershed downstream of the Lam Takhong Dam. The major watercourse causing flooding in the study area refers to Lam Takhong River that flows through the study area.

1.4 Conceptual Framework



1.5 Expected Results

Aiming at proposing the modified drainage pattern with retention basins, this study anticipates that artificial drainage pattern with retention basins and either type of linkages connecting them with Lam Takhong River could mitigate flood in Muang Nakhon Ratchasima District by lowering the highest flood level. The modified drainage pattern is expected to reduce flood levels in Muang Nakhon Ratchasima District as well as to increase the overall capacity of Lam Takhong Watershed, the maximum volume of water the watershed could handle with flooding occurrence.

1.6 Definition

Retention Basin is an artificial pool of water that permanently stores water and is designed to capture excessive storm water runoff during runoff period and gradually release runoff once watercourses can handle runoff within their banks (Jovanovic, 2007; Setty, 2009). Stored water will be replaced by runoff of the following runoff event (Paine & Akan, 2004; United States Environmental Protection Agency, 1999). For plain area, a retention basin should be created by excavation (Jovanovic, 2007).

Runoff is a result of precipitation. Precipitation leads to runoff when rate of rainfall is greater than rate of infiltration. Precipitation trapped above land surface will flow down-slope, as runoff, to streams, rivers, and seas (San Siripak, 1993).

CHAPTER II

LITERATURE REVIEW

2.1 Lam Takhong Watershed

Lam Takhong River is the main watercourse in a significant portion of Nakhon Ratchasima Province with watershed covering a catchment area of 3,518 square kilometers. The watershed is located to the west of Mun Watershed is Lam Takhong River is a tributary of Mun River which flows from the west to the east. Lam Takhong River is originated in San Pan Nam Mountain Range, specifically between Mount Khao Fa Pa in Pakchong District, Nakhon Ratchasima and Mount Khao Fa La Mee, Muang Nakhon Nayok District, Nakhon Nayok. The river flows through Nakhon Ratchasima Province with a total length of 220 kilometers before merging with Mun River in Chakarat District, Nakhon Ratchasima (Royal Irrigation Department, n.d.; Suranaree University of Technology, 2005).

Lam Takhong Watershed is one of several watersheds in Nakhon Ratchasima Province. It is adjacent Lam Choengkrai Watershed to the north; Upper Part of Mun Watershed to the east; Lam Phraphloeng Watershed, Nakhon Nayok Watershed, and Hanuman Watershed to the south; and Huai Muak Lek Watershed and Lam Sonthi Watershed to the west as depicted in Figure 2.1. In this study, the study area, however, covers about two-thirds of Lam Takhong Watershed, which is the downstream area of Lam Takhong Dam (Figure 2.2). The study area covers an area of 2,158.28 square kilometers or 1,348,922.66 *rai*.

The southwest portion of Lam Takhong Watershed where the river is originated is dominated by steep valleys in Pak Chong and See Kiew Districts (Muang Nakhon Ratchasima Agricultural Office, n.d.). An average annual rainfall of the watershed is 1,200.42 millimeters, 81% of which (976.72 millimeters) occurs between August and September which is the rainy season. The rainy season accounts

for 77% of average annual runoff of 467.47 million cubic meters, while the dry season accounts for the remaining runoff (Suranaree University of Technology, 2005). About 30.85% of the watershed area or 1,085.32 square kilometers are protected in the national parks (898.28 square kilometers) and reserved forests (187.04 square kilometers) (Suranaree University of Technology, 2005).

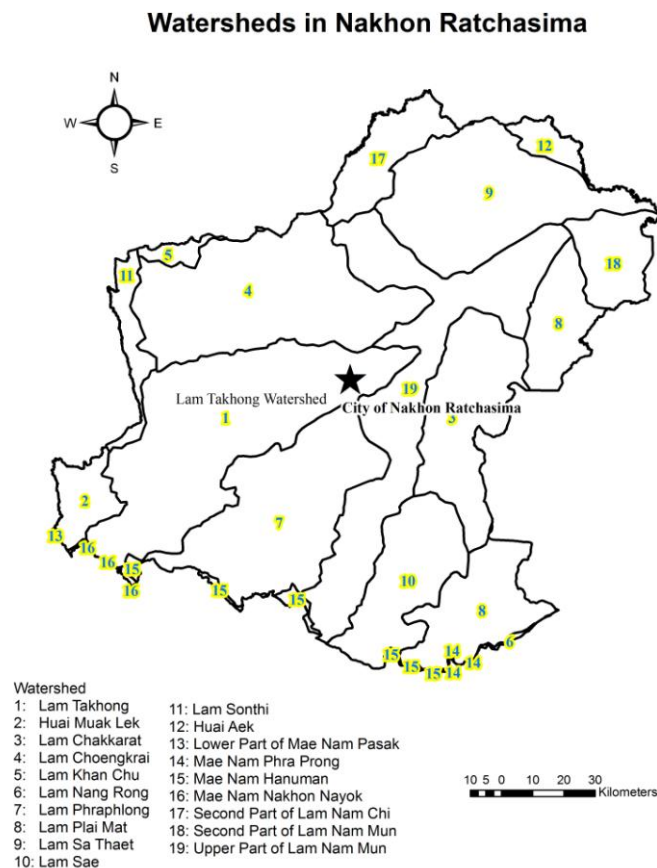


Figure 2.1 Watersheds in Nakhon Ratchasima Province.

Source: Department of Environmental Promotion Quality, 2004.

There is a number of existing watershed management projects in a form of reservoirs in the watershed, most of which have been designed for agricultural water supply purposes. The large-size reservoir is Lam Takhong Dam, which also provides raw water to produce urban water supply and generate electricity, in addition to provide agricultural water supply. Significantly, Lam Takhong Dam was also built to

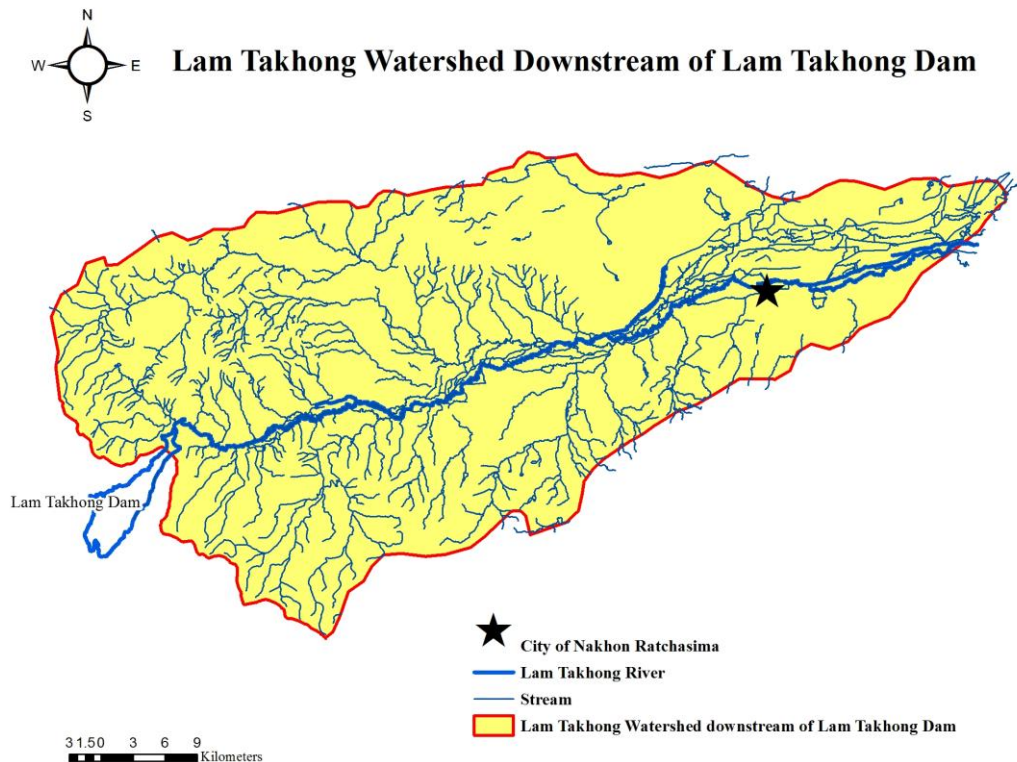


Figure 2.2 Lam Takhong Watershed downstream of Lam Takhong Dam.

Source: Department of Environmental Promotion Quality, 2004.

alleviate flood in Lam Takhong floodplain and part of Mun floodplain (Royal Irrigation Department, n.d.; Suranaree University of Technology, 2005). Medium-size reservoirs include Huay Sab Pra Doo Reservoir and Huay Baan Yang Reservoir. Other reservoirs include Huay Sab Wai Reservoir, Bueng Nong Koo Reservoir, Huay Thaloeng Pon Reservoir, Bung Ta Lua Reservoir, Nong Prue Reservoir, and Nong Haen Reservoir (Suranaree University of Technology, 2005). As of 2005, water supply for irrigation is 287.770 million cubic meters which is anticipated to increase by 3.55% to 297.978 million cubic meters by 2023. Urban water supply is anticipated to increase by 4 million cubic meters by the same year (Suranaree University of Technology, 2005).

2.2 Flood

Flood is an event of river or stream overflows that are induced by excessive runoff generated by rain storm or melting snow, resulting in inundation along sides of rivers or streams (Sukan Rattaloednusorn, 2007; Weerapon Taesombat, 1988). Other factors influencing flood include floodplain topography, destructed natural plants, dam failure, and high tide coinciding with a large volume of storm water runoff which affects low-lying areas near the seashores, such as Bangkok. Urban development resulting in waterway invasion and displacement of natural detention basin also contribute to flooding (Sukan Rattaloednusorn, 2007; Weerapon Taesombat, 1988).

Flood Types

Flood events vary due to various factor influencing flood characteristics, such as geographic features, types of waterways, flow processes and land uses. Flood events occurring in Thailand can be categorized into four primary types (Douglas et al., 2007; United Nations, 1999) as follows:

1) Regional, widespread flood or riverine flood caused by widespread long-duration heavy rain over river basins. Monsoonal depressions from May to October or tropical cyclones usually catalyze this prolong heavy rain which sometimes results in river overflows that typically affect communities, towns, cities as well as agricultural lands along rivers in impacted basins. Soils with low permeability exacerbate the flooding severity. Regional flood usually lasts for weeks.

2) Flash flood in steep, mountainous small watersheds where, due to steep slope, runoff usually causes severe damage to structures. The usual causes of flash flood are intense thunderstorms during the summer months or thunderstorms catalyzed by strong monsoonal depressions.

3) Urban flood caused by heavy, short-duration thunderstorm occurring over urbanized area. This type of flood is expected to happen more frequently as a result of increased urban development resulting in an increase in portions of catchments occupied by impervious surface. Urbanization also displaces

natural wetlands. Therefore, rainwater accumulates in urban area rather than draining to nearby wetlands.

4) Coastal flood which is caused by storm surges or tidal waves including tsunamis. This type of flood event, however, impacts only a narrow strip near the coast.

Other notable types of flood that are unlikely to occur in Thailand can be identified. They include (Douglas et al., 2007):

1) Sewer flooding caused by high levels of storm water in rivers that cause overflowing of sewers as water cannot be drained to rivers; this type of flooding is likely to happen in low-lying urban areas in close proximity to rivers; and

2) Groundwater flooding that can happen in areas with certain geologic features, particularly chalk aquifers, when such areas receive long-duration rainfall; groundwater flooding can last several weeks or even months.

2.3 Flood Mitigation Measures

Fortunately, government agencies, related organizations as well as individuals have adopted various measures to alleviate or prevent flood. Major flood mitigation measures are discussed below.

1) Flood Storage

This flood mitigation measure includes a detention of excessive storm water runoff in natural wetlands, ponds, or artificial reservoirs (Hamid & Amaning, 1991). This measure will be discussed in more details in the following section.

2) Channel Improvement and Enlargement

In order to keep excessive runoff in water channel, water channel may be enlarged either by widening or deepening (Sukan Rattanalodnusorn, 2007; Hamid & Amaning, 1991). Containing of excessive runoff in watercourses can also be achieved by improving hydraulic capacity through eliminating obstructions in water channels, including sediment and tree limbs. Hydraulic capacity improvement can also be

achieved by straightening of waterway bends (Weerapon Taesombat, 1988). This measure also includes channel lining that reduces roughness of the channel (Hamid & Amaning, 1991).

3) Utilization or Modification of Flood Control Structures

This type of measure includes (1) installing, lowering, or widening of weirs; (2) removal or converting of sluices, gates and trash screens or grids; and (3) increasing width and/or height of conduits and bridges (Hamid & Amaning, 1991).

4) Bypass Channels or Floodways

This mitigation measure includes open channels and culverts (Hamid & Amaning, 1991). Not only do bypass channels act as addition outlets, expediting water flow speed and reducing water level, they also perform as storm water retention basins, reducing water in main rivers (United Nations, 1999; Weerapon Taesombat, 1988). One of its advantages is that it avoids damaging river habitats. Bypass channels, however, require land acquisition which may be limited by high-value land (United Nations, 1999; Hamid & Amaning, 1991).

5) Levees and Flood Walls

Constructing levees or dikes and flood walls is a prevailing means of bank raising. This measure, however, requires land acquisition and protects only areas immediately behind the levees to some extent depending upon levee heights (Hamid & Amaning, 1991; United Nations, 1999; Weerapon Taesombat, 1988). These levees should be annually inspected and maintained to prevent failure (Weerapon Taesombat, 1988).

6) Pumping

In certain low-lying areas, pumping may be an only promising measure to control flood. A mean of pumping of runoff overflows, however, should be avoided if possible because it requires high costs and maintenance of costly machines, namely pumps, control switchgear, and motors, all of which are intermittently used (Hamid & Amaning, 1991).

7) Land Use Control

Legislation can control land use and urban development that minimize flood risk to people and reduce natural resource degradation. This can be achieved by imposing laws for watershed management or developing watershed management plans

that minimize flood risk and avoid natural resource degradation (United Nations, 1999).

8) Forest Plantation

Forest can slow down runoff velocity. Therefore, forest plantation can help retain runoff before it reaches communities or cities downstream (Sukan Rattanaloeednusorn, 2007).

2.4 Retention Basins

As a tool of alleviating flood in many flood plains, a retention basin acts as a pool of storm water to retain excessive water to prevent flood or lower flood level in other areas. A retention basin's characteristics, variants, functions, and suitable location are discussed in this chapter.

Characteristics

A retention basin is one of the Best Management Practices (BMPs) that has a primary purpose of alleviating inundation by capturing excessive storm water runoff and of improving storm water quality (Jovanovic, 2007; Setty, 2009). A retention basin is an artificial lack that permanently stores water (Jovanovic, 2007). In other words, a retention basin stores old runoff until the next runoff event occurs and replaces old runoff by new incoming runoff, partially or totally (Paine & Akan, 2004; United States Environmental Protection Agency, 1999). It can either be dug out of a natural ground or be formed by a built embankment to encircle an area of retention basin (Setty, 2009). It is critical to plants some trees on and landscape surrounding land adjacent to the basin to resemble natural environment as much as possible. This naturally-look environment around the basin can provide habitats to urban wildlife as well as recreational area for general people (Ellis et al., 1991)

An ideal shape of the basin is elliptical or rectangular with a length-to-width ratio or 2:1 or greater to allow water flow in a preferred direction and to maximize treatment time as well as to prevent water stagnancy which is a breeding

area of mosquitoes (Setty, 2009). The basin ideal depth is 1 to 2.5 meters to ensure biological water treatment processes by maintaining aerobic conditions without thermal stratification and to allow sunlight to reach the basin bottom (Setty, 2009). The diagram of typical retention basin is displayed in Figure 2.3.

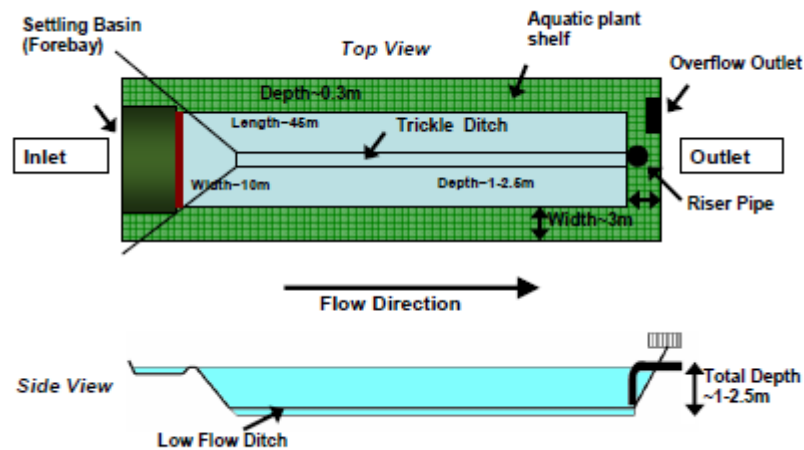


Figure 2.3 Typical Retention Basin Diagram.

Source: Setty, 2009.

Variants

A retention basin is one of flood alleviation measures that capture excessive storm water for a period of time or indefinitely. Variants of a retention basin include:

- 1) Detention basin, also known as dry pond, which temporarily holds excessive storm water for a particular period of time during and immediately after a runoff event before gradually releasing stored water to natural waterways until the pool is empty (Walesh, 1989; United States Environmental Protection Agency, 1999);
- 2) Infiltration basin which is intended to infiltrate excessive storm water stored in the basin through permeable basement, such as sand soil and organic materials, partially in order to recharge groundwater (Jovanovic, 2007; United States Environmental Protection Agency, 1999); and
- 3) Sedimentation basin which is designed to detain runoff to trap suspended solids, debris, and pollutants carried by runoff. This function can,

however, be one of a function served by retention basins and detention basins (Walesh, 1989).

Functions

Not only is a retention basin designed to mitigate flood, it is also designed to perform various beneficial functions as follows:

1) Flood alleviation: as previously stated, a retention basin plays a major role in storing excessive storm water runoff to reduce runoff, particularly an amount of flood peak, that enters a flood-protected area (Setty, 2009; Weerapon Taesombat, 1988).

2) Water quality improvement: while water runoff is being stored in a retention basin, physical and biological processes occurred in the basin will improve water quality before the basin gradually discharges storm water runoff downstream (University of California, Santa Barbara Donald Bren School of Environmental Science and Management, 2009). Physical processes which are induced by sheet flow characteristic of runoff retained in the basin, slow runoff velocities and hydraulic resistance created by aquatic plants play a major role in sedimentation that removes runoff-carried debris and sediment (Schueler et al., 1992; United Nations, 1999). Being a permanent water storage allows for biological processes that perform as biological and biochemical pollutant removal mechanisms with aquatic plants and microorganisms forming lake ecosystem (Setty, 2009; United States Environmental Protection Agency, 1999). Nutrients and pollutants dissolved in water, such as phosphate and ammonia, are reduced by biological uptake by aquatic plants and algae while metals are reduced by an uptake by plant tissue (Schueler, 1992; United States Environmental Protection Agency, 1999). In addition, a retention basin is usually equipped with a trash grate on either an inlet or an outlet or both to remove solid wastes carried by storm water runoff (Setty, 2009).

3) Water supply: a feature of permanent pool of water of a retention basin allows for a role played by a retention basin of water supply (Ellis et al., 1991; Setty, 2009).

4) As a pond that always contain a volume of water with naturally landscaped bank, a retention basin can also play a role as a recreational area (Walesh, 1989).

5) Retention basins can conserve nature and environment by provided habitats to wildlife through naturalistic landscapes (Ellis et al., 1991).

6) Groundwater recharge: some basins are designed to infiltrate storm water stored in the pool through permeable soils beneath the pool to recharge groundwater in the groundwater aquifer (Setty, 2009).

Suitable Location

When determining location of a retention basin, decision-makers have to consider several aspects of location that are appropriate to retention basins, including the followings:

1) Location relative to protected area: A retention basin should be located upstream of and in close proximity to a city, community or area that needs flood protection so that excessive runoff can be captured before it reaches the protected areas (Setty, 2009; Walesh, 1989; Weerapon Taesombat, 1988). A retention basin should be close to an area in need of flood protection because, in such a location, a retention basin would be able to control runoff from a large portion of a tributary area (Walesh, 1989). Such an ideal location, however, usually lies in a flood plain that covers large area and has high land prices, resulting in high costs of land acquisition and resettlement (Weerapon Taesombat, 1988).

2) Topography: retention basins may be constructed in both steep and plain regions. While it is appropriate to construct a retention basin with an embankment in a steep region, it is difficult to construct such a basin in a plain area due to depth to water table which ensures permanent stored water. Instead, in a flat area, a retention basin created by excavation is more appropriate. For basin outlets, weirs and open channel outlets are suitable to retention basins in flat area whereas drop structures are appropriate to those in steep areas (Jovanovic, 2007).

3) Soil characteristics: generally, highly permeable soils are strongly not suitable to be a base of retention basins as such soils induce high infiltration rate that would eventually empty the basin during dry seasons. Some

measures, however, can cope with the problems of high infiltration rate. Such measures include compacting of the bed, integrating clay to the existing highly permeable soils or utilizing a synthetic liner (Jovanovic, 2007).

4) Safety concerns: As with other types of water pool, retention basins expose people in close proximity to drowning hazard. Therefore, retention basins should not be placed near roadways where traffic accidents may occur and result in drowning. To prevent people who happen to be close to retention basins from being too close to the pool edge that has a risk of drowning, thick and prickly plants should be plentifully planted around the basins (Paine & Akan, 2004).

5) Other relative locations: because a retention basin can be a source of water supply (Setty, 2009), it should be located in an area that is accessible to perspective users; because a retention basin needs regular inspection, maintenance, and repair, a retention basin should be located in an area that is accessible to government officials or responsible staff by means of roadways or contiguous publicly owned land, etc. (Walesh, 1989).

Literature review of retention basins provides the researcher with an insight into retention basins: characteristics, functionality, and most importantly, factors affecting suitability of land for retention basins. This helps locate retention basins and examine how, and to what extent, prospective retention basins would prevent or mitigate flood in Muang Nakhon Ratchasima District. The next section reviews the primary tool used in this research, MIKE 11 in order to understand how the models work.

2.5 MIKE 11

MIKE 11 is a model developed by the Danish Hydraulic Institute (DHI) for runoff simulation and, thus, flood forecasting. MIKE 11 consists of several modules: Rainfall – Runoff Model (NAM-Model), Hydrodynamic module (HD-module), Advection-Dispersion module, Water Quality module, and Flood Forecasting module (FF module) (Bureau of Hydrology and Water Management Section of Hydrology, 2007; DHI Water & Environment, 2003). However, only three of those, including NAM-Model, HD-module, and FF module, can apply to the study of flood (Bureau of Hydrology and Water Management Section of Hydrology, 2007).

MIKE 11 is able to forecast flood of given return periods in the form of frequency distribution (Bureau of Hydrology and Water Management Section of Hydrology, 2007). Input data varies depending on the modules being used. Generally, MIKE 11 requires rainfalls, evaporation, water levels, water discharge rate, and water quality (Wastewater Management Authority, 2009). Geographic Information System (GIS) can now work with MIKE 11 to spatially display MIKE 11 simulation. This paper discusses NAM Model, MIKE 11 HD, FF module, and MIKE 11 GIS in more detail.

