EFFECTIVENESS OF DETENTION PONDS FOR FLOOD MITIGATION PROJECT: A CASE STUDY FOR SUNGAI PECHONG, TANAH MERAH, KELANTAN

by

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LIST OF SYMBOLS

$\bar{f}$	Average infiltration rate over time step
$\bar{I}$	Average rainfall rate over time step
Δt	Time interval
A	Catchment area
A_C	Controlled release rate form the pond (mm/hr)
A_{Ci}	Surface area of the ith catchment
C_{Pi}	Level of pollution control provided by the ith catchment
C_{Pmin}	Runoff quality control
C_{Ptot}	Area-weighted average level of pollution control
C_{Ri}	Level of runoff control provided by the ith catchment
C_{Rmin}	Runoff quantity control
C_{Rtot}	Area-weighted average level of runoff control
D	Diffusion coefficient
g	Acceleration due to gravity (m/s^2)
h_A	Pond depth (m)
I	Average rainfall intensity (mm/hr)
I_1	Inflows at the beginning of routing period (m^3/s)
I_2	Inflows at the end of routing period (m^3/s)
n	Manning roughness coefficient for the catchment
O	Outflow (m^3/s)
O_1	Outflows at the beginning of routing period (m^3/s)
O_2	Outflows at end of routing period (m^3/s)
ϕ	Runoff coefficient

P_E	Present value of construction and operation, maintenance and repair costs (dollars/m^3)
P_L	Present land value (dollars/m^2)
P_{Pond}	Total cost of pond (dollars)
q	Lateral inflow (m^3/s)
Q	Discharge/flow (m^3/s)
R	Average return intervals
S	Slope
S_1	Storage volume at the beginning of routing period (m^3)
S_2	Storage volume at end of routing period (m^3)
S_A	Active storage volume of the pond (mm)
S_f	Friction slope
S_o	Bed slope
t	Duration (mins)
u	Flow velocity (m/s)
V	Kinematic wave speed
W	Representative width for the catchment
y	Water depth (m)
y_1	Depth at the beginning of time step (m)
y_2	Depth at the end of time step (m)
y_d	Average depth of depression (m)
Ω	Control release rate (mm/hr)

LIST OF ABBREVIATION

ARI	Average Recurrence Interval
AD	Above Datum
BMPs	Best Management Practices
CN	Curve Number
CSOs	Combined Sewer Overflows
DID	Department of Irrigation and Drainage
DP	Dynamic Programming
FV	Flap Valve
GPT	Gross Pollutant Traps
GL	Ground Level
HRU	Hydrologic Response Unit
ID	Identification
IDF	Intensity Duration Frequency
InfoWorks CS	InfoWorks Collection System
MSMA	Manual Saliran Mesra Alam Malaysia (Urban Stormwater Management Manual for Malaysia)
NGOs	Non-government Organizations
NIH	National Institute for Health
P1	First Pond
P2	Second Pond
REDAC	River Engineering and Urban Drainage Research Centre
RTC	Real Time Control
SMART	Stormwater Management and Road Tunnel

SYNOPSIS	Synchronous Uptimization and Simulation of Urban Wastewater System
USA	United States of America
US-EPA	United States – Environmental Protection Agency
USM	Universiti Sains Malaysia

KEBERKESANAN KOLAM TAHANAN UNTUK PROJEK TEBATAN BANJIR: KAJIAN KES DI SUNGAI PECHONG, TANAH MERAH, KELANTAN

ABSTRAK

Kejadian banjir semakin berleluasa di seluruh dunia disebabkan tahap pembangunan yang meningkat secara ketara terutamanya sejak kebelakangan ini. Masalah ini diburukkan lagi oleh sistem perparitan bandar yang tidak sesuai dibina di kawasan membangun. Kerajaan Malaysia telah mengambil langkah proaktif untuk menangani isu banjir memandangkan negara ini dijangka menjadi sebuah negara maju pada tahun 2020 dengan melaksanakan Manual Saliran Mesra Alam (MSMA) di Malaysia. Salah satu Amalan Pengurusan Terbaik (BMP) yang dikenalpasti dalam MSMA ialah pembinaan kolam tahanan untuk tebatan banjir. Pelaksanaan struktur ini telah terbukti berkesan dalam menyelesaikan masalah banjir terutamanya di kawasan hilir. Walau bagaimanapun, pengenalan kolam tahanan juga boleh menyebabkan kesan buruk terharap kawasan hulu sungai seperti banjir. Oleh itu, terdapat keperluan segera bagi menilai kesan kolam kepada ciri-ciri aliran sungai dari bahagian hulu sehingga ke hilir. Kajian ini telah dijalankan di salah satu kawasan tadahan di daerah Tanah Merah, Kelantan yang sering dilanda banjir iaitu kawasan tadahan Pechong. Pengiraan pemodelan telah dijalankan dengan menggunakan perisian InfoWorks. Kedua-dua kawalan kes aliran dan kawalan isipadu yang terdiri daripada sembilan jenis pengaturan kolam telah diambilkira dalam simulasi ini. Daripada hasil kajian, didapati bahawa fungsi utama kolam untuk mengurangkan aliran puncak di alur keluar tadahan telah

tercapai dalam semua senario yang telah dicadangkan. Walau bagaimanapun, senario kolam yang dicadangkan di aliran atas hingga ke aliran tengah telah mempengaruhi ciri-ciri aliran di hulu kolam. Paras air dalam hulu kolam meningkat dengan ketara manakala halaju aliran bahagian yang sama menurun. Penemuan ini adalah penting bagi merekabentuk kapasiti parit di hulu kolam agar tidak membanjiri kawasan-kawasan ini dalam usaha untuk mengawal aliran di hilir.Antara sembilan kes kolam yang disiasat, Kes 5, di mana kolam yang terletak di persimpangan dua aliran masuk dari kawasan hulu sungai, didapati sebagai senario kolam yang paling optimum untuk kawasan tadahan