Rainfall-Runoff Model

This model simulates runoff volumes after rainfall events, represented by average rainfall of a watershed. The NAM Model simulates the physical features of the watersheds using mathematical model, thus, requiring data such as length of major river, average gradient, infiltration rate, etc. (Royal Irrigation Department, 2003; Dedkhard, 2002). The Model divides soil into four layers: snow storage, surface storage, root zone, and groundwater storage. The Model is based on water loss after rainfall events (Figure 2.4). Some amount of rainfall flows directly to watercourses as overland flow; some accumulates as humidity below soil surface; excessive humidity flows down to plant roots and aquifer; some rainfall evaporates; some groundwater in aquifer becomes baseflow and joins water in watercourses (Royal Irrigation Department, 2003).

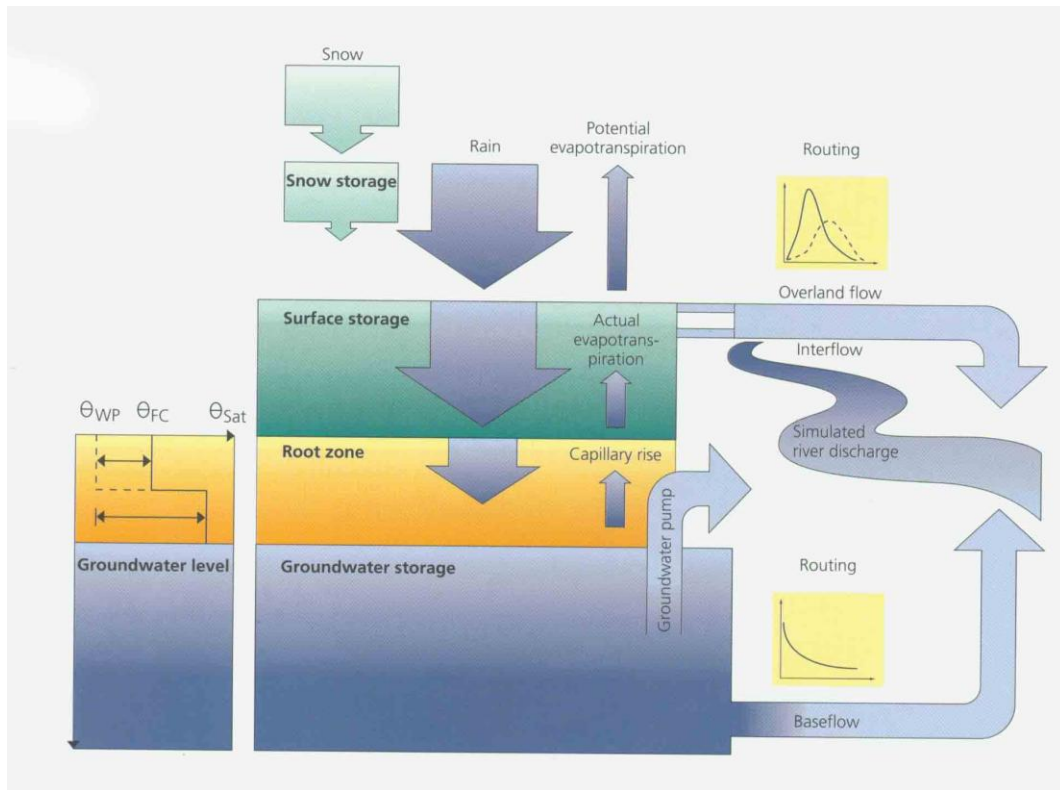


Figure 2.4 Schematic Diagram of the NAM Model.

Source: Royal Irrigation Department, 2003.

Hydrodynamic Module

The Hydrodynamic module (MIKE 11 HD or HD-module) is the primary module which includes several applications: flood forecasting and reservoir operation; flood control measure simulation; irrigation and surface draining operation; channel system design; and studies of tidal and storm surge in rivers and estuaries (DHI Water & Environment, 2003). MIKE 11 HD adopts the Implicit Finite Difference as a measure to simulate an unsteady flow in an open channel and its mouth (Royal Irrigation Department, 2003; Dedkhard, 2002). The primary input data of this module include the cross sections and runoff volume derived from the NAM Model. The HD-module also estimates a lateral flow (Dedkhard, 2002). It is critical for the users to specify the watershed limits: upstream, downstream, and possibly, lateral flow (Royal Irrigation Department, 2003).

MIKE 11 HD adopts the Saint – Venant Equations which have the following hypotheses (Royal Irrigation Department, 2011):

- 1) Flowing material is mass movement and cannot be compacted;
- 2) the flow is one-dimensional with steady velocity;
- 3) river bed gradient is low;
- 4) minimal change in parameter values along the length of river; and
- 5) the principal of hydrostatic pressure can apply.

The Saint – Venant Equations consist of two equations: Continuity Equation and Momentum Equation. The followings are details of the two equations (Mujumdar, 2001; Royal Irrigation Department, 2003).

Continuity Equation

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q$$

Momentum Equation

$$\frac{\partial Q}{\partial t} + \frac{\partial \left[\alpha \frac{Q^2}{A} \right]}{\partial x} + yA \frac{\partial h}{\partial x} + g \frac{Q|Q|}{C^2 AR} = 0$$

- Where Q is Discharge (m³/s)
 A is Flow area (m²)
 q is Lateral inflow (m³/s)
 h is Stage above datume (m)
 C is Chezy resistance coefficient (m^{1/2}/s)
 R is Hydraulic or resistance radius (m)
 A is Momentum distribution coefficient

Flood Forecasting Module

The Flood Forecasting module has an ability to simulate runoff volume in advance. The result of the simulation is updated by the updating mode, using actual water levels and/or water volumes, in order to minimize errors in the forecast (Royal Irrigation Department, 2003).

MIKE 11 GIS

With the technology of Geographic Information System or GIS, MIKE 11 can now be displayed on GIS software called ArcGIS. The application of MIKE 11 on GIS is known as MIKE 11 GIS. The results of MIKE 11 can be displayed on ArcGIS to generate flood maps. Besides results of MIKE 11, MIKE 11 GIS also needs topographic map, aerial photos, and satellite images in order to serve as a base map. The base map needs to be highly accurate and of high resolution so that flood map accurately reflects the actual flood (Royal Irrigation Department, 2003).

2.6 Related Researches

Nutjaree Charoenboonwanon (2009) determines flood retention areas by applying Geographic Information System to the analysis in a research entitled “*An Application of Geoinformatic Systems for Determining Flood Retention Areas: A Case Study of Nakhon Pathom Province*”. The study area is Nakhon Pathom Province which regularly sees flood with 300 million baht of damage in the flood of 2006. She identifies some characteristics of retention area, namely large depression area, low productivity, being located in close proximity to water sources and waterways, flood area, low appraisal land prices, non government/built-up area, and suitable soil conditions. Initial flood retention areas are generated by GIS through an intersection function. The study found that the initial retention areas are located in Bang Len, Kamphaeng Saen, and Don Tum Districts. A map of retention area is later created by DEM with elevations derived from GPS. The research found that low-lying area at 3 to 6 meters above mean sea level can offer a suitable retention area of 82 million square meters to 207 million square meters located in Bang Len District. In case of using rental paddy field to temporarily store runoff during the rainy season, the retention area can capture from 82 million m³ to 207 million m³ of water which can reduce 13% to 34% of flood water volume in 2006. In case of constructing a retention basin with the depths of 2.89 meters to 7.31 meters, a built retention basin can store 600 million m³ of water. This research very much suggests GIS as a tool to

locate suitable retention basins. Topography of Nakhon Pathom which is a large floodplain, however, is considerably different than that of Muang Nakhon Ratchasima which is a plateau with some small mountains. The study of Muang Nakhon Ratchasima also integrates a smaller number of factors affecting suitability for retention basins. In addition, the study of Muang Nakhon Ratchasima integrates weighting process into the analysis.

Jirattinart Thungngern (2004) applies MIKE 11, a mathematical model for flood forecasting developed by the Danish Hydraulic Institute, to the study of water level and discharge of Yom basin entitled "*A Study of Flood Alleviation of Yom River Basin Using Existing Natural Retention Area, Sukhothai Province*". She also assesses the role and suitability of existing natural retention areas in the Province of Sukhothai, including Bung Yai, Nong Pla Mor, Bung Mild, and Bung Sauy, and found that the existing natural retention basins in Sukhothai decreased water level in Muang District, Sukhothai Province by 2.22 meters. This study shows that flood-retarding areas can reduce flood levels.

Pet Techarat (2008) conducted a research entitled "*An Application of Mathematical Model for Flood Mitigation with Water Retention Areas a Case Study of Nakhon Pathom*", which is aimed at proposing an appropriate method to properly manage runoff by opening and closing sluice gates along Tachin River to channel excessive runoff to retention areas at a proper time to mitigate flood in Nakhon Pathom Province. The study found that flood in Nakhon Pathom was a result of a lack of draining channels rather than limited capacity of retention areas because excessive runoff leading to flood in 2006 ($73,715,632 \text{ m}^3$) did not exceed the total capacity of retention areas ($997,000,000 \text{ m}^3$). Pet recommends that draining channels connecting Tachin River with retention areas be improved to increase their draining capacity. This concern about not having adequate draining channels is a lesson previously learned and policy-makers should be aware of when adopting retention basins in any given areas. This study of Nakhon Ratchasima also takes into consideration this possible limitation of retention basins when locating suitable retention basins.

Theerapun Dedkhard (2002) utilizes MIKE 11 to study flood characteristics in Lam Phung Chu river basin with objectives of forecasting flood in the river basin and suggesting appropriate flood mitigation measures in the study titled

“Study on Flood Characteristics in Lam Phung Chu River Basin by MIKE 11 Model”. Using MIKE 11, he found that for 50 years return period, areas along 43 kilometers out of 69 kilometers of Lam Phung Chu River would be flooded with an average depth of 1.4 meters above the river banks. This study suggests three flood mitigation measures: channel modification, heightening of existing dikes, and reduction of weir crest.

The review of previous related researches suggests how GIS can be a tool to assess land suitability for retention basins, benefits of retention basins, and concerns about retention basins. It also suggests how MIKE 11, working together with GIS, can simulate flood and help suggest appropriate flood mitigation measures. Generally, this chapter reinforces understanding of retention basins as well as the study area, Lam Takhong Watershed. The next chapter discusses required data and methodology this research adopts to carry out the analysis.

CHAPTER III

MATERIALS AND METHODS

This study utilizes GIS and MIKE 11 as a tool to locate potential retention basin and its capacity in terms of flood mitigation. In doing so, certain data is required and methods need to be employed. This chapter discusses required materials and methodologies used for the analysis.

3.1 Materials

3.1.1 Data

Table 3.1 Required Data

Data	Source
GIS shapefiles: political boundaries, landmarks, contour lines, waterways and water bodies, watershed boundaries, and transportation routes	Department of Environmental Quality Promotion
DEM	ASTER GDEM
Soil series group	Land Development Department
Land Uses	Land Development Department
Geological map	Department of Mineral Resources
Amount of rainfall	Thai Meteorological Department
Evaporation rates	Thai Meteorological Department
River cross section profile of Lam Takhong	Royal Irrigation Department
Discharges and water levels	Royal Irrigation Department
Flooded areas of October 2010	GISTDA

3.1.2 Software

This study mainly employs MIKE 11 Hydrodynamic and Rainfall-Runoff to carry out the investigation. The study also needs other related software, including ArcGIS 9.3 to assess land suitability for retention basins.

3.2 Research Procedure

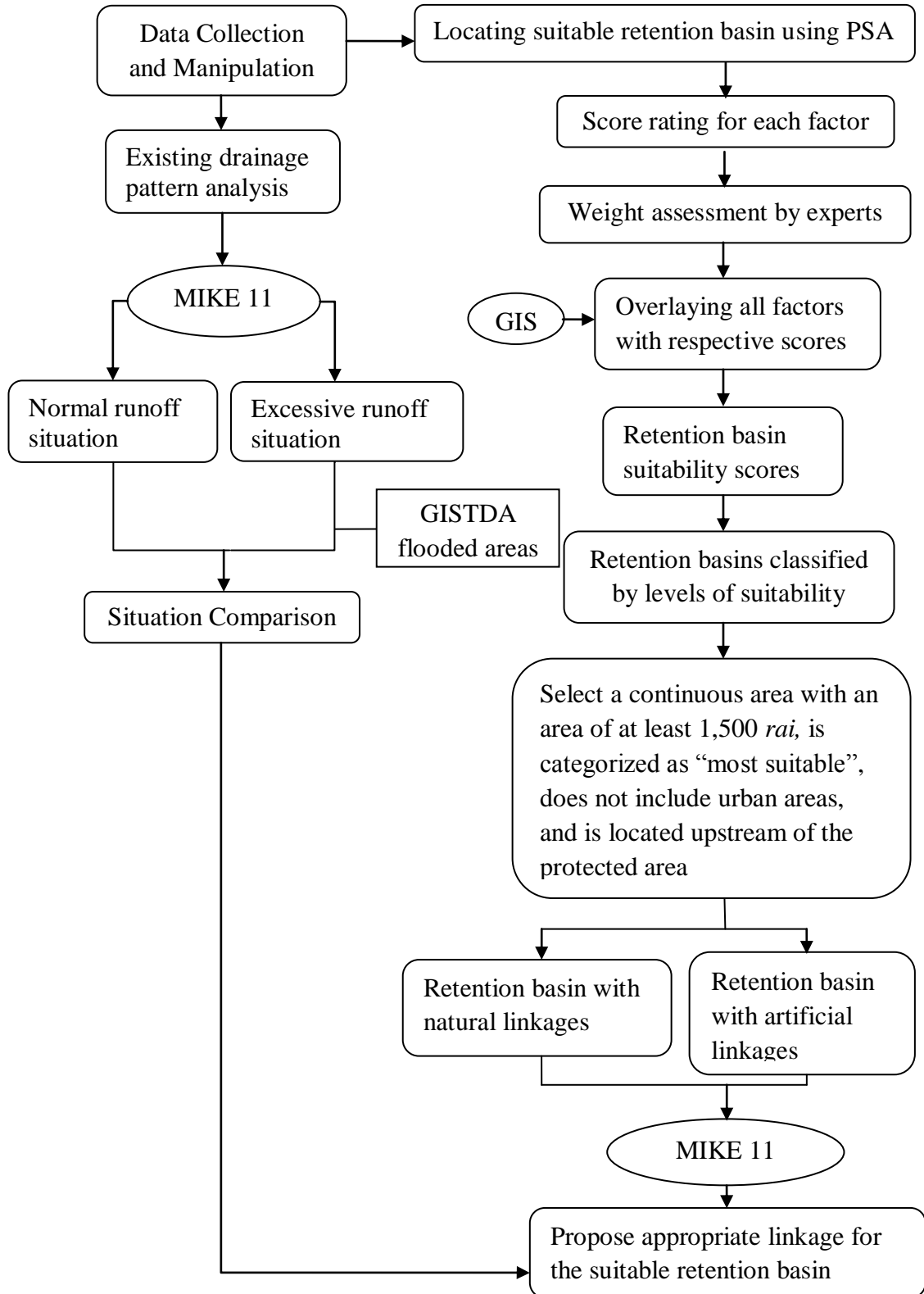


Figure 3.1 Research Procedure

3.3 Data Collection and Manipulation

1) Data for Locating Suitable Retention Basin

- DEM is the courtesy of ASTER GDEM.
- Soil permeability is determined by soil series group characteristics.
- Soil fertility is also determined by soil series group characteristics.
- Slope is classified into several classes according to steepness which is derived from contour lines.
- Distance to major watercourses is obtained by creating of buffers of several distances from major watercourses.
- Rock permeability is based on rock types which are obtained from geological map of the Department of Mineral Resources.
- Distance to protected area is obtained by creating of buffers of several distances around the Nakhon Ratchasima built-up area.
- Land uses are based on land use data of the Land Development Department.
- Urban areas are determined by land uses assigned as 'Urban' by the Land Development Department, and are excluded from the assessment.
- An area downstream of Nakhon Ratchasima built-up area is excluded from the assessment.

2) Inputs of MIKE 11

- Watershed boundary complies with the GIS shapefile of the Department of Environmental Quality Promotion.
- Discharge is collected from the Royal Irrigation Department. The study requires daily discharge data of year 2008 to year 2010.
- Water levels are collected from the Royal Irrigation Department. This study requires daily water level data of year 2008 to year 2010.
- Cross-section profile of water causes are obtained from the Royal Irrigation Department

- Amounts of rainfall and evaporation rates are collected from the Thai Meteorological Department. The study requires daily amount of rainfall of year 2008 to year 2010.

3.4 Analysis of Existing Drainage Pattern in Lam Takhong Watershed

In order to be able to examine the benefits of retention basins, one needs to study the state of existing drainage pattern in an area of interest. The very first section of this research employs MIKE 11 Hydrodynamic and Rainfall-Runoff to learn how existing drainage system in Lam Takhong Watershed played a role in draining runoff out of the Watershed during the Great Flood of 2010. However, in order for all simulations to be accurate, the MIKE 11 model needs to be calibrated by inputting MIKE 11 parameters of the last three years (2008 – 2010).

Two runoff situations, including normal runoff situations and excessive runoff situation, will be simulated by MIKE 11. The simulations reveal how increasing amounts of runoff in Lam Takhong Watershed result in changes in hydrological flow and, eventually, when and how floodplain in the Watershed gets inundated.

3.5 Locating of Suitable Retention Basins Using Potential Surface Analysis

ArcGIS 9.3 is used for an assessment of suitable retention basins that employs potential surface analysis (PSA). Of all factors taken into consideration, upstream location and non urban area are considered basic requirements for retention basins. Other areas not having any of these features are excluded from the assessment. The remaining factors, including soil permeability, soil fertility, slope, distance to major waterways, rock permeability, distance to protected area, and land uses, are assigned score ranging from 1 to 5, where 1 being less suitable for retention basins and

5 being most suitable for retention basins. A suitable area for retention basin should feature base soil that has poor permeability, low soil fertility, flat slope, impervious rock, and is located in close proximity to major watercourses and is reasonably far from protected area. To validate score assignment, this study has all score assignments verified by concerned government agencies.

Because different factors post difference significance, each factor has to be weighted before the overlay operations. Weight of each factor indicates how significant that factor is to the suitability for retention basins. Weight assignment is based on an assessment by concerned government agencies in the field of water resource management, including the Royal Irrigation Department, the Department of Water Resources, the Land Development Department, and the Department of Mineral Resources. Each concerned government agency gives a weight for each factor, ranging from 0 - 10, where 0 being least significant and 10 being most significant. All weights given by different entities for each factor are then used to calculate an average, resulting in an averaged weight for each factor. Raw scores are later multiplied by their respective weights to obtain weighted scores used for spatial analysis using GIS operations.

A spatial analysis called “Intersection” provided by ArcGIS 9.3 overlays these factors and the summation of weighted scores is obtained and recorded in an attribute table of the overlaid layer. The maximum score possible is 350 because there are 7 factors, each of which has a maximum weighted score of 50, taken into accounts. Suitability levels are classified into three levels: most suitable level, moderately suitable level, and least suitable level, with the moderately suitable level is around the average weighted score in a range of a standard deviation. Only a continuous area (1) covering an area of at least 1,500 *rai*, (2) with the suitability level of “most suitable”, (3) not including urban areas, and (4) located upstream of the protected area, is selected to be potential retention basin which is expected to alleviate flood in Muang Nakhon Ratchasima District. This expectation is then proven in the following section.

3.6 Comparison between Retention Basin with Natural Linkages and Retention Basin with Artificial Linkages

It is the goal of this study to compare capabilities between retention basin with natural linkages and retention basin with artificial linkages. This section employs MIKE 11 Hydrodynamic and Rainfall-Runoff to simulate water flow in Lam Takhong River with the presence of a retention basin on either one of its sides. The retention basin, however, can be implemented only with channels connecting them with Lam Takhong River which, in this study, are referred to as linkages. For natural linkages, this study selects appropriate natural streams that naturally connect the Lam Takhong River with the retention basin to be natural linkages. For artificial linkages, this study draws lines connecting retention basins with Lam Takhong River. These lines must avoid passing through urban areas and comply with the law of gravity. The artificial linkage is 20 meters in width and 2.5 meters in depth. The depth of potential retention areas obtained in 3.5 is hereby proposed to be 2.5 meters.

MIKE 11 simulates water flow in Lam Takhong Watershed which is modified by adding the suitable retention basin with each of the two types of linkages. Through this operation, the model suggests to what extent the modified drainage pattern with retention basins could have lowered the peak flood level of the Great Flood of 2010 in the City of Nakhon Ratchasima in Muang Nakhon Ratchasima District, comparing natural linkages with artificial linkages.

This last section leads to a conclusion. The study proposes the appropriate linkages for retention basin in Lam Takhong Watershed, based on the model created by MIKE 11 Hydrodynamic. The proposal is expected to best suit the drainage pattern of the Lam Takhong Watershed and to alleviate flood in Muang Nakhon Ratchasima District.

CHAPTER IV

RESULT AND DISCUSSION

Through all the processes of analysis this study utilizes, the following results can be achieved. The first section of this chapter explores and discusses how the existing drainage pattern in Lam Takhong Watershed plays a role in draining runoff off Lam Takhong Watershed, how it led to the Great Flood of 2010. It then lays all factors influencing retention basin suitability in terms of location, which leads to classification of land suitability for flood retention area. The last section of this chapter discusses how suitable retention basin, the continuous, large area, could help Muang Nakhon Ratchasima District mitigate flood, the process which is completed by modeling through MIKE11 Hydrodynamic of the great flood of 2010. The results compare two types of linkage: natural linkage and artificial linkage.

4.1 Existing Drainage Pattern in Lam Takhong Watershed

Lam Takhong Watershed has Lam Takhong River as its major waterway. Running relatively in the middle of the Watershed, the Lam Takhong River receives runoff from the Lam Takhong Dam and additional runoff from its tributaries. The Lam Takhong Watershed drains runoff from west southwest to east northeast. With different volume of runoff, the consequences of drainage capacities tend to be different.

4.1.1 Existing Drainage Pattern in Lam Takhong Watershed in Normal Situation

Normal situation refers to a situation in which there is no flood occurring in the Lam Takhong Watershed. This study chooses the year 2009 as normal situation.

Runoff in the Lam Takhong Watershed originates from rainfall. Rainfall at Nakhon Ratchasima Station in 2009 is shown on Figure 4.1.

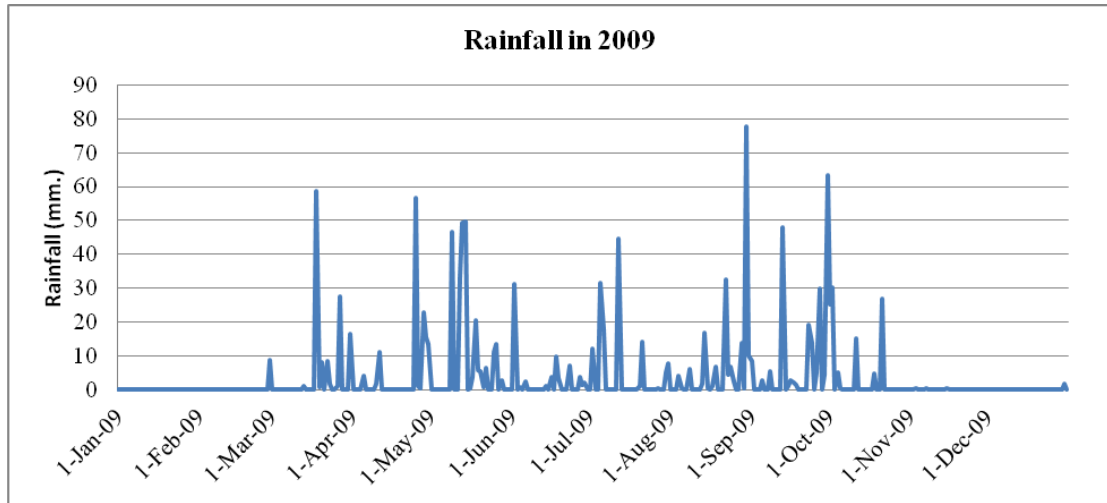


Figure 4.1 Rainfall in Lam Takhong Watershed in 2009 as Measured at Nakhon Ratchasima Station

Source: Thailand Meteorological Department, 2010.

Figure 4.1 shows that the wet season of the Lam Takhong Watershed starts from April and terminates at the end of October. After that the dry season takes place and ends at the end of March right before the wet season reclaims its role. Runoff volume in Lam Takhong River should correspond with rainfall. However, due to water management scheme, the Lam Takhong Dam interferes with the flow of runoff, resulting in discharges, which was measured at Station M.177 (Figure 4.3), shown in Figure 4.2 which did not completely correspond with amount of rainfall as discharges were still relatively high during the dry season.

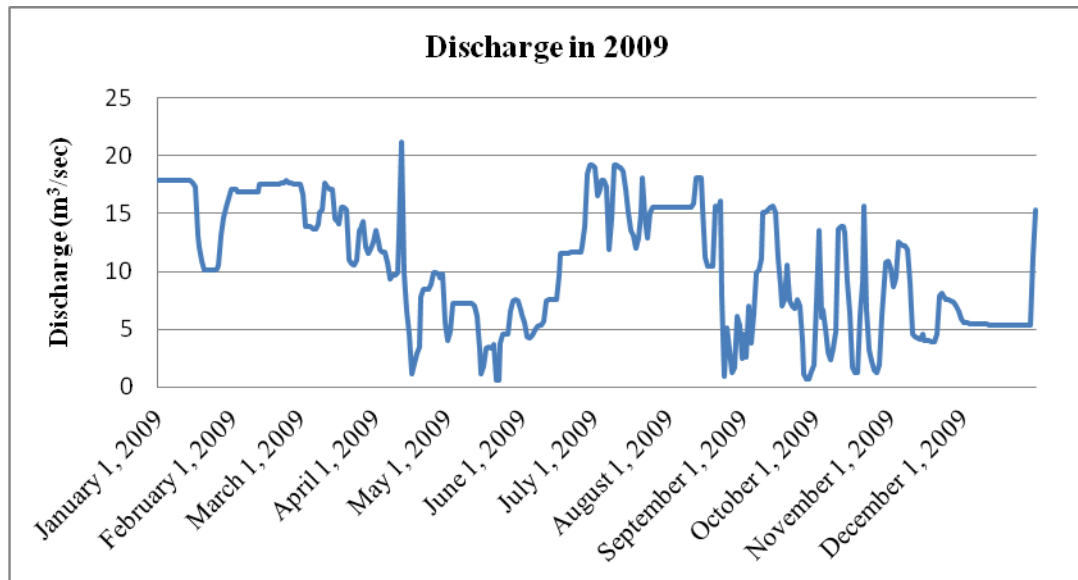


Figure 4.2 Daily Discharges at Station M.177 in 2009

Source: Royal Irrigation Department, 2011.

Figure 4.2 shows the discharges as measured at Station M.177, which is twelve kilometers downstream from the Lam Takhong Dam in Sikhiu District (Figure 4.3). At Station M.177, the lowest discharge in 2009 took place on May 22nd, 2009 with the discharge of only 0.61 m³/second. A MIKE 11 model simulating the situation in 2009 suggests that the Lam Takhong River in Muang Nakhon Ratchasima District also reached the lowest level at the end of May 2009. The greatest discharge in 2009 took place on April 12th, 2009 with the discharge of 21.16 m³/second. However, the MIKE 11 model suggests that the Lam Takhong River in Muang Nakhon Ratchasima District reached the highest level early in October 2009 with the level of slightly higher than 178 meters, about 1.5 meters below the banks. Evidently, no flood occurred in 2009.

4.1.2 Existing Drainage Pattern in Lam Takhong Watershed in Flooding Situation

Lam Takhong Watershed has had a drainage system that evidently could not handle excessive runoff bringing about by the depression trough in October 2010. This section analyzes how the drainage system led to the Great Flood of 2010 by creating a hydrodynamic model in MIKE 11.

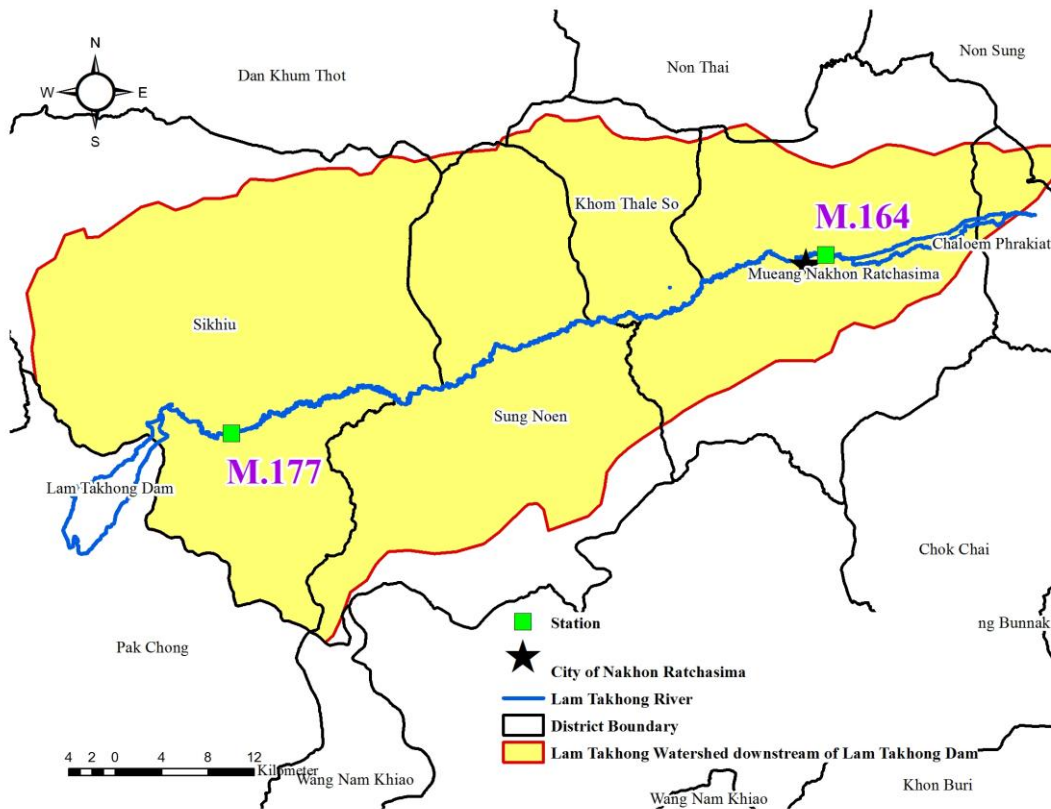


Figure 4.3 Location of Station M.177 in Sikhiu District

Source: Royal Irrigation Department, 2011.

Figure 4.4 compares rainfall patterns of 2009, 2010, and the 20-year averaged rainfall. Total annual rainfall amount of 1,212.5 millimeters in 2009 and the 20-year averaged rainfall tend to be better distributed throughout the year with two peaks, whereas most of the total annual rainfall amount of 1,386.2 millimeters in 2010 occurred only in September and October, the only outstanding peak of the year. The concentration of rainfall in September and November 2010 dumped too much rain to the Lam Takhong Watershed, leaving too much runoff for it to hold within its water channels. Furthermore, rainfall fallen in 2010 was greater than that fallen in 2009 by 173.7 millimeters (14.33 % greater) and even greater than the 20-year averaged annual rainfall of 1,085.89 millimeters by 300.31 millimeters which account for 27.66%. Flood in 2010 could unarguable be attributed to the shift of rainy season closer to the end of the year.

More specifically, rainfall in 2010 also concentrated its rainfall in a day. Figure 4.5 shows that the outstandingly heaviest rainfall occurred on October 15th, 2010 when the Watershed received a total rainfall amount of 116.3 millimeters in a day, the greatest amount of rainfall fallen in a day in 2010 (Thailand Meteorological Department, 2010). Although receiving the greatest amount of rainfall in 2010, September of 2010 did not witness the same rainfall concentration in a day (Figure 4.6) because rainfall was better distributed throughout the month as compared to October of 2010. Therefore, the Lam Takhong Watershed could drain runoff downstream without flood occurrence in September 2010.

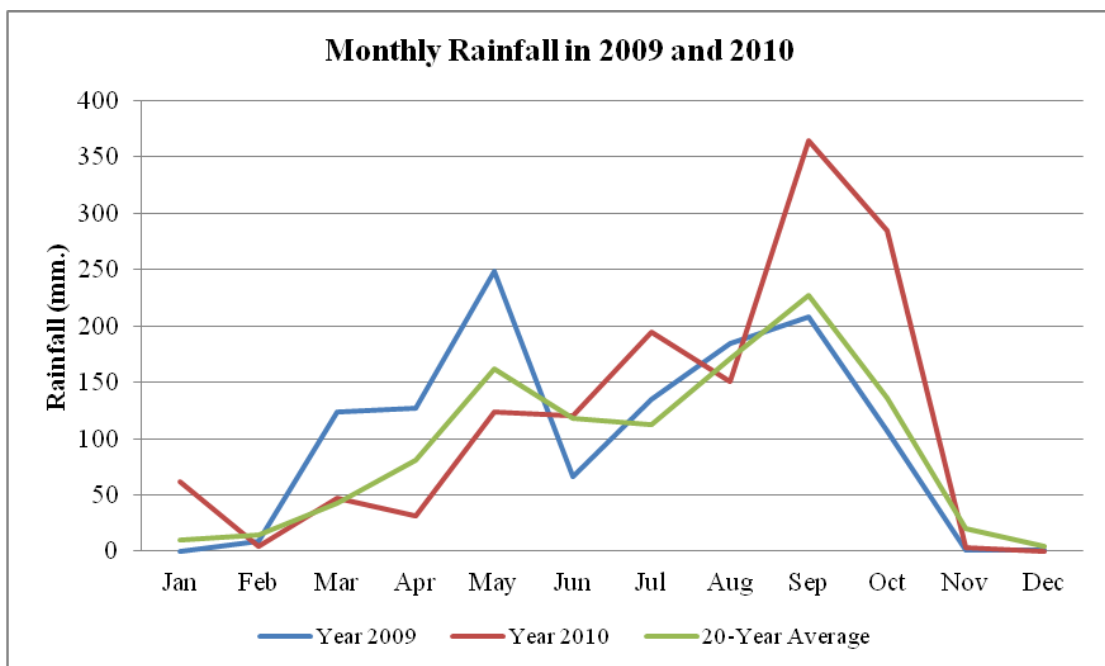


Figure 4.4 Rainfall Distribution in 2009 and 2010 and the 20-Year Averaged Rainfall
Source: Thailand Meteorological Department, 2010.

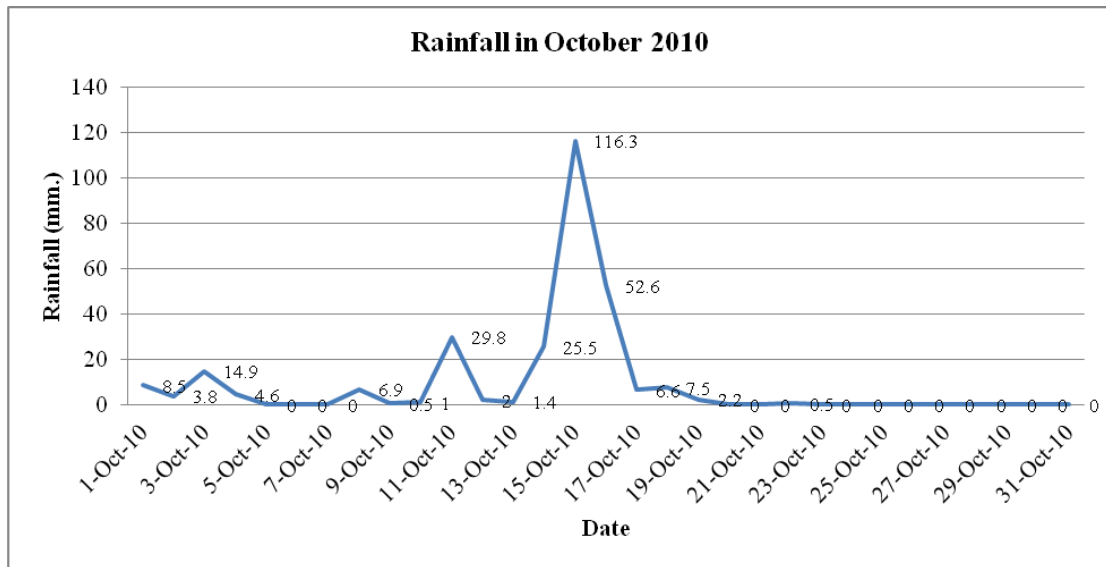


Figure 4.5 Rainfall measured at Nakhon Ratchasima Station in Lam Takhong Watershed in October of 2010

Source: Thailand Meteorological Department, 2010.

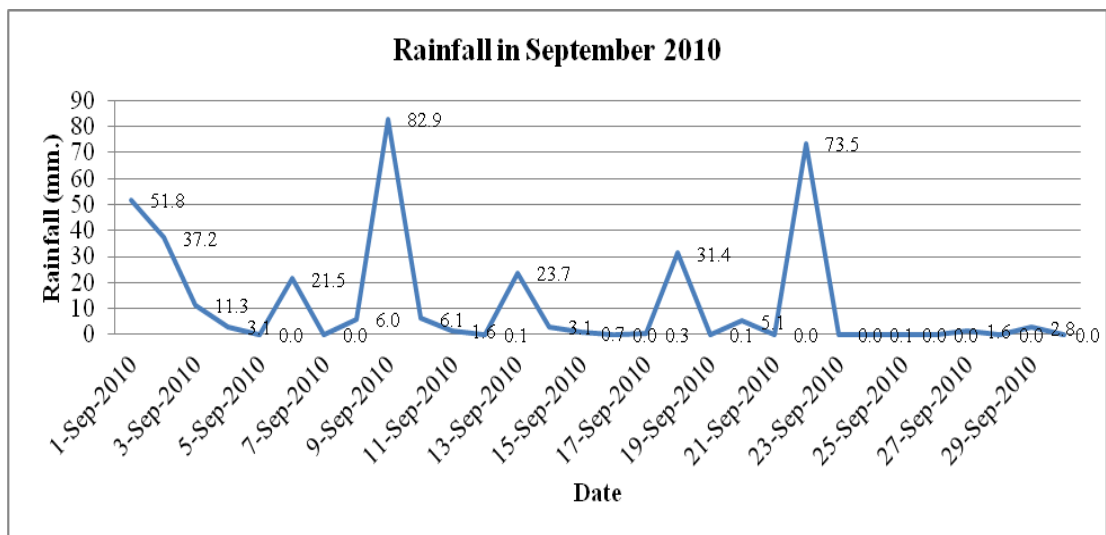


Figure 4.6 Rainfall measured at Nakhon Ratchasima Station in Lam Takhong Watershed in September of 2010

Source: Thailand Meteorological Department, 2010.

Considering water levels and discharges in the Lam Takhong River, they tend to correspond with rainfall. However, it took some time for them to reach the highest levels. Daily discharges in 2010 are shown in Figure 4.7. The Figure suggests

the outstandingly great volume of runoff late in October 2010, the time of the Great Flood of 2010, with the highest discharge reaching 97.64 m³/second on October 21st, 2010. In order to study flood situation in Muang Nakhon Ratchasima District, this study selects cross section at chainage 111,800 meters (km 111.8) to represent Muang Nakhon Ratchasima District as its both banks are of uniform height and it is located in a close proximity of Mitrapab Road (Highway 2) and the City of Nakhon Ratchasima. The location of chainage 111,800 meters is displayed in Figure 4.8. At chainage 111,800 meters in Muang Nakhon Ratchasima District, Figure 4.9 shows daily water levels (the blue lines) on selected days in October 2010. The Figure suggests that water in Lam Takhong River reaches the highest level on October 22nd, 2010, seven days after rainfall peak.

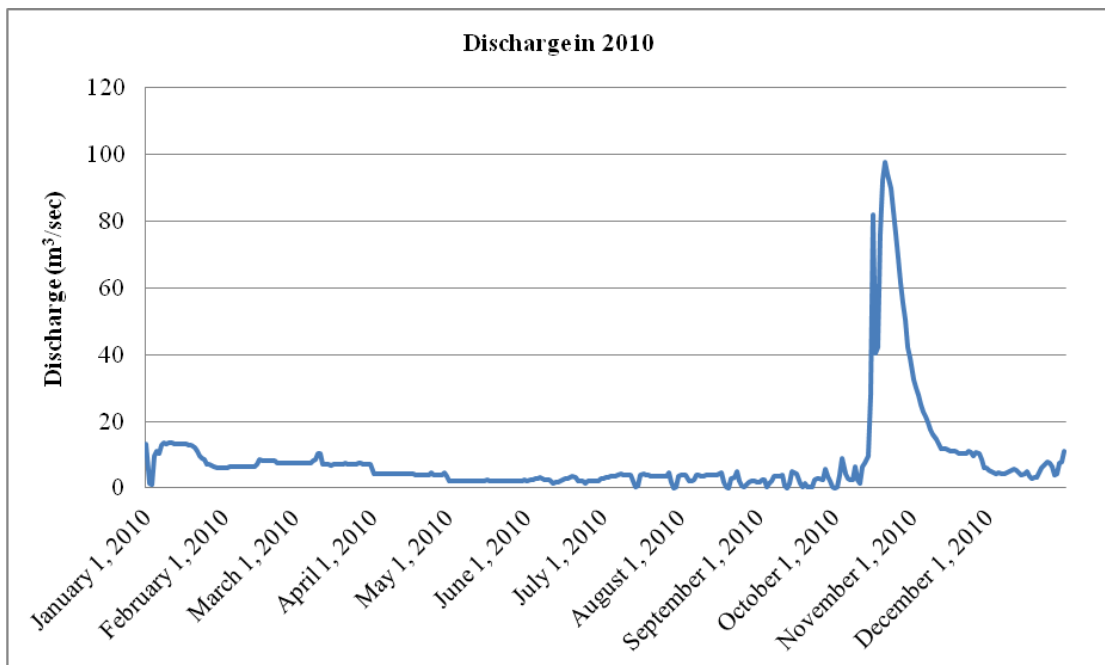


Figure 4.7 Daily Discharges at Station M.177 in 2010

Source: Royal Irrigation Department, 2011.

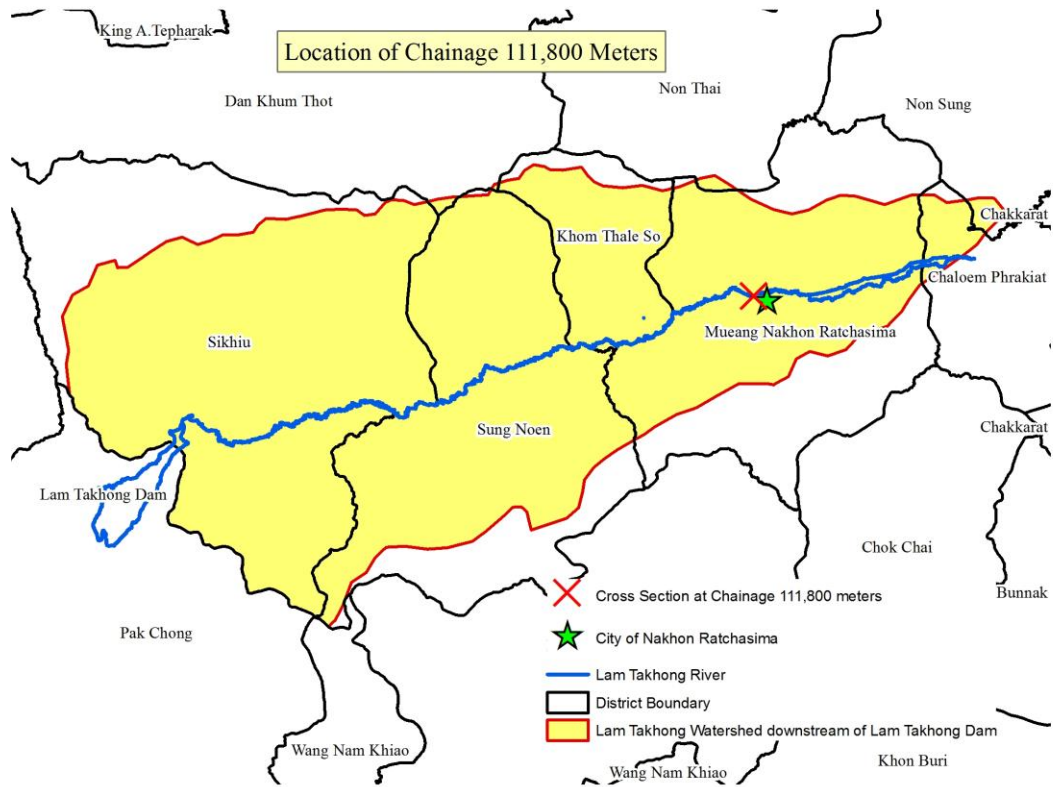


Figure 4.8 Location of Chainage 111,800 Meters

Source: Department of Environmental Quality Promotion, 2004.

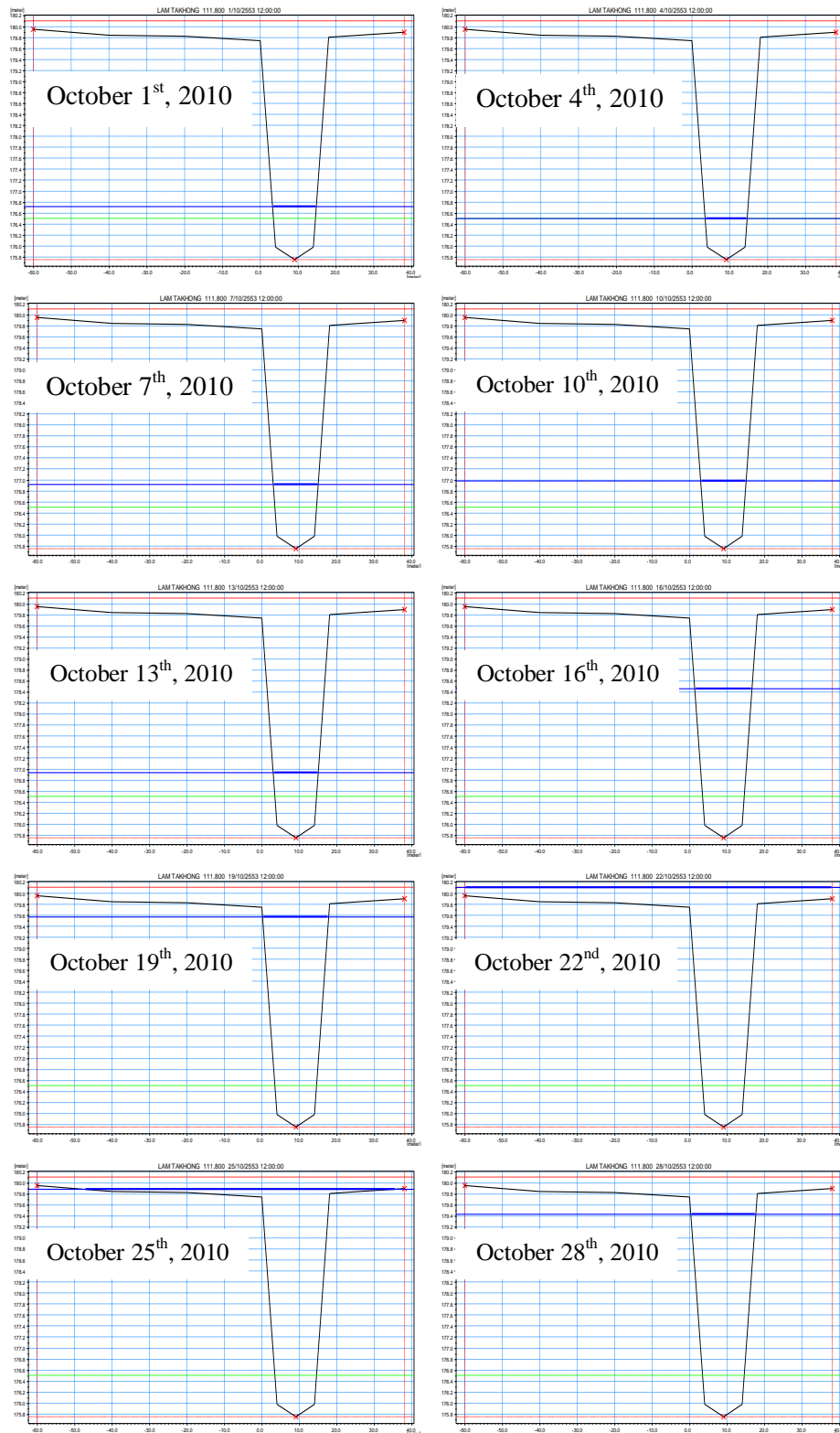


Figure 4.9 Daily Water Levels on Selected Days in October 2010 in Muang Nakhon Ratchasima District

Source: Royal Irrigation Department, 2011; MIKE 11 Model.

According to GISTDA (2010), areas downstream of the Lam Takhong Dam in the Lam Takhong Watershed first witnessed an overflow of the Lam Takhong River of the year on October 16th, 2010, one day after the heaviest rain of the season, in the area of Sikhiu District. The flood continued downstream to Sung Noen, Kham Thale So, and Muang Nakhon Ratchasima Districts. By October 20th, 2010, the Lam Takhong River at chainage 111,800 meters witnessed the first overflow, when the water level reached 179.86 meters (Figure 4.10), exceeding the left bank by 0.116 meter and the right bank by 0.055 meter, with the discharge of 75.815 cubic meters per second. As a result, the flood had well inundated Muang Nakhon Ratchasima District (Figure 4.11) with flooded areas in Muang Nakhon Ratchasima District within the Lam Takhong Watershed of 31,418.621 *rai*. It should be noted that on October 20th, 2010, flood actually inundated areas along sides of the Lam Takhong River from the Lam Takhong Dam to Muang Nakhon Ratchasima District. However, due to certain reasons, GISTDA could not obtain flooded areas data around the area immediately downstream of the Lam Takhong Dam on that day, resulting in an inaccurate flood map in Figure 4.11, particularly on the west side of the area shown on the map.

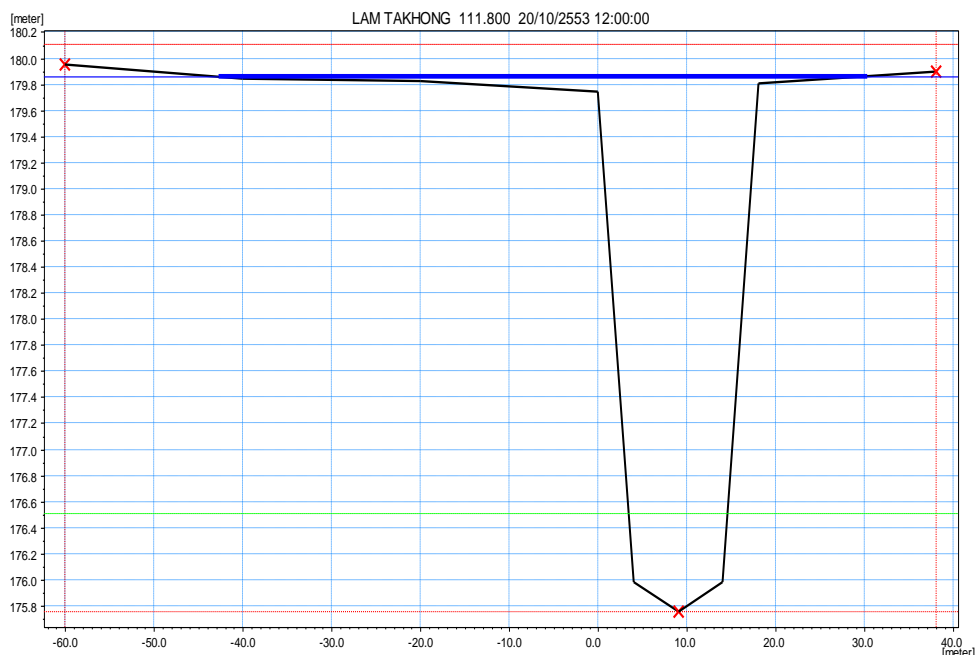


Figure 4.10 Water Level at Chainage 111,800 Meters of Lam Takhong River on October 20th, 2010

Source: MIKE 11 Model.

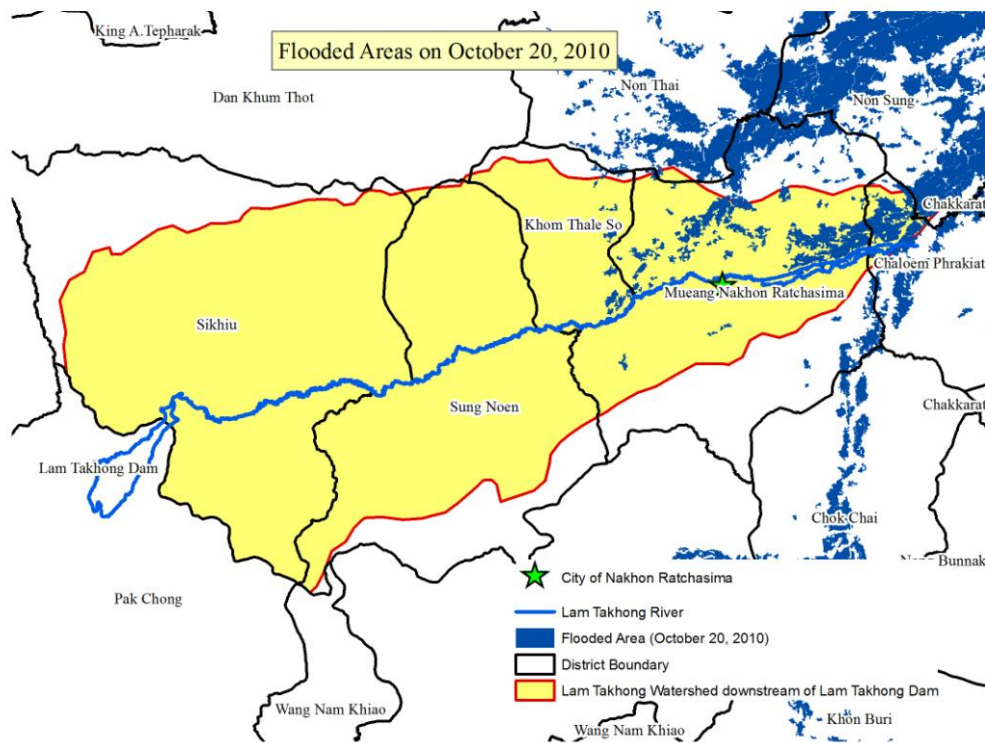


Figure 4.11 Flooded Areas in Lam Takhong Watershed on October 20th, 2010

Source: Department of Environmental Quality Promotion, 2004; GISTDA, 2010.

By October 23rd, 2010, the water level reached 180.075 meters (Figure 4.12) with the discharge of 94.054 cubic meters per second. The increase in water level and discharge resulted in larger areas of flood. Flooded areas in the Lam Takhong Watershed in Muang Nakhon Ratchasima District covered 31,851.874 *rai* on that day (Figure 4.13).

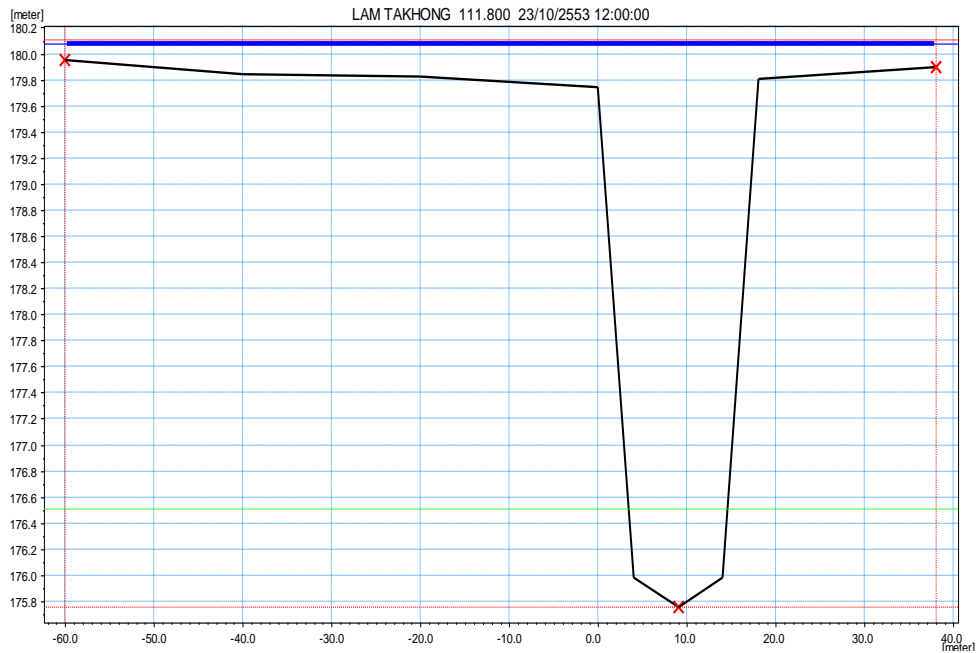


Figure 4.12 Water Level at Chainage 111,800 Meters of Lam Takhong River on October 23rd, 2010

Source: MIKE 11 Model.

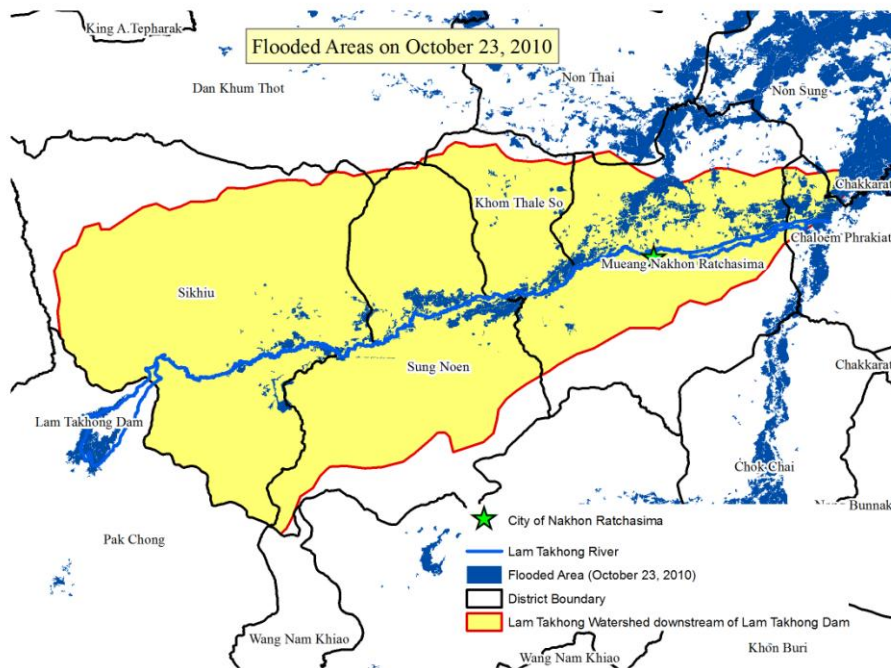


Figure 4.13 Flooded Areas in Lam Takhong Watershed on October 23rd, 2010

Source: Department of Environmental Quality Promotion, 2004; GISTDA, 2010.

The flood then gradually receded from the Lam Takhong Watershed. By October 30th, 2010, water level in Muang Nakhon Ratchasima District fell to 179.081, 0.663 meter below the banks of Lam Takhong River (Figure 4.14). The discharge also decreased to 49.796 cubic meters per second. Consequently, flooded areas in Muang Nakhon Ratchasima District within the Lam Takhong Watershed shrank to 21,801.429 *rai* (Figure 4.15).

Table 4.1 and Figure 4.16 show the positive relationship between water levels, discharges and flooded areas, suggesting that the greater the volume of runoff, the larger the flooded areas. A linear regression is also formulated and displayed in Figure 4.16, asserting the positive relationship between discharges and flooded area. The linear regression takes the form of $y = 236.81x + 11018$.

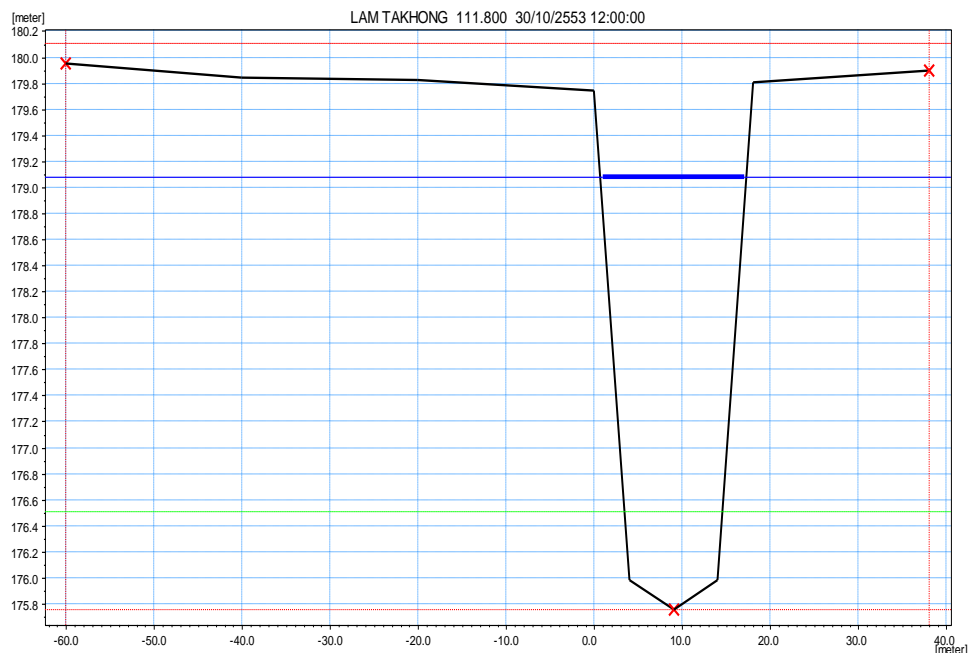


Figure 4.14 Water Level at Chainage 111,800 meters of Lam Takhong River on October 30th, 2010

Source: MIKE 11 Model.

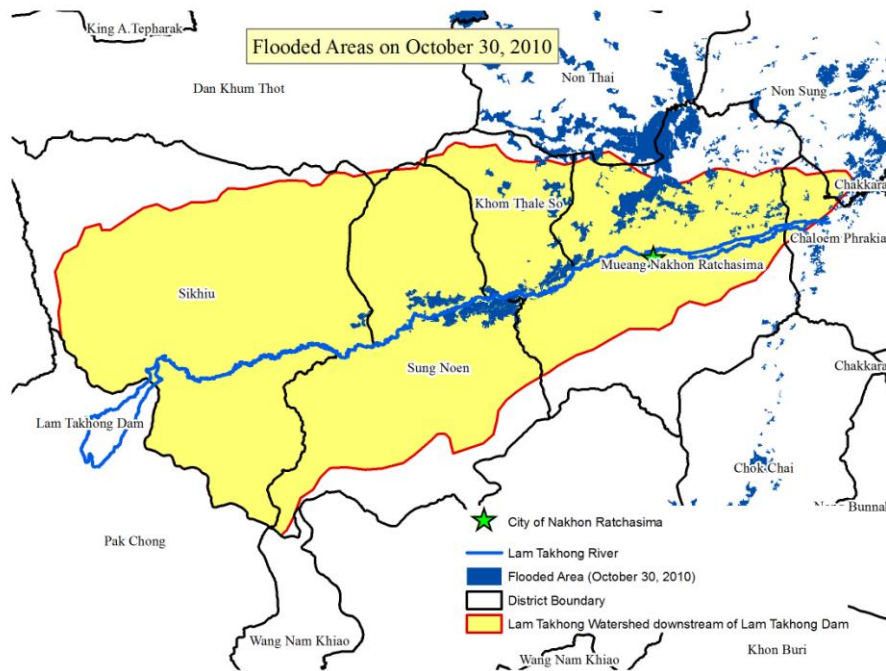


Figure 4.15 Flooded Areas in Lam Takhong Watershed on October 30th, 2010
 Source: Department of Environmental Quality Promotion, 2004; GISTDA, 2010.

Table 4.1 Water levels, Discharges and Flooded Area in Muang Nakhon Ratchasima District

Date	Water Level (m)	Discharge (m ³ /sec)	Flooded Area (rai)
October 20, 2010	179.86	75.815	31,418.621
October 23, 2010	180.075	94.054	31,851.874
October 30, 2010	179.081	49.796	21,801.429

Source: GISTDA, 2010; MIKE 11 Models.

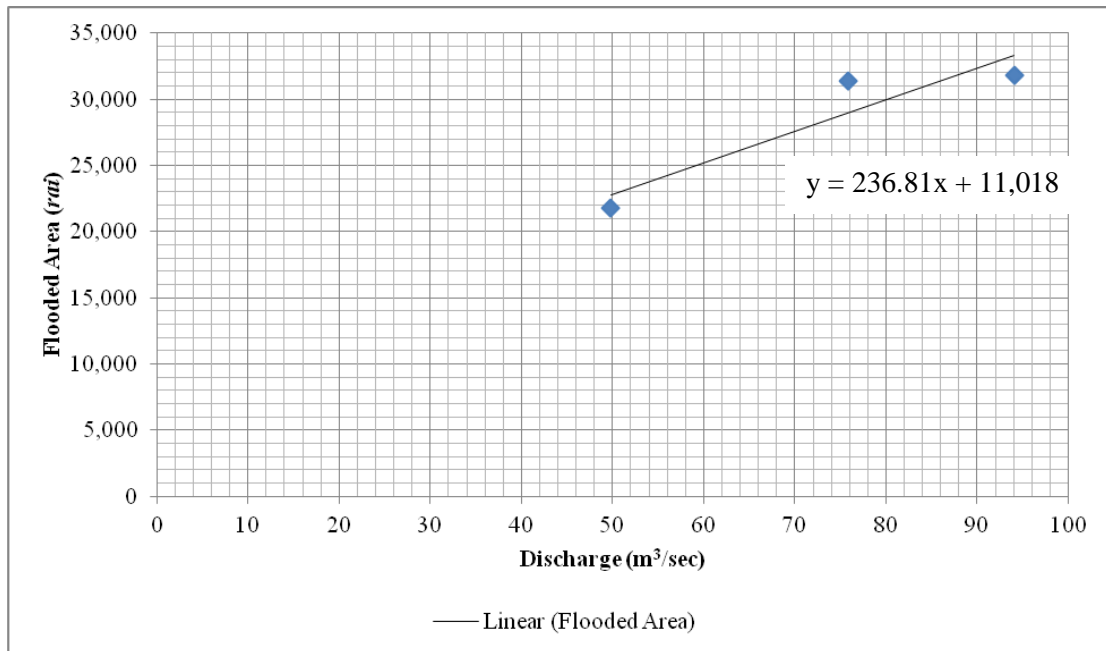


Figure 4.16 Positive Relationship between Discharges and Flooded Area

Source: GISTDA, 2010; MIKE 11 Models.

4.2 Factors Influencing Flood Retention Basin Suitability

As mentioned in Chapter III, factors are grouped into two groups: basic requirements, which are very essential, and other factors which are assigned ranging scores according to their suitability for retention basin. The study first explores those of basic requirements.

4.2.1 Basic Requirements

1) Non urban area is any area not determined by land use data of the Land Development Department as “urban”. Urban areas are displayed in Figure 4.17, and are assigned zero score.

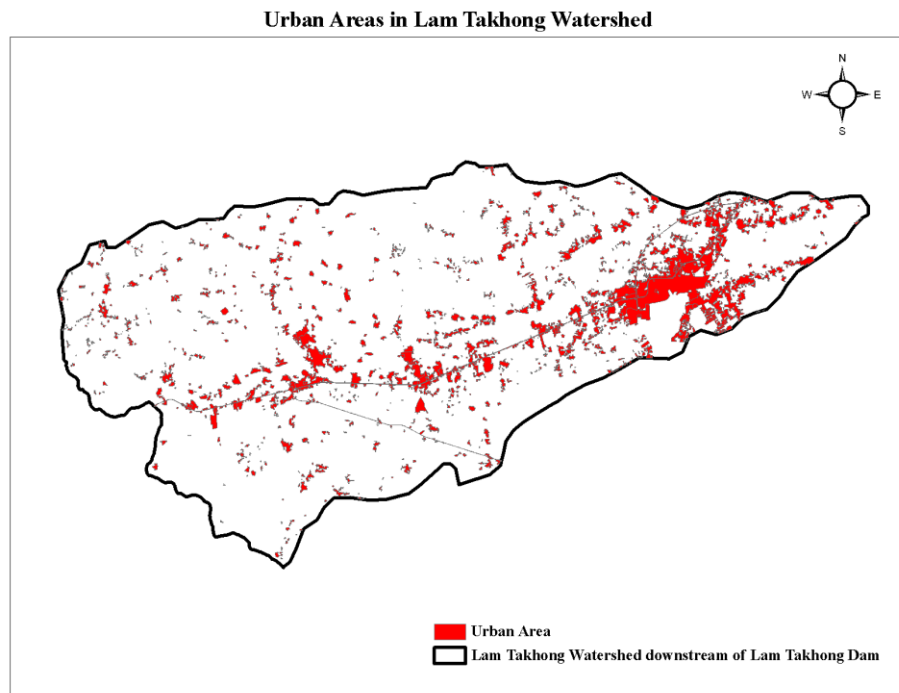


Figure 4.17 Urban Areas in Lam Takhong Watershed

Source: Land Development Department, 2008.

2) Upstream location of the City of Nakhon Ratchasima is an essential feature of potential retention basin which is expected to alleviate flood in Muang Nakhon Ratchasima District. Therefore, it needs to be located upstream of the protection area so that it can capture some excessive runoff before it enters the protection area. Upstream area of the City of Nakhon Ratchasima is shown in Figure 4.18.

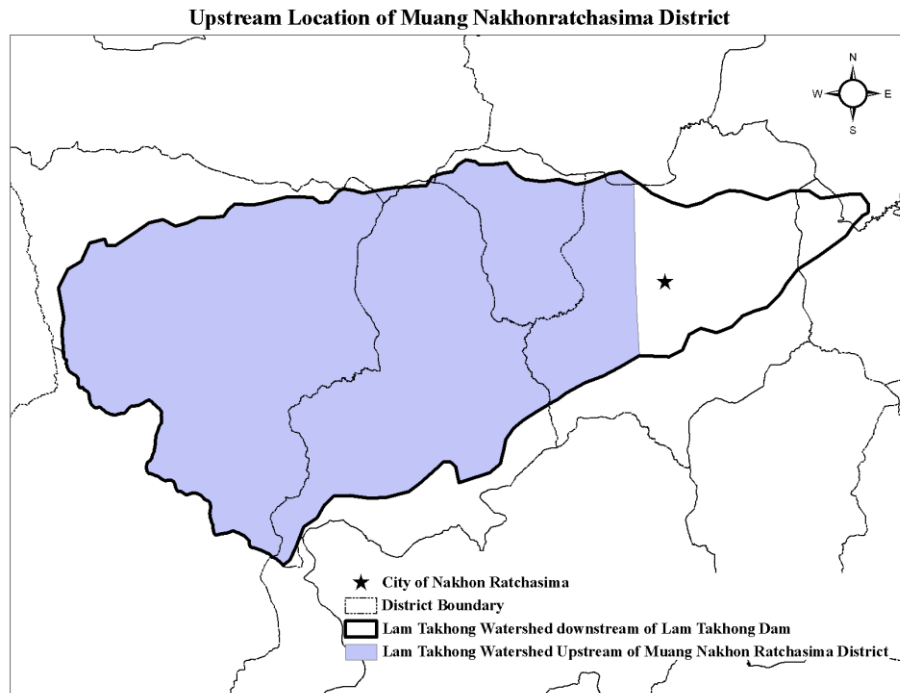


Figure 4.18 Upstream Area of the City of Nakhon Ratchasima

Source: Department of Environmental Quality Promotion, 2004.

4.2.2 Other Requirements

These requirements are factors that are not vital for retention basins but are those characteristics retention basins should feature. Therefore, these factors are assigned score according to their retention basin suitability. These factors include:

1) Slope are classified into five classes, ranging from very steep (gradient of greater than 20%) to flat (gradient of less than 1%). Classification and score assignment is shown in Table 4.2. Slope in Lam Takhong Watershed is displayed in Figure 4.19.

Table 4.2 Slope and Score Assignment

Slope	Score
Less than or equal to 1%	5
Greater than 1% and less than or equal to 2%	4
Greater than 2% and less than or equal to 10%	3
Greater than 10% and less than or equal to 20%	2
Greater than 20%	1

Source: Concerned Government Agency Assessment, 2011 (Department of Water Resources).

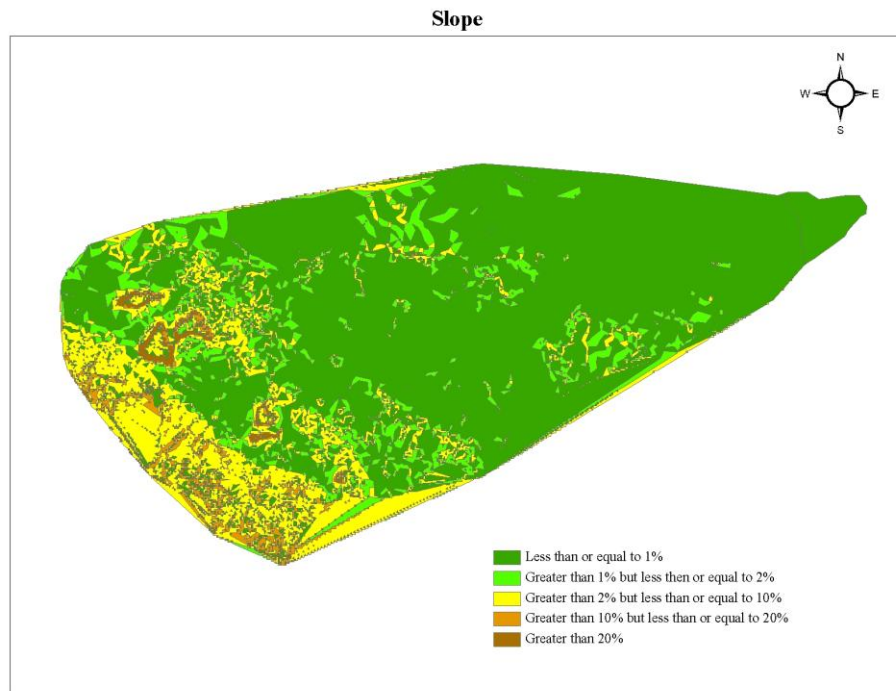


Figure 4.19 Slope in Lam Takhong Watershed

Source: Department of Environmental Quality Promotion, 2004.

2) Soil fertility is also classified into five groups. Soil with low fertility is best suited to be a location of retention basins. Classification and score assignment is laid out in Table 4.3. Soil fertility in Lam Takhong Watershed is displayed in Figure 4.20.

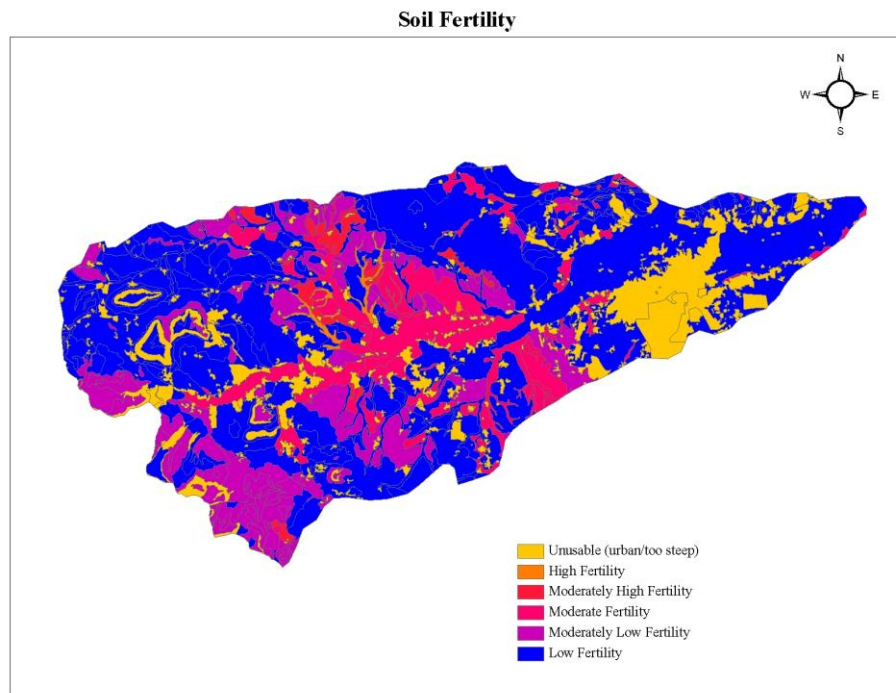


Figure 4.20 Soil Fertility

Source: Land Development Department, 2008.

3) Soil permeability should be poor underneath retention basins. Classification and score assignment is shown in Table 4.3. Soil permeability in Lam Takhong Watershed is displayed in Figure 4.21.

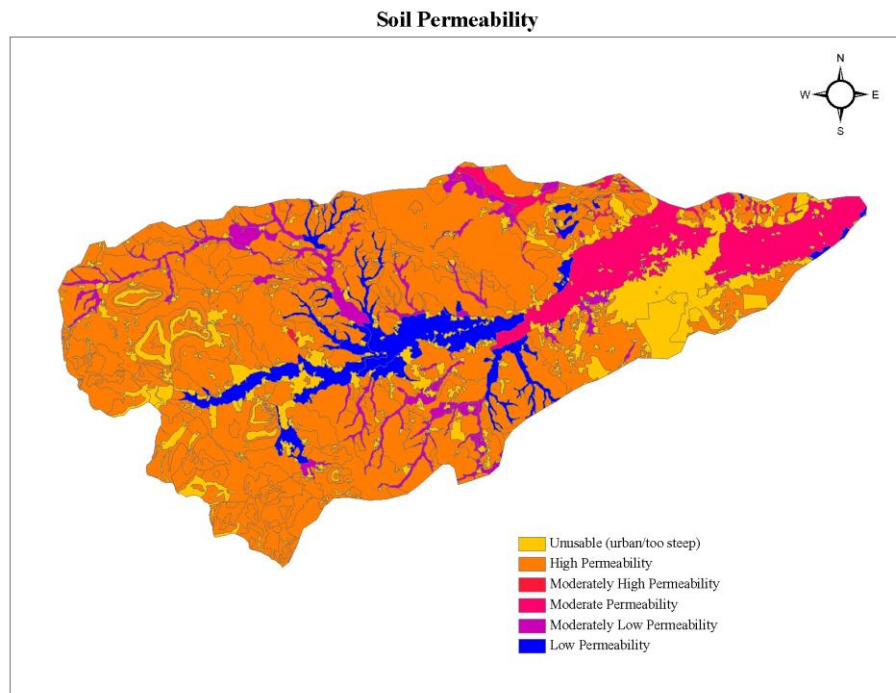


Figure 4.21 Soil Permeability

Source: Land Development Department, 2008.

Table 4.3 Soil Series Group and Score Assignment

Soil Series Group	Fertility	Fertility Score	Permeability	Permeability Score
1	High	1	Moderately poor - poor	5
4	Moderate	3	Moderately poor - poor	5
7	Moderate	3	Moderately poor - poor	5
18	Moderate	3	Moderately poor	4
20	Poor	5	Moderately poor – moderately high	3
22	Poor	5	Moderately poor	4
28	Moderate – high	2	Moderately high - high	1
31	Moderate	3	Moderately high - high	1
35	Poor	5	High	1
36	Moderate – poor	4	High	1
37	Poor	5	Moderately high	2
40	Poor	5	High	1
41	Poor	5	Moderately high - high	1
44	Poor	5	Moderately high - high	1
48	Moderate – poor	4	High	1
52	Moderate – high	2	High	1
55	Moderate – high	2	Moderately high - high	1
56	Poor	5	High	1

Soil Series Group	Fertility	Fertility Score	Permeability	Permeability Score
35/56	Poor	5	High	1
38/4	Moderate	3	Moderate	3
41/40	Poor	5	Moderately high - high	1
41/44	Poor	5	Moderately high - high	1
47/55	Moderate	3	Moderately high - high	1
48/56	Moderate – poor	4	High	1
56/48	Moderate – poor	4	High	1
62	Unsuitable (high gradient or high elevation)	0	Unsuitable (high gradient high elevation)	0

Source: Concerned Government Agency Assessment, 2011 (Land Development Department).

4) Rock permeability is also an important factor as is soil permeability to suitability for being a location of retention basin. Rock permeability classification along with its score assignment is shown in Table 4.4. Rock permeability in Lam Takhong Watershed is display in Figure 4.22.

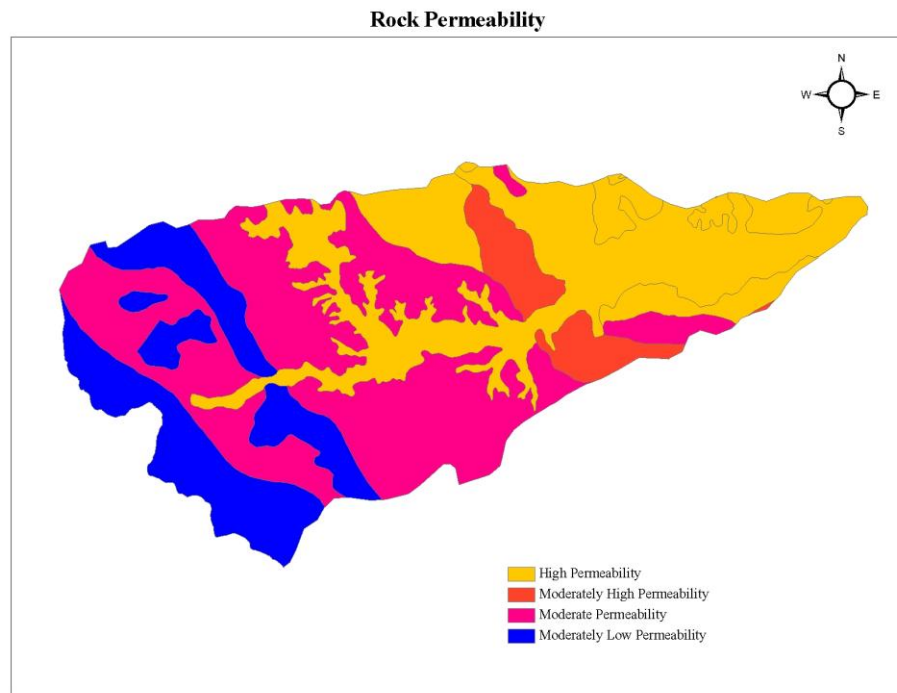


Figure 4.22 Rock Permeability

Source: Department of Mineral Resources, 2004.

Table 4.4 Rock Permeability and Score Assignment

Rock Group	Formation	Rock Type	Score
Qa	Alluvial Deposits	Fluvial deposits	1
Qt	Terrace Deposits	Terrace deposits	2
KTms	Maha Sarakham	Siltstone	1
Kkk	Khok Kruat	Siltstone and sandstone	3
Kpp	Phu Phan	Sandstone	4
Ksk	Sao Khua	Siltstone and sandstone	3
Jkpw	Phra Wihan	Quartzitic sandstone	4

Source: Concerned Government Agency Assessment, 2011 (Department of Mineral Resources); Department of Mineral Resources, 2004.

5) Land use is a very crucial factor as it practically designates which areas or even which parcels can be used for retention basins. Land use classification and its score assignment are shown in Table 4.5. Land uses in Lam Takhong Watershed is displayed in Figure 4.23.

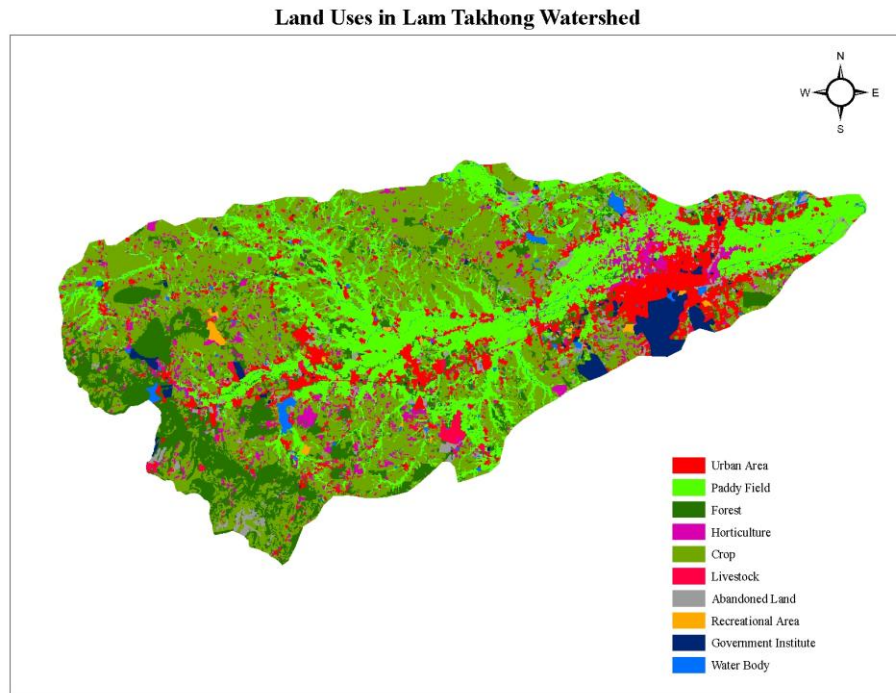


Figure 4.23 Land Uses

Source: Land Development Department, 2008.

Table 4.5 Land Uses and Score Assignment

Land Use	Score
Abandoned land	5
Water body	4
Recreational area	3.33
Paddy field	2.67
Horticulture	1.33
Crop	1
Forest	1
Government institute	0.3
Urban area	0

Source: Concerned Government Agency Assessment, 2011 (Land Development Department, Royal Irrigation Department, Department of Water Resources)

6) Distance to major waterway is also very important when planners try to locate retention basins. They should be located in close proximity to major waterways so that excessive runoff can readily be channeled to retention pools. For this study, the major waterway of Lam Takhong Watershed is Lam Takhong River. Classification and score assignment of distance to waterway is shown in Table 4.6 and is also displayed spatially in Figure 4.24.

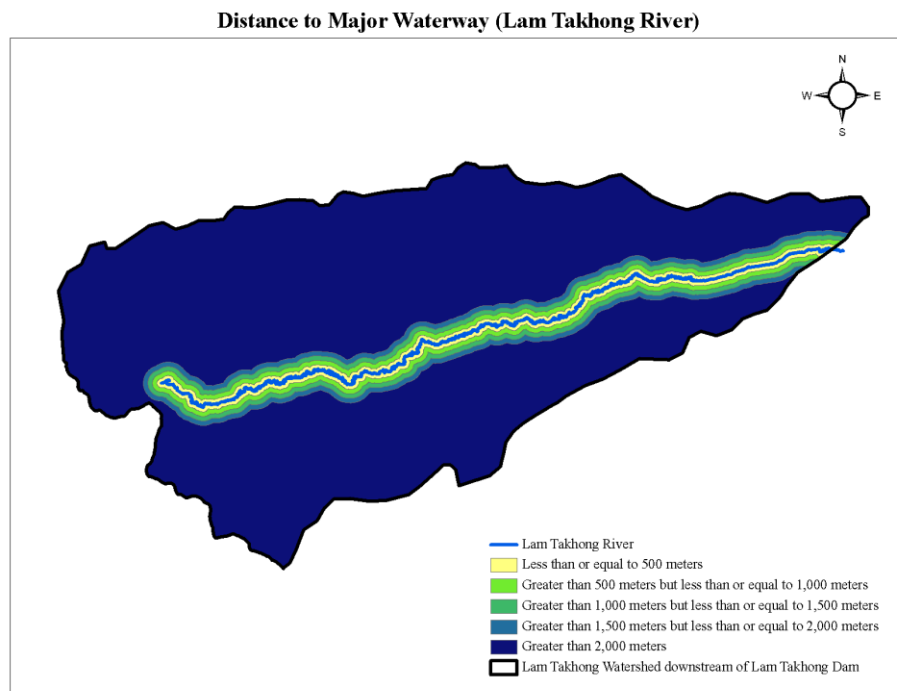


Figure 4.24 Distance to Major Waterway

Source: Department of Environmental Quality Promotion, 2004.

Table 4.6 Distance to Major Waterway and Score Assignment

Distance to Major Waterway	Score
Less than or equal to 500 Meters	5
Greater than 500 meters and less than or equal to 1,000 meters	4
Greater than 1,000 meters and less than or equal to 1,500 meters	3
Greater than 1,500 meters and less than or equal to 2,000 meters	2
Greater than 2,000 meters	1

Source: Concerned Government Agency Assessment, 2011 (Royal Irrigation Department, Department of Water Resources).

7) Distance to protected area is also taken into account. All concerned government agencies agree that the farther the retention basins to the protected areas the better. The factor classification and score designation is shown in Table 4.7 and is spatially displayed in Figure 4.25.

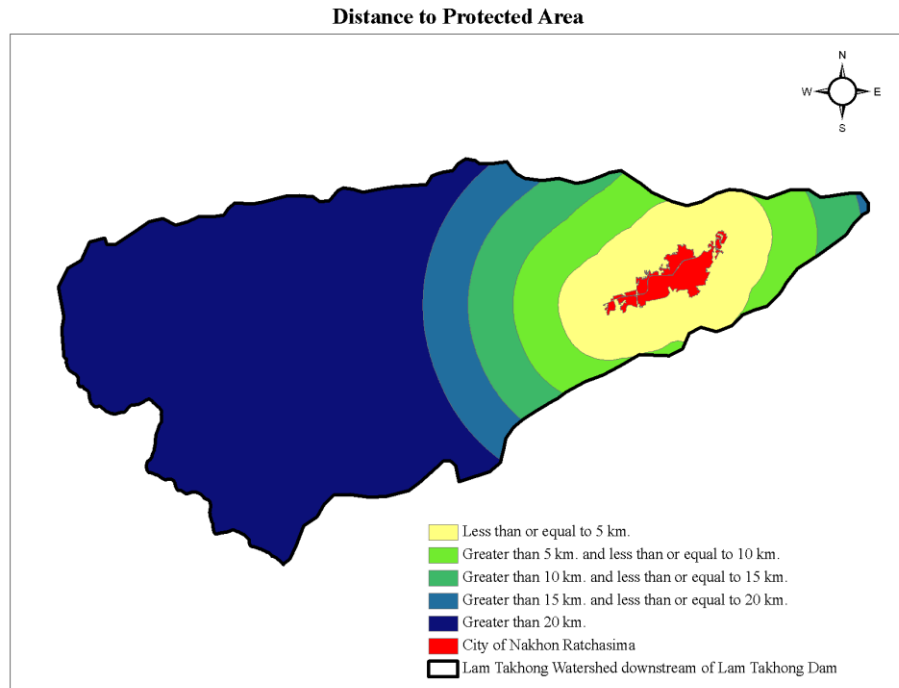


Figure 4.25 Distance to Protected Area

Source: Department of Environmental Quality Promotion, 2004.

Table 4.7 Distance to Protected Area and Score Assignment

Distance to Protected Area	Score
Less than or equal to 5 kilometers	1
Greater than 5 kilometers and less than or equal to 10 kilometers	2
Greater than 10 kilometers and less than or equal to 15 kilometers	3
Greater than 15 kilometers and less than or equal to 20 kilometers	4
Greater than 20 kilometers	5

Source: Concerned Government Agency Assessment, 2011 (Department of Water Resources).

Since each factor has different significance to retention basin suitability, these factors need to be weighted according to their significance. Table 4.8 summarizes weights pertaining to these factors which are derived from assessment of concerned government agencies.

Table 4.8 Weights for Factors

Agency	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Department of Water Resources	5	5	10	10	10	8	8
Department of Mineral Resources	8	2.5	6	5.5	10	4.5	7
Royal Irrigation Department	9	1	1	1	5	8	3
Land Development Department	9	9	8	9	10	9	9
Average	7.75	4.375	6.25	6.375	8.75	7.375	6.75

Remark:

- (1) Slope
- (2) Soil Fertility
- (3) Soil Permeability
- (4) Rock Permeability
- (5) Land Use
- (6) Distance to Major Waterway

(7) Distance to Protected Area

Source: Concerned Government Agencies Assessment, 2011.

4.3 Retention Basin Suitability Classification

Using all of the factors described above, the results of the overlay operation called Potential Surface Analysis (PSA) of this section can be displayed in the map in below (Figure 4.26). The suitability scores are classified in to three categories: least suitable, moderately suitable, and most suitable. The classification is obtained by the use of standard deviation of the summation of all of the weighted scores. That is, the suitability scores within the standard deviation range around the averaged score are categorized as “moderate suitability”. The statistical summary of the suitability scores is as follows:

Minimum: 14.125

Maximum: 214.250

Average: 125.160848

Standard Deviation: 23.046953

The classification of suitability scores is as follows:

- 1) Least Suitable with the score ranging from 14.125 to 102.113894
- 2) Moderately Suitable with the score ranging from 102.113895 to 148.207801
- 3) Most Suitable with the score ranging from 148.207802 to 214.250

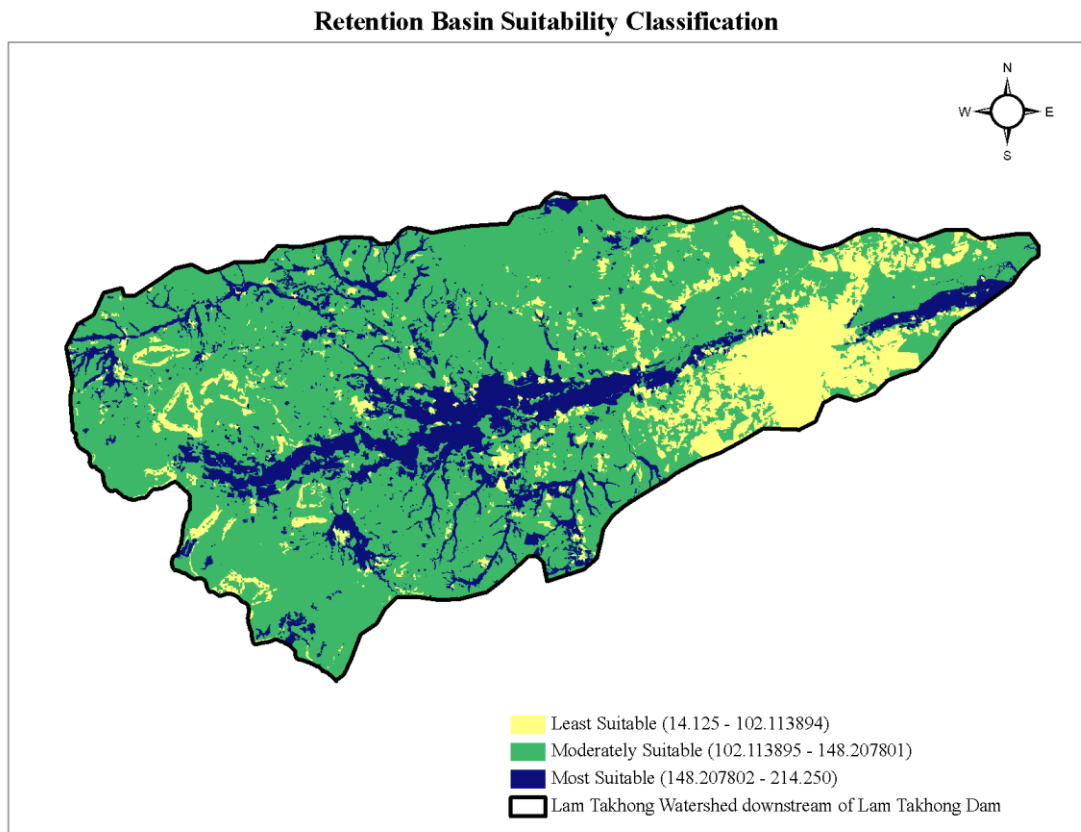


Figure 4.26 Retention Basin Suitability.

4.4 Locating of Suitable Retention Basin

Retention basin suitability classification is a process which narrows down areas that can potentially be retention basins which could alleviate flood in Muang Nakhon Ratchasima District. Areas classified as most suitable are of interest. In locating suitable retention basins, two criteria are considered: area continuity and area size of at least 1,500 *rai*. Moreover, according to the basic requirements, suitable retention basin must not be located on urban areas or areas downstream of Muang Nakhon Ratchasima District. Due to the two criteria and the basic requirements, area of interest can be located (Figure 4.27). The highlighted area shown on Figure 4.28 is then selected to be the most suitable retention basin which would later be imported to the MIKE 11 model in order to simulate the flooding situation to assess its performance. The selected retention basin covers an area of 3,515.854 *rai*. With the

proposed depth of 2.5 meters (Setty, 2009), the retention basin capacity is 14,063,414.1 cubic meters of runoff.

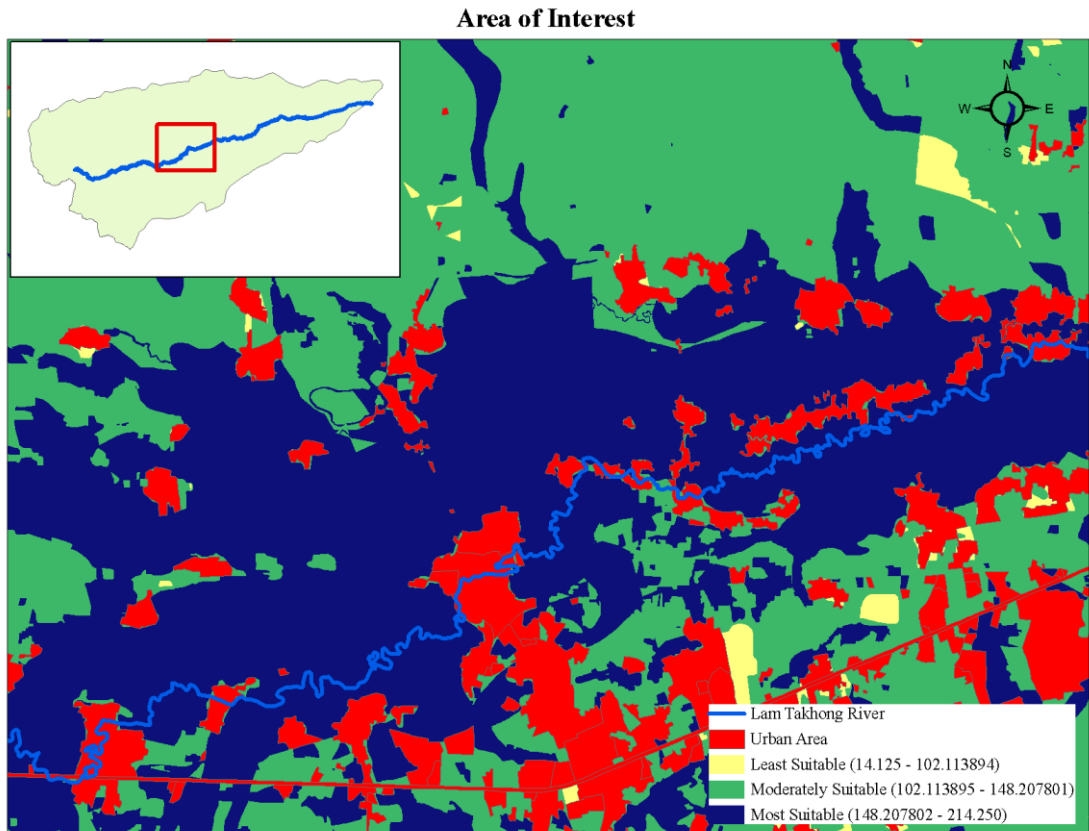


Figure 4.27 Area of Interest.

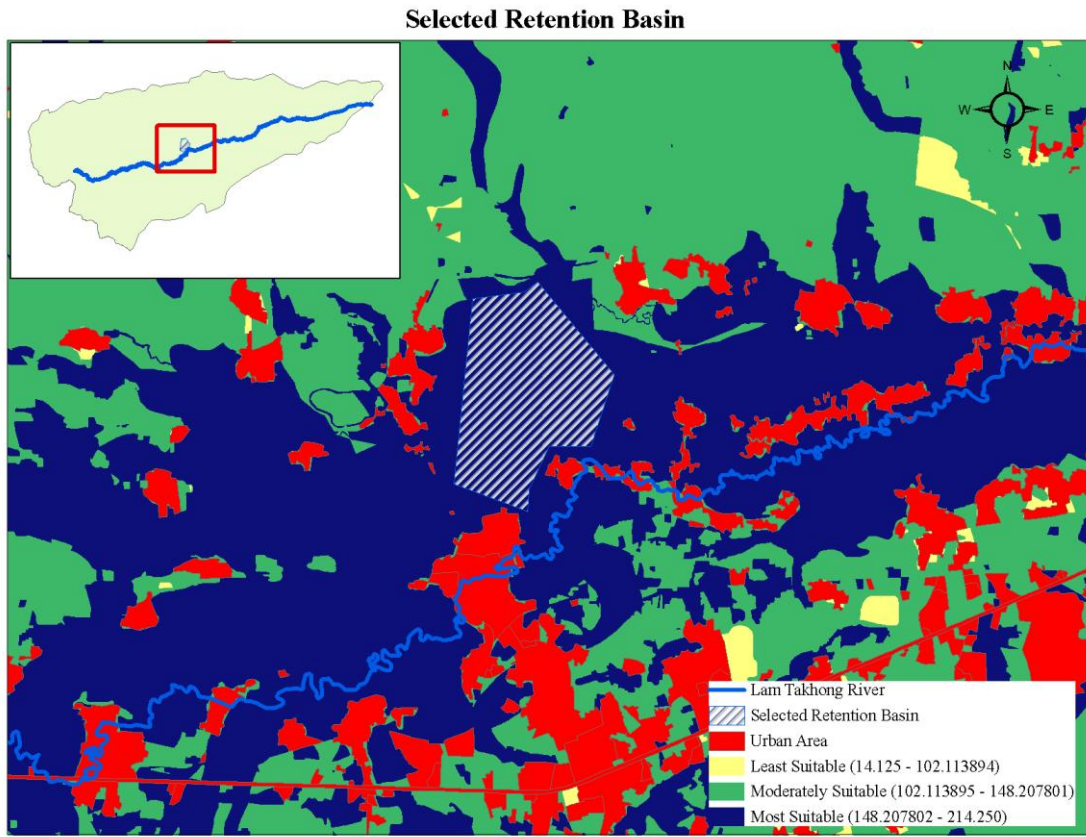


Figure 4.28 Selected Retention Basin.

4.5 Natural Linkages and Artificial Linkages and Their Capabilities

Retention basins could not perform on their own with channel connecting them to rivers whose excessive runoff would be retained. This study compares two types of linkages: natural linkage and artificial linkage. Natural linkage is chosen from natural stream that diverts from Lam Takhong River, passes through the suitable retention basin, and then flows into Lam Takhong River. Natural drainage system around the suitable retention basin is displayed in Figure 4.29. Streams selected to be natural linkages are shown in Figure 4.30. The channel cross section, including width and depth, which is obtained by a field survey, is divided into two sections: inlet channel and outlet channel. Inlet channel width is 11 meters and inlet channel depth is 2.2 meters, whereas outlet channel width is 6.9 meters and outlet channel depth is 1.73 meters.

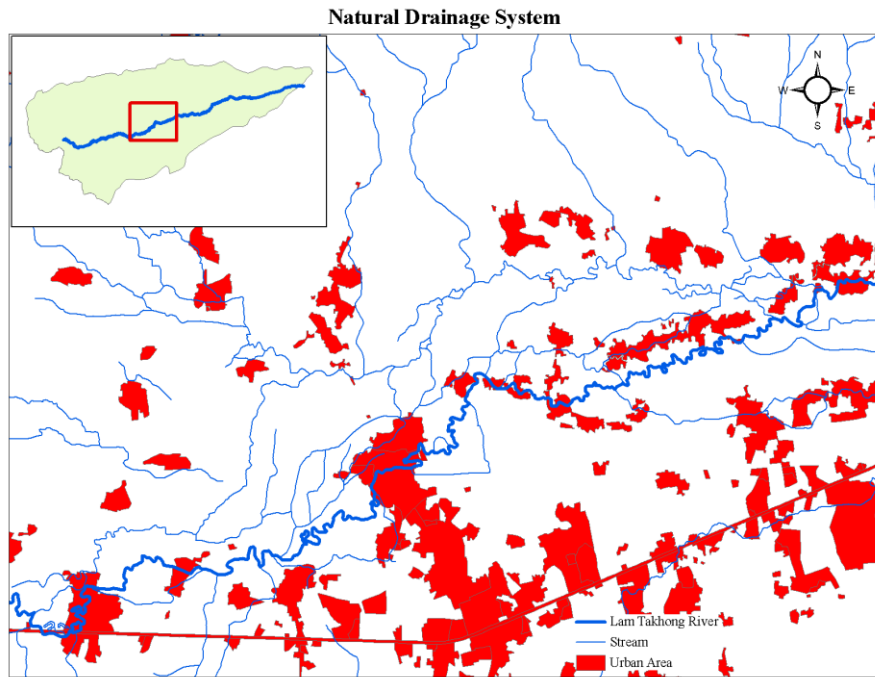


Figure 4.29 Natural Drainage System in the Area of Interest

Source: Department of Environmental Quality Promotion, 2004; Land Development Department, 2008.

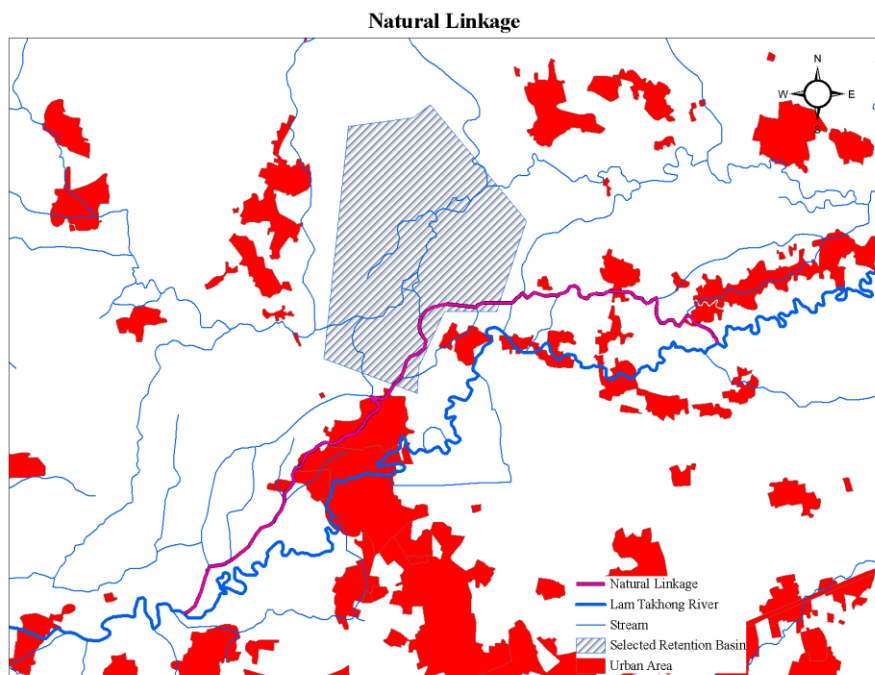


Figure 4.30 Natural Linkages

Source: Department of Environmental Quality Promotion, 2004; Land Development Department, 2008.

Artificial linkage is an alternative created to be compared to natural linkage in terms of flood alleviation performance. Artificial linkage is designed to be more straightened and wider than natural linkage, with a width of twenty meters and depth of 2.5 meters. Similar to locating suitable retention basin, an artificial linkage must not penetrate urban areas. Artificial linkages are displayed in Figure 4.31.

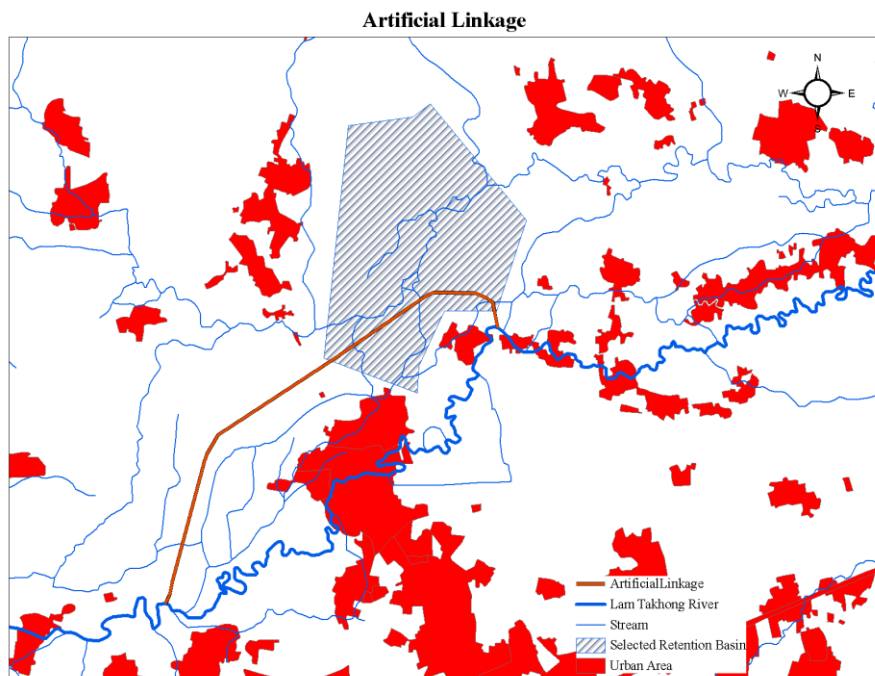


Figure 4.31 Artificial Linkages

Source: Department of Environmental Quality Promotion, 2004; Land Development Department, 2008.

Capability of retention basins coupled with each of the two linkages is anticipated to vary from each other. MIKE 11 is again used to create simulations of two scenarios: natural linkage scenario and artificial linkage scenario.

4.5.1 Retention with Natural Linkages

This study first investigates how the suitable retention basin (Figure 4.28) would perform if it is connected to Lam Takhong River by the natural linkages (Figure 4.30) chosen earlier. A MIKE 11 model simulating retention basin with natural linkages reveals that the retention basin could have lowered the flood level of the

Great Flood of 2010 in the City of Nakhon Ratchasima in Muang Nakhon Ratchasima District. At chainage 111,800, the overflow occurs first on October 21st, 2010 (Figure 4.32). The flood peak occurs on October 23rd, 2010 with the highest water level of 179.902, 0.158 meter above the bank level (Figure 4.33). This flood peak level is lower than the actual water level without retention basin by 0.207 meter (Table 4.9). The flood finally recedes and the water level is below the banks again on October 27th, 2010 (Figure 4.34). The flood occurs for six straight days in this scenario which is one day shorter than the actual flood in 2010. Furthermore, the lower flood peak also indicates smaller flooded area.

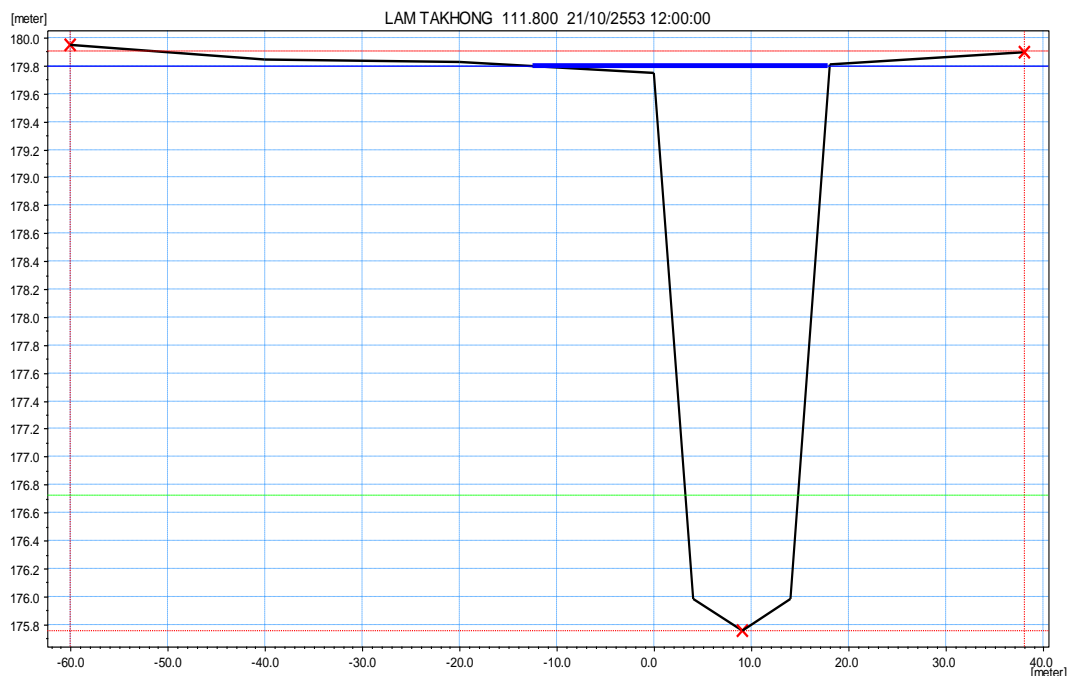


Figure 4.32 Water Level on the First Day of Flood (October 21st, 2010)

Source: MIKE 11 Model.

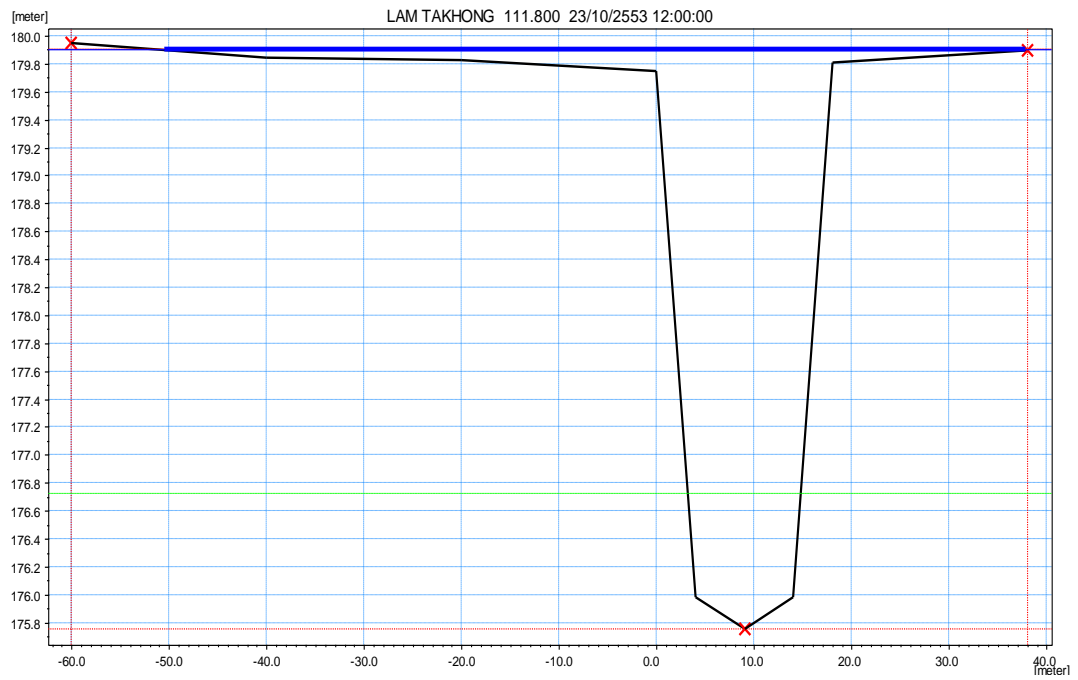


Figure 4.33 Water Level on the Day of Flood Peak (October 23rd, 2010)

Source: MIKE 11 Model.

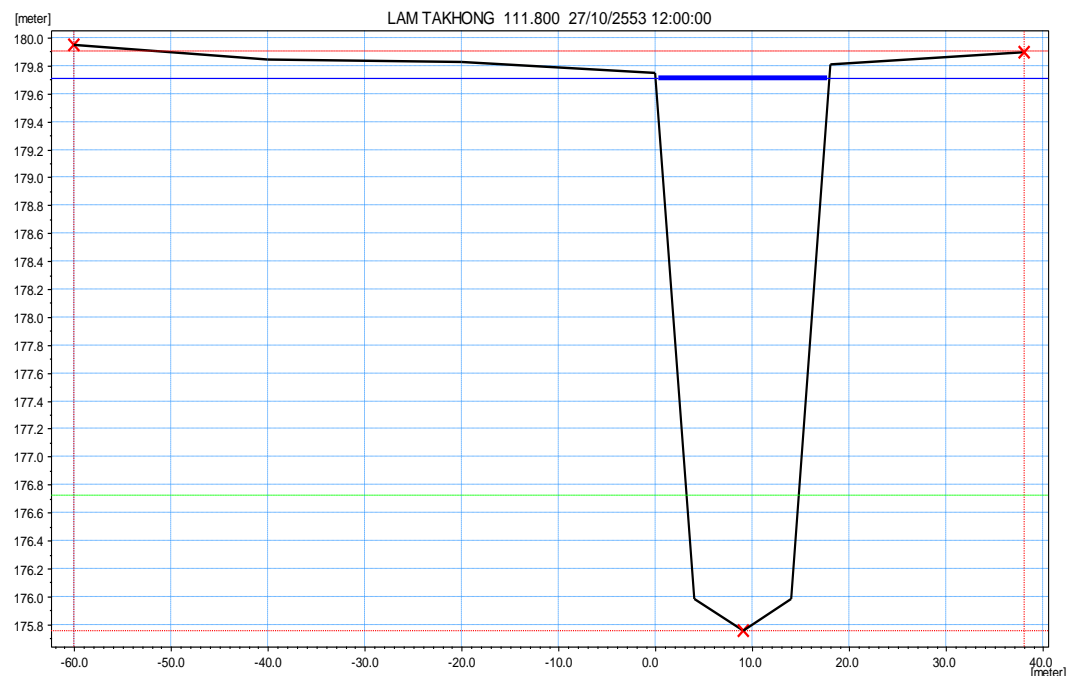


Figure 4.34 Water Level on the First Day after Flood (October 27th, 2010)

Source: MIKE 11 Model.

4.5.2 Retention with Artificial Linkages

This study also investigates how the suitable retention basin (Figure 4.28) would perform if it is connected to Lam Takhong River by the artificial linkages (Figure 4.31) chosen earlier. The overflow begins on October 20th, 2010 (Figure 4.35). The flood reaches the highest level on October 22nd, 2010 with the water level of 180.050 meters, 0.306 meter above the bank level (Figure 4.36). This flood peak level is lower than the actual flood level by 0.059 meter (5.9 centimeters). Finally, the water level begins to drop below the banks on October 28th, 2010 (Figure 4.37). The flood, in this scenario, lasts for eight straight days which is one day longer than the actual flood in 2010. Nonetheless, the last day of flood witnesses only 1.5-centimeter flood level (Table 4.9).

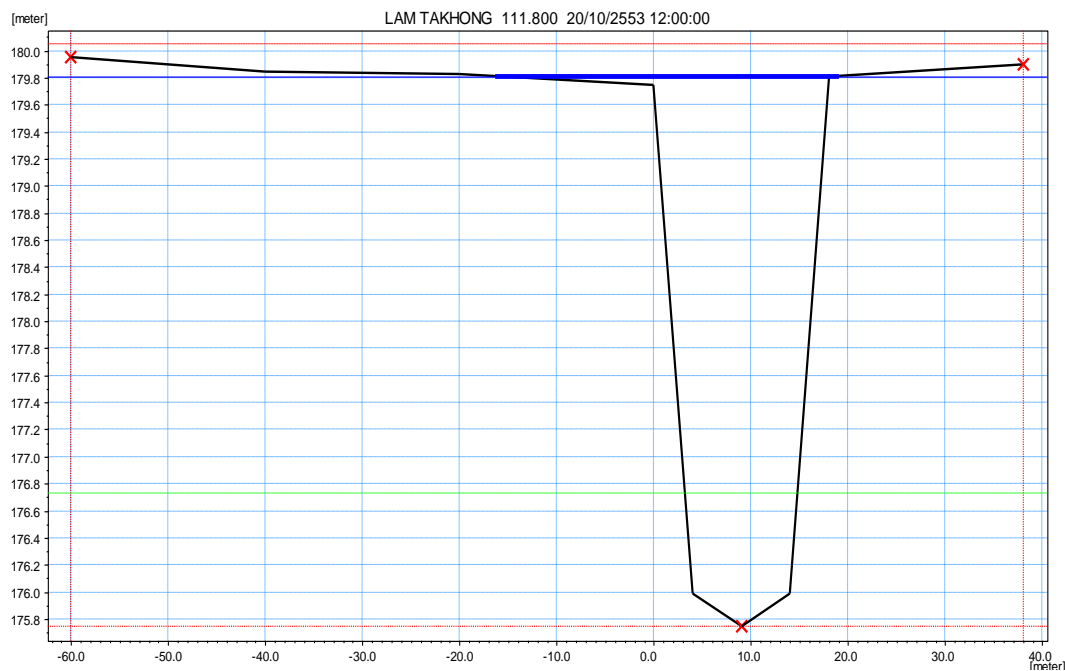


Figure 4.35 Water Level on the First Day of Flood (October 20th, 2010)

Source: MIKE 11 Model.

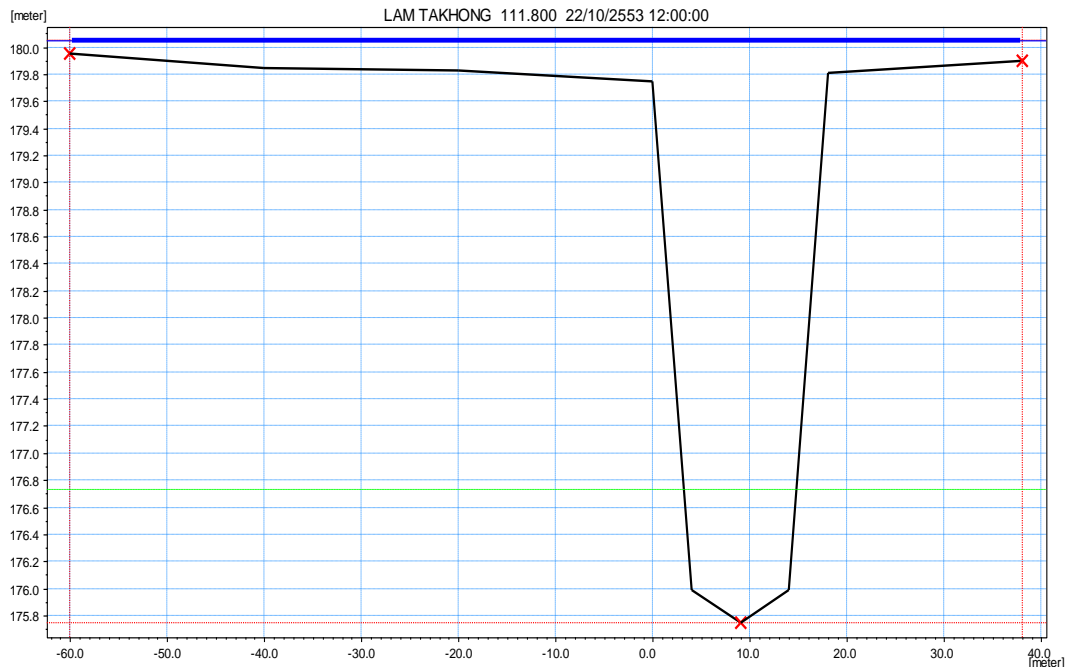


Figure 4.36 Water Level on the Day of Flood Peak (October 22nd, 2010)

Source: MIKE 11 Model.

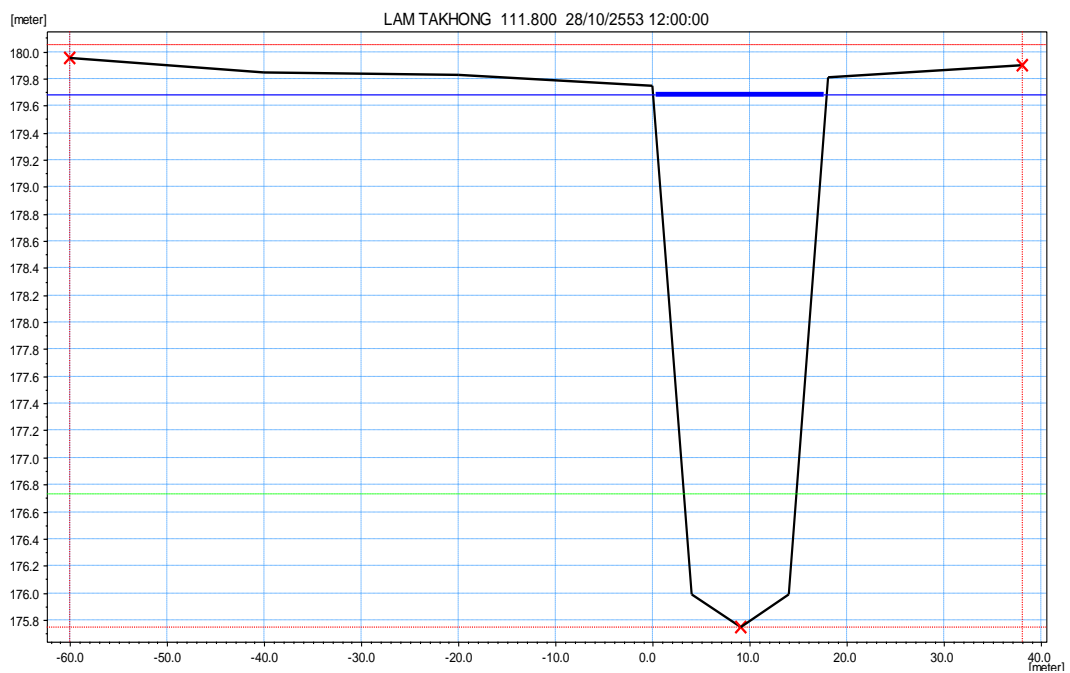


Figure 4.37 Water Level on the First Day after Flood (October 28th, 2010)

Source: MIKE 11 Model.

Table 4.9 Water Levels Comparison between Existing Drainage System, Retention Basin with Natural Linkages, and Retention Basin with Artificial Linkages

Date	Actual (Meter)	Natural (Meter)	Artificial (Meter)	Bank Level (Meter)
Oct 19 th , 2010	179.556	178.374	179.520	179.744
Oct 20 th , 2010	179.861	179.616	179.811	179.744
Oct 21 st , 2010	180.042	179.795	179.983	179.744
Oct 22 nd , 2010	180.109	179.880	180.050	179.744
Oct 23 rd , 2010	180.075	179.902	180.025	179.744
Oct 24 th , 2010	180.01	179.894	179.981	179.744
Oct 25 th , 2010	179.885	179.844	179.916	179.744
Oct 26 th , 2010	179.757	179.787	179.827	179.744
Oct 27 th , 2010	179.614	179.711	179.759	179.744
Oct 28 th , 2010	179.438	179.633	179.679	179.744
Oct 29 th , 2010	179.254	179.573	179.622	179.744

Source: MIKE 11 Models.

4.6 Discussion

Table 4.9 shows that actual flood lasts for seven days. Retention basin with natural linkages results in a considerably shorter flood period. It could have lowered flood level at the flood peak by 0.207 meters, 56.71% lower than the actual flood peak level above the bank. Decreased water levels suggest smaller flooded area. Retention with artificial linkages could also have helped mitigate flood in Muang Nakhon Ratchasima District to a smaller extent. In other words, the retention basin with artificial linkages could have lowered flood peak level by 0.059 meter which accounts for 16.16% compared to the actual flood peak level above the bank.

Figure 4.38 shows changes in water levels of the three scenarios: actual, retention basin with natural linkages, and retention basin with artificial linkages. It can be determined that retention basin with natural linkages gives the best result, lowering

flood peak to the greatest extent (0.207 meters or 56.71%). Retention of excessive runoff in suitable retention basin occurs naturally as natural linkages, particularly the one draining runoff back to Lam Takhong River, are narrow with the width of 6.9 meters and depth of 1.73 meters and meander, allowing runoff to be captured longer in the suitable retention basin.

Suitable retention basin with artificial linkages provides little flood alleviation to Muang Nakhon Ratchasima District. This is because the artificial linkages draining runoff to the suitable retention basin and draining runoff back to Lam Takhong River area wide (20 meters in width and 2.5 meters in depth) and relatively straight. The water speed in the linkages and retention basin, therefore, is greater than the natural linkage and the Lam Takhong River itself, presenting a limitation of an ability to contain excessive runoff within the retention basin. The greatest discharge of the artificial linkage downstream of the retention basin occurs on October 22nd, 2010 with the discharge of 86.927 cubic meters per second (Figure 4.39). While the greatest discharge of the natural linkage downstream of the retention basin occurs on October 25th, 2010 with the discharge of 22.003 cubic meters per second (Figure 4.39), suggesting not only the smaller discharge but also the delay of releasing excessive runoff.

The result of this study can be compared with that of Pet Techarat's study of 2008 entitled "*An Application of Mathematical Model for Flood Mitigation with Water Retention Areas a Case Study of Nakhon Pathom*", which recommends improved linkages and, thus, draining capacity. This study, however, suggests that, without runoff control structure, linkages should not be wide and straight because they would contribute to a lack of an ability to "retain" excessive runoff within a retention basin. Furthermore, the result of this study generally agrees with the result of other related researches conducted by Nutjaree Charoenboonwanon (2009) and Jirattinart Thungngern (2004) as retention basin can lower flood level or flood volume by certain but varying extent.

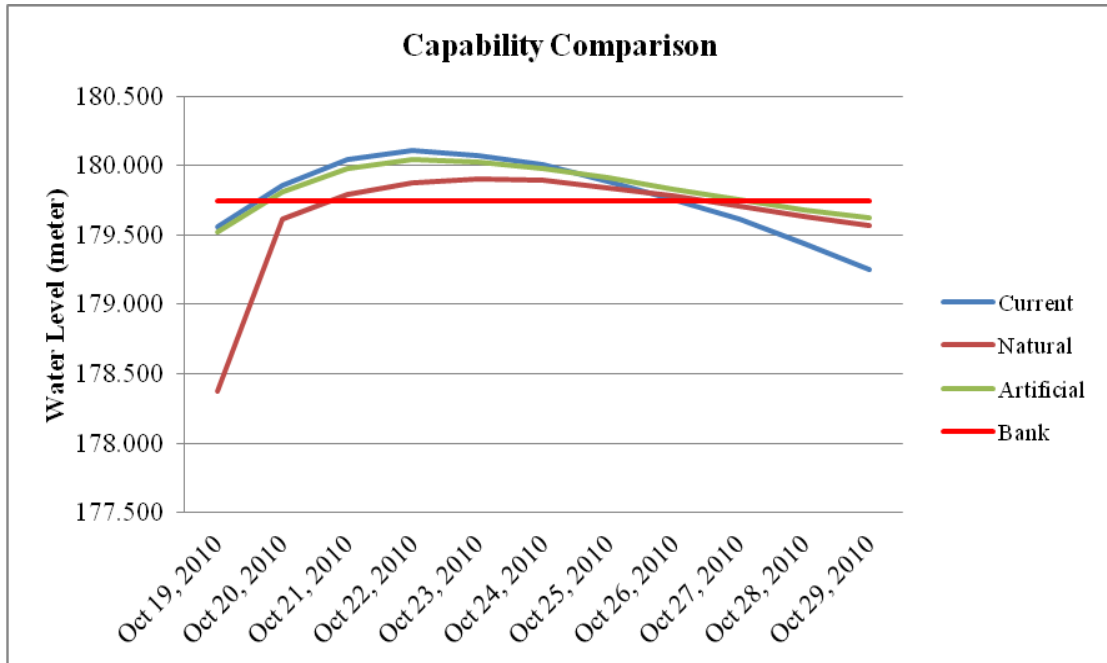


Figure 4.38 Capability Comparison between Actual Drainage System, Retention Basin with Natural Linkages, and Retention Basin with Artificial Linkages

Source: MIKE 11 Models.

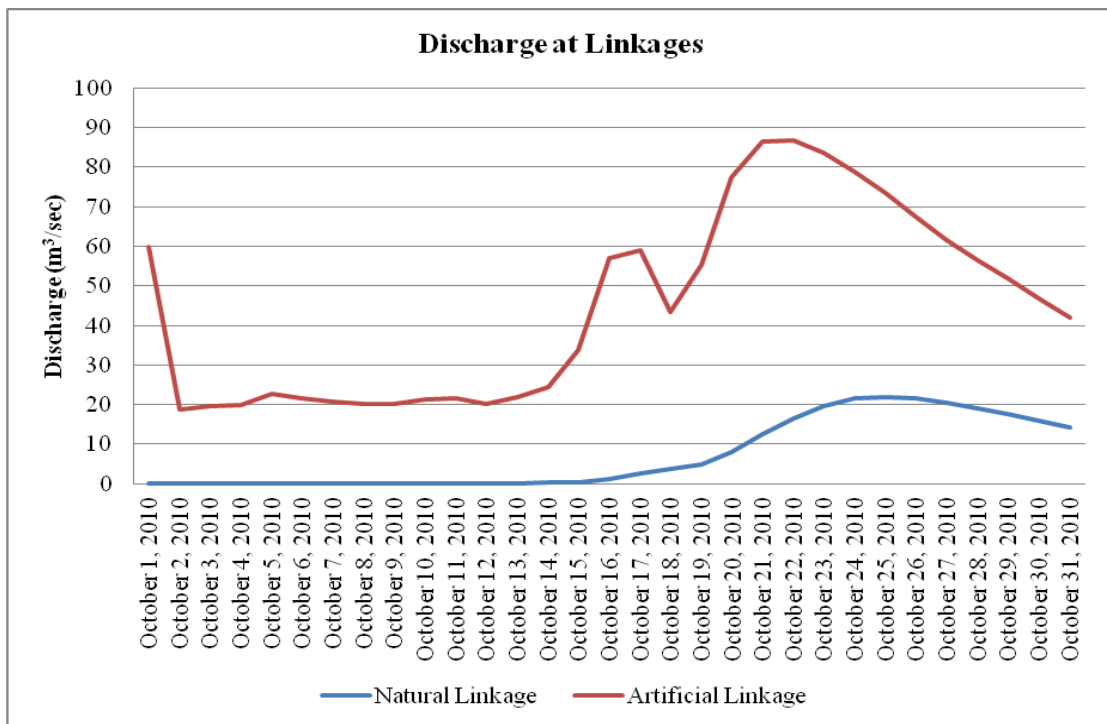


Figure 4.39 Discharges at Linkages Downstream of the Retention Basin

Source: MIKE 11 Models.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

The study has investigated all three scenarios of drainage system in the Lam Takhong Watershed, including (1) existing drainage system, (2) drainage system with retention basin with natural linkages, and (3) drainage system with retention basin with artificial linkages. Drainage system with retention basin with natural linkages has the greatest capability in lowering flood level in Muang Nakhon Ratchasima District. Conclusion of the study is given below. Furthermore, a new study can further be developed. The recommendation section addresses this opportunity for improvement and further study.

5.1 Conclusion

The potential surface analysis is adopted in locating suitable retention basin. The PSA takes into account nine factors: two basic requirements (non urban area and upstream area) and seven other requirements (slope, soil fertility, soil permeability, rock permeability, land use, distance to major waterway, and distance to protected area). The PSA results in suitability classification: high suitability, moderate suitability, and low suitability. The suitable retention basin must be located in the continuous area of high suitability. The selected retention basin covers an area of paddy field of 3,515.854 *rai*. With the proposed depth of 2.5 meters, the retention basin capacity is 14,063,414.1 cubic meters of runoff.

Because the main criteria determining the extent of flood alleviation is the highest flood level at the time of flood peak, the modified drainage system with retention basin with natural linkages is evidently a promising measure that could alleviate flood in Muang Nakhon Ratchasima District. The retention basin with

natural linkages could lower the flood peak level by 0.207 meter or 56.71% compared to the actual flood peak level of 0.365 meter above the bank level. Moreover, by lowering flood level, the retention basin with natural linkages could also decrease the size of flooded areas in the Lam Takhong Watershed, thus fewer areas would be adversely affected by flood.

Retention basin with artificial linkage with a width of 20 meters could lower flood peak level by only 0.059 meter in Muang Nakhon Ratchasima District because the wide and straight artificial linkages have high drainage efficiently, releasing a great volume of excessive runoff that should have been contained in the retention basin back to the Lam Takhong River during the flood peak period. This lack of ability to contain runoff within the retention basin leads to a disappointingly slight decrease in flood peak level caused by the retention basin with artificial linkages.

5.2 Recommendations

The Great Flood of 2010 in the Lam Takhong Watershed was a result of the heaviest rain in fifty years due to the trough over the Watershed for several days. Consequently, the Great Flood of 2010 occurred. With this large volume of runoff, the retention basin with limited space could have done little to mitigate flood in Muang Nakhon Ratchasima District. This study suggests that normal flood of a lower magnitude be more appropriate for studies investigating retention basins because the capability of retention basins in normal flood could be more promising.

If flood events with great magnitude are to be studied, this research suggests that two or more retention basins be proposed in order to increase retention capacity and to eventually obtain a better result with obvious flood mitigation. The retention basins should be located evenly along both sides of the major river of the watershed, both upstream and downstream.

The flow of runoff in the retention basin can be managed to the greater extent in order to improve capability of the retention basin. This study strongly recommends that sluice gates be adopted to control and effectively retain excessive runoff in the retention basin. The sluice gate is beneficial because it ensure the

retention of excessive runoff within the retention basin, holding runoff longer enough in order to release it after the flood peak instead of during the flood peak. However, in order to adopt water regulating structures such as sluice gates, the researcher should obtain engineering information about runoff regulating structure control.

A maximum of two sluice gates can be adopted, one at the inlet and the other at the outlet of the retention basin. If one sluice gate is adopted, it should be located at the outlet of the retention basin as it could ensure the retention of excessive runoff. If runoff control structure is not to be constructed, this study suggests that linkages should not be wide and straight because they would contribute to a weak ability to “retain” excessive runoff inside a retention basin.

According to discharges in 2009 and 2010 measured at Station M.177 which is very close to the Lam Takhong Dam, this study suggests that the Lam Takhong Dam drain runoff not greater than 21.16 cubic meters per second in order to prevent flood downstream in the Watershed.

The benefits of retention basin greatly depend on the size of the retention basin as the larger retention basin can capture the larger volume of runoff. Practically, finding a large area to be retention basin, which does not directly provide financial benefits, is very challenging. Therefore, the concerned organization should adopt as many measures as possible in order to mitigate flood. One of the promising measures to alleviate flood is retention basin.

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APPENDIX

Lam Takhong Cross-Section Profile

Chainage 111,800 meters (Km. 111.800)

No	X	Z	Type
1	-60	179.951	RD
2	-40	179.846	Sph
3	-20	179.825	Sph
4	0	179.744	LLV
5	4	175.985	Sph
6	9	175.750	CL
7	11	176.550	LWT
8	14	175.985	Sph
9	18	179.805	RLV
10	38	179.895	BDV

Where:

No: Point Numbers

X: Easting

Z: Elevation

Type: Description

Sph: Spot Height

LLV: Left Bank Level

CL: Centerline

LWT: Water level at the time of survey

RLV: Right Bank Level

RD: Road Level

BDV: House, Mountain, Pond, and Stream

**Discharge at Station M.177, in Cubic Meter per Second,
Water Year April 1, 2007 to March 31, 2008**

Date	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	8.18	6.78	4.76	20.30	16.05	0.00	11.82	9.30	6.92	11.40	12.52	7.20
2	8.60	0.00	6.38	20.10	13.36	0.00	9.30	9.30	8.88	12.10	9.86	7.20
3	9.44	0.00	6.26	23.30	13.22	0.00	9.16	7.90	8.88	12.10	9.86	7.20
4	9.44	3.28	6.26	23.30	12.66	0.00	3.14	7.76	8.88	11.82	9.86	6.78
5	9.44	0.22	6.38	23.30	11.96	0.00	0.00	7.48	8.88	11.82	8.60	8.04
6	9.02	2.64	6.38	23.30	11.54	0.27	4.49	7.48	8.88	12.24	6.92	8.88
7	9.02	6.26	6.38	23.30	14.70	0.00	5.66	7.34	8.88	12.38	6.92	8.74
8	9.02	0.00	6.38	23.30	11.68	0.00	8.60	7.48	9.16	12.38	6.92	8.88
9	5.90	0.32	6.78	23.30	11.68	0.40	9.86	9.72	9.16	12.38	6.92	8.88
10	8.88	0.36	6.78	23.30	11.68	7.90	10.14	11.12	9.16	12.38	6.92	8.74
11	9.16	0.50	7.06	23.30	11.68	3.98	11.82	11.12	9.44	12.38	6.92	8.74
12	9.16	0.17	7.62	23.30	11.68	7.34	13.22	11.12	10.00	12.38	6.92	8.88
13	9.16	0.00	8.46	23.30	11.40	5.12	16.50	11.12	10.00	12.38	6.78	9.44
14	9.72	0.00	8.32	22.10	11.40	0.17	27.90	11.26	10.00	12.38	6.64	10.56
15	10.70	3.91	8.32	22.10	10.84	4.85	18.70	11.12	10.00	12.52	6.64	11.68
16	9.44	1.32	8.32	22.10	10.14	0.00	21.70	11.12	10.14	12.80	6.64	10.98
17	8.32	1.36	9.16	19.10	10.56	0.00	10.98	11.12	10.28	12.94	6.64	9.16
18	6.64	0.00	8.32	17.50	10.70	1.36	7.90	11.12	10.28	13.08	6.64	9.16
19	6.92	0.00	3.28	17.10	11.12	5.90	5.90	11.12	10.28	13.65	7.90	9.16
20	6.92	0.00	3.42	15.15	10.00	10.00	4.12	11.12	10.28	13.65	10.14	9.16
21	7.06	0.00	5.30	13.50	10.70	4.33	3.14	11.12	10.28	13.65	11.68	9.16
22	6.92	0.00	5.90	13.22	10.56	4.67	0.36	10.00	10.28	13.65	9.72	11.12
23	6.64	0.00	7.90	10.70	10.56	5.12	0.00	5.54	10.28	13.65	9.58	12.52
24	6.64	0.00	8.04	12.80	10.84	4.94	0.00	4.76	10.28	13.65	9.30	10.70
25	6.14	0.00	7.90	15.00	15.30	5.21	0.00	7.20	10.28	13.65	9.30	10.70
26	7.06	0.00	8.18	15.60	14.40	8.60	1.36	7.20	10.28	13.65	9.30	10.70
27	3.84	4.40	8.04	16.20	12.66	11.40	10.00	7.06	10.28	13.65	9.58	10.70
28	3.91	4.40	8.04	16.05	18.70	20.10	12.66	6.92	10.28	13.65	9.58	10.70
29	3.91	4.40	12.10	13.80	12.10	10.70	12.66	6.92	10.28	13.65	7.48	10.70
30	3.98	4.94	23.70	16.05	4.33	13.95	9.58	6.92	10.28	13.65		10.70
31		4.58		16.05	3.63		9.30		10.70	13.65		10.28

**Discharge at Station M.177, in Cubic Meter per Second,
Water Year April 1, 2008 to March 31, 2009**

Date	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	7.70	3.60	3.75	12.12	12.50	9.00	8.10	6.60	11.58	17.90	17.10	17.50
2	8.00	2.94	4.41	12.12	11.04	11.76	9.90	7.41	10.40	17.90	17.10	16.70
3	6.40	2.82	6.15	12.12	10.86	11.94	11.58	5.60	8.80	17.90	16.90	13.90
4	7.23	5.07	4.83	12.30	13.50	11.40	7.14	9.00	8.80	17.90	16.90	13.90
5	8.60	4.56	4.89	12.30	13.30	8.00	4.53	6.30	8.80	17.90	16.90	13.90
6	7.70	4.50	5.04	12.50	12.30	9.10	4.92	5.75	8.80	17.90	16.90	13.70
7	4.41	4.44	5.01	12.50	11.04	15.50	11.94	5.04	8.80	17.90	16.90	13.70
8	8.30	4.41	4.86	12.90	11.04	11.76	10.40	4.83	8.80	17.90	16.90	14.10
9	4.62	4.41	2.92	13.30	11.04	4.32	5.65	4.44	8.80	17.90	16.90	15.10
10	5.20	4.26	2.70	13.70	11.04	4.50	5.80	4.32	8.80	17.90	16.90	15.30
11	5.15	10.30	2.58	13.70	11.04	19.26	7.23	6.35	8.80	17.90	16.90	17.70
12	5.10	10.20	3.63	13.70	11.04	14.90	10.86	7.70	8.80	17.90	17.50	17.30
13	5.01	10.30	2.78	13.50	11.04	6.96	10.86	7.23	8.80	17.90	17.50	17.10
14	4.95	16.50	2.54	13.10	11.04	5.45	9.80	7.05	8.80	17.90	17.50	17.10
15	4.95	7.05	4.02	13.10	11.04	4.80	9.80	6.30	8.80	17.70	17.50	14.50
16	5.60	5.80	4.11	13.10	11.04	17.50	9.30	5.65	8.80	17.30	17.50	14.30
17	3.93	4.50	4.08	13.10	11.04	11.22	8.70	5.80	8.80	13.10	17.50	14.10
18	5.25	4.32	6.10	13.10	11.04	7.60	8.10	5.85	8.80	12.12	17.50	15.50
19	7.32	4.08	6.25	13.10	11.22	6.05	6.78	5.80	8.80	10.86	17.50	15.50
20	7.05	3.90	6.25	13.10	9.20	5.25	6.60	5.60	8.80	10.10	17.50	15.30
21	7.05	3.60	6.30	13.10	8.50	4.92	6.69	5.40	8.80	10.10	17.70	11.04
22	7.41	3.39	6.35	13.10	6.10	4.68	9.20	5.35	8.80	10.10	17.70	10.68
23	11.76	3.27	6.35	13.10	6.25	4.35	10.10	5.25	8.90	10.10	17.90	10.50
24	4.77	3.18	6.35	13.10	8.00	4.08	11.40	5.10	8.90	10.10	17.70	11.04
25	4.59	3.00	6.40	13.10	7.90	3.87	11.58	5.07	8.90	10.20	17.70	13.50
26	3.06	2.96	6.50	13.10	8.00	3.66	19.58	5.40	8.90	10.50	17.50	13.70
27	6.05	2.98	6.60	13.10	8.10	4.23	6.96	5.25	8.90	13.10	17.50	14.30
28	5.30	2.92	8.60	13.10	4.35	5.95	5.55	5.07	8.90	14.70	17.50	12.12
29	5.65	2.90	10.40	13.10	5.90	8.70	5.85	7.05	9.50	15.50		11.58
30	4.44	3.09	11.76	14.30	9.30	7.70	7.14	7.14	13.10	16.30		11.94
31		3.81		15.70	8.60		12.30		17.90	17.10		12.50

**Discharge at Station M.177, in Cubic Meter per Second,
Water Year April 1, 2009 to March 31, 2010**

Date	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	13.50	4.06	6.20	18.93	15.50	4.52	7.32	10.26	5.56	13.30	6.12	7.56
2	12.50	4.84	5.56	16.50	15.50	2.60	13.50	8.70	5.56	1.52	6.20	7.44
3	11.86	7.20	4.36	17.04	15.50	6.96	5.96	9.46	5.56	1.14	6.36	7.44
4	11.70	7.20	4.20	17.85	15.50	3.85	6.72	12.50	5.48	9.78	6.36	7.56
5	11.70	7.20	4.44	17.85	15.50	6.36	5.00	12.34	5.48	11.06	6.36	7.44
6	10.74	7.20	4.92	17.31	15.50	9.94	3.00	12.18	5.48	10.26	6.36	7.44
7	9.30	7.20	5.24	11.86	15.50	10.10	2.36	12.18	5.48	12.70	6.36	7.44
8	9.62	7.20	5.32	14.50	15.50	11.06	3.30	11.86	5.48	13.70	6.44	8.10
9	9.62	7.20	5.40	19.20	15.50	15.10	4.84	9.00	5.48	13.30	6.52	8.40
10	9.94	7.20	5.72	19.20	15.50	15.10	13.70	4.60	5.48	13.50	6.52	10.26
11	13.10	7.20	7.44	18.93	15.90	15.30	13.90	4.36	5.48	13.50	6.44	10.42
12	21.16	6.96	7.56	18.93	18.12	15.50	13.90	4.28	5.40	13.30	6.44	7.20
13	9.94	6.12	7.56	18.66	18.12	15.70	13.30	4.13	5.40	13.10	6.44	6.96
14	6.60	3.20	7.56	17.04	18.12	15.10	9.15	4.60	5.40	13.10	6.96	6.96
15	4.60	1.14	7.56	15.10	15.50	11.06	6.36	4.06	5.40	13.10	8.40	6.84
16	1.16	1.76	9.62	13.50	11.22	8.70	1.64	4.06	5.40	13.10	8.25	6.96
17	2.04	3.40	11.54	13.10	10.42	6.96	1.24	3.99	5.40	13.10	8.25	6.96
18	2.88	3.45	11.54	12.02	10.42	7.56	1.22	3.92	5.40	12.90	8.25	6.96
19	3.45	3.40	11.54	12.90	10.42	10.58	6.20	3.92	5.40	12.70	8.25	7.20
20	7.80	3.64	11.54	15.10	15.70	7.44	9.15	4.60	5.40	12.18	8.10	7.20
21	8.40	0.62	11.70	18.12	15.30	6.96	15.70	7.95	5.40	11.06	8.10	7.32
22	8.40	0.61	11.70	14.50	16.10	6.84	6.72	8.10	5.40	9.78	7.56	7.20
23	8.40	3.85	11.70	12.90	7.95	7.56	3.25	7.95	5.40	9.00	7.56	7.20
24	8.85	4.60	11.70	15.10	0.92	6.96	2.24	7.56	5.40	8.40	7.56	7.20
25	9.94	4.60	11.70	15.50	5.16	3.99	1.48	7.56	5.40	7.08	7.56	7.20
26	9.94	4.60	12.18	15.50	3.25	1.12	1.22	7.44	5.40	7.08	7.56	7.32
27	9.78	6.52	13.90	15.50	1.26	0.74	1.92	7.32	5.40	6.72	7.56	7.32
28	9.46	7.44	18.39	15.50	1.68	0.71	6.28	6.96	5.40	6.28	7.44	7.20
29	9.78	7.56	19.20	15.50	6.12	1.32	7.68	6.52	5.40	6.20		7.08
30	5.56	7.44	19.20	15.50	5.40	1.88	10.74	5.88	11.22	6.20		7.08
31		6.72		15.50	2.44		10.90		15.30	6.20		7.20

**Discharge at Station M.177, in Cubic Meter per Second,
Water Year April 1, 2010 to March 31, 2011**

Date	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	4.35	2.25	2.30	2.75	3.75	1.64	0.13	32.45	5.42	13.16	12.65	11.12
2	4.28	2.10	2.45	3.15	3.95	2.35	0.18	30.20	5.10	13.16	12.65	11.12
3	4.21	2.15	2.50	3.25	3.95	2.60	3.80	28.00	4.63	13.16	12.65	11.12
4	4.35	2.20	2.80	3.60	2.25	0.24	8.84	25.12	4.28	13.16	12.48	11.12
5	4.28	2.25	2.70	3.65	2.10	1.39	4.21	22.96	4.70	13.16	12.31	11.12
6	4.28	2.15	3.20	3.70	2.35	2.20	2.95	21.56	4.42	13.16	12.31	11.12
7	4.21	2.15	2.90	4.00	4.00	3.40	2.35	19.59	4.28	13.16	12.14	11.12
8	4.21	2.10	2.65	4.21	3.75	3.60	2.40	17.49	4.63	13.16	11.80	10.95
9	4.21	2.10	2.50	4.00	3.60	3.55	6.60	16.23	4.94	13.16	11.80	10.95
10	4.14	2.05	2.40	3.90	3.70	4.07	2.55	14.76	5.50	13.16	11.80	10.95
11	4.28	2.10	1.42	4.07	4.07	0.82	1.51	13.16	5.60	12.99	11.46	10.95
12	4.28	2.20	1.76	3.80	3.90	0.11	6.40	11.80	5.42	12.99	10.95	10.95
13	4.28	2.20	1.80	2.20	3.90	1.33	7.40	11.80	4.56	12.99	10.95	10.95
14	4.21	2.20	2.05	0.18	3.90	5.10	9.68	11.80	4.00	12.99	10.95	10.95
15	4.14	2.20	2.60	0.64	3.95	4.70	28.00	11.29	4.42	12.99	10.95	10.95
16	4.14	2.35	2.80	3.80	4.14	4.28	81.99	10.95	4.86	12.99	11.46	10.95
17	4.14	2.30	2.95	4.14	4.56	1.33	40.48	10.95	3.45	12.99	12.82	10.95
18	4.07	2.30	3.15	4.00	1.72	0.29	42.38	10.95	2.75	12.99	13.16	10.95
19	3.95	2.20	3.50	3.90	0.22	1.54	76.20	10.44	3.15	12.14	12.82	10.95
20	3.90	2.15	3.05	3.70	0.14	0.40	92.36	10.44	3.35	11.80	12.82	10.95
21	3.85	2.05	2.25	3.65	2.75	0.18	97.64	10.44	4.70	11.80	12.82	10.95
22	3.85	2.10	2.25	3.65	3.10	0.20	94.06	10.44	6.00	11.80	11.97	10.95
23	4.00	2.05	2.00	3.65	4.94	2.60	89.64	10.95	6.70	11.80	9.82	10.95
24	4.49	2.00	1.51	3.70	2.20	2.80	82.98	10.78	7.86	11.80	15.60	10.78
25	4.00	2.00	2.05	3.55	0.52	2.90	76.20	9.54	7.62	11.80	15.60	10.78
26	3.90	2.10	2.10	3.65	0.19	2.55	69.02	10.61	6.30	11.80	13.50	10.78
27	3.85	2.20	2.10	4.63	1.03	5.70	61.58	10.44	3.95	9.40	11.12	10.61
28	4.07	2.20	2.10	1.84	1.60	3.45	55.62	8.46	4.14	7.62	11.12	10.61
29	4.49	2.25	2.15	0.14	1.96	2.05	50.50	6.10	7.50	8.22		10.61
30	3.50	2.30	2.70	0.29	1.96	0.22	42.38	6.20	7.98	8.58		10.44
31		2.35		3.40	1.72		38.86		10.95	8.58		10.44

Daily Rainfall in 2008 (mm.) at Nakhon Ratchasima Weather Station

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0.4	0	0	T	0	10	4.6	0.2	14	35	0
2	0	T	0	T	9.2	0	6.8	0	0	2.4	0	0
3	0	1.1	0	T	13.3	4.7	0.6	21	60	T	0	0
4	0	0	0	0	2.9	3.3	T	0	0.5	1.5	12	0
5	0	0	0	38	0	T	0	5.3	T	2.1	0.7	0
6	0	0	0	2.3	0.9	37	T	T	21	2.1	1	0
7	0	0	0	6	0	1.5	1.9	0.1	6.7	0.6	0	0
8	0	0	0	0	0	0.3	13	0.5	18	46	0	0
9	0	0	0	4.1	0	0.5	9.4	0	14	T	0	0
10	0	0	0	0	8.1	0	T	1.3	35	0	0	0
11	0	0	0	0	17.4	8.6	0	11	26	0	0	0
12	0	0	0	T	25.6	9	0	0.9	1.5	0	0	0
13	0	0	0	4.9	22.7	5.9	T	7.3	5	0	0	0
14	0	0	T	0	0.5	0.2	2.7	0	0	0	0	0
15	0	0	0	48	41.1	1.3	0.2	0	35	0	0	0
16	0	0	0	0	0	0.7	0	0	20	0	0	0
17	0	0	0	0	0	2.2	0	0	62	0.5	T	0
18	0	0	0	0	0	T	4.2	45	T	23	T	0
19	0	0	0	T	0	0.6	34	1.3	19	0	0	0
20	0	0	0	0	0	T	T	4.9	3.3	0	0	0
21	0	0	0	0	15.7	0	1.7	10	0	0	0	0
22	0	0	25.3	13	0.1	0	0.4	26	0	0	0	0
23	0	0	0	3.8	0	0	0	0	0	0	0	0
24	0.5	0	0	T	7.1	0	0	T	0	18	0	0
25	0	0	0	0	0	0	0	1.3	0	7.5	0	0
26	0	0	5.7	0	0.1	0	7	0.3	T	4.2	0	0.2
27	0	0	0	92	0	0	0	11	3.3	2	0	0.1
28	5.4	0	0	30	0	0	0	1.1	5.3	0.1	0	0
29	0	0	0	14	0	0	0	8.3	11	1.7	0	0
30	0		0	0	0	14	0.5	27	3.4	11	0	0
31	0		T		0		5.4	T		6.2		0

Daily Rainfall in 2009 (mm.) at Nakhon Ratchasima Station

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	8.3	25	0	0
2	0	0	0	0	0	31	12	0	0	30	0	0
3	0	0	0	0	0	0	0	0	T	T	0.3	0
4	0	0	0	0	0	0.6	0	4	0.1	5	0	0
5	0	0	T	4.2	0	0.1	32	0.3	2.9	0.4	0	0
6	0	0	0	0	0	2.3	18	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0.4	0
8	0	0	0	0	0	0	0	6.2	5.5	0	0.1	0
9	0	0	0	0	46.7	0.1	0	0	0	0	0	0
10	0	0	0	1.6	0	0	0	T	0	0	0	0
11	0	0	T	11	0	0	0	0	0	15	0	0
12	0	0	0.2	T	33.1	0	45	0	0	T	0	0
13	0	0	1.1	0	49.4	0	0	1.6	48	0	0	0
14	0	0	0	0	49.7	1	T	17	0	0	0	0
15	0	0	0	0	0	0	0	0.4	1.1	T	0.4	0
16	0	0	0	0	0.3	3.9	T	0	2.7	0	0	0
17	0	0	T	0	3.6	0	0	1	2.1	T	T	0
18	0	0	58.5	0	20.4	9.9	0	6.6	1.3	4.7	0	0
19	0	0	0.6	0	5.9	3.4	0	0	0	0	0	0
20	0	T	8	0	5.5	0	0.9	0	0.1	T	0	0
21	0	0	0	0	0.8	0	14	0	0.1	27	0	0
22	0	0	8.5	0	6.3	0	0.1	32	0	0	0	0
23	0	0	1.8	0	0	7	0	4.3	19	0	0	0
24	0	0	0	0	0	0	T	6.9	14	0	0	0
25	0	0	0	57	11	0	0	2.3	0.1	0	0	0
26	0	0	1	1.2	13.3	0	0	0	5.1	T	0	0
27	0	0	27.5	0.3	0	3.6	0.3	0	30	0	0	0
28	0	8.8	0	23	2.8	1.5	0	14	0	0	0	T
29	0		0	15	0	2	0	0.5	4.4	0	0	0
30	0		0	14	0	T	5.1	78	63	0	0	1.6
31	0		16.4		0		7.8	10		0		0

Daily Rainfall in 2010 (mm.) at Nakhon Ratchasima Station

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	0.0	0.0	0.9	19.0	51.8	8.5	0.0	0.0
2	0.0	0.0	0.4	0.0	0.0	0.0	1.7	0.9	37.2	3.8	T	0.0
3	0.0	T	0.0	0.0	4.0	8.6	3.8	16.8	11.3	14.9	0.0	0.0
4	0.0	4.0	0.0	0.0	0.0	13.9	13.0	2.0	3.1	4.6	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.6	T	3.3	0.0	T	0.0	0.0
6	T	0.0	0.0	0.0	0.0	0.2	12.2	0.0	21.5	0.0	T	0.0
7	0.0	0.0	0.0	0.0	0.0	T	0.0	0.0	T	0.0	T	0.0
8	16.1	0.0	0.0	0.0	0.0	0.0	0.6	0.0	6.0	6.9	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	45.6	3.6	0.0	82.9	0.5	0.0	0.0
10	0.0	0.0	0.0	0.0	5.6	0.0	14.8	3.6	6.1	1.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	T	2.5	8.3	1.6	29.8	T	0.0
12	0.0	0.0	0.0	0.0	3.0	0.0	33.4	16.8	0.1	2.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.9	23.7	1.4	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	4.7	4.5	3.1	25.5	0.0	0.0
15	0.0	0.0	0.0	0.6	2.4	2.7	22.4	4.6	0.7	116.3	3.0	0.0
16	0.0	0.0	T	0.4	39.5	0.0	0.2	15.2	T	52.6	T	0.0
17	0.0	0.0	0.0	2.3	T	2.2	7.0	10.4	0.3	6.6	0.0	0.0
18	0.0	0.0	0.0	0.0	65.0	2.7	5.5	0.1	31.4	7.5	0.0	0.0
19	0.0	0.0	0.0	1.1	T	15.0	0.0	0.6	0.1	2.2	0.0	0.0
20	7.0	0.0	0.0	0.0	0.0	0.0	29.2	18.6	5.1	0.0	0.0	0.0
21	1.4	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	T	0.0	0.0
22	28.2	0.0	0.0	0.1	T	18.6	2.7	5.1	73.5	0.5	0.0	0.0
23	6.1	0.0	0.0	1.1	0.4	T	0.0	0.0	T	T	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	T	0.0	1.2	0.1	0.0	0.0	0.0
25	0.0	0.0	19.4	0.0	0.0	0.0	1.0	T	0.0	0.0	0.0	0.0
26	0.0	0.0	27.0	21.2	T	0.2	14.8	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	T	0.0	0.0	13.8	2.9	1.6	0.0	0.0	0.0
28	0.0	0.0	0.0	4.4	1.1	T	0.5	5.0	0.0	0.0	0.0	0.0
29	0.0		0.0	0.0	2.4	0.6	6.0	6.7	2.8	0.0	0.0	0.0
30	3.4		0.0	0.0	0.0	9.7	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0		0.6		0.0		0.0	0.6		0.0		0.0

BIOGRAPHY

NAME	Miss Paween Panyaphol
DATE OF BIRTH	18 JULY 1985
PLACE OF BIRTH	Sai Mai, Bangkok, Thailand
INSTITUTIONS ATTENDED	Chiang Mai University, 2004 – 2008 Bachelor of Science (Geography) Mahidol University, 2010 – 2012 Master of Science (Technology of Environmental Management)
HOME ADDRESS	4/285 Paholyothin 52 Rd. Khlong Thanon, Saimai, Bangkok, 10220
E-MAIL ADDRESS	pan_kwa@yahoo.com g5336511@student.mahidol.ac.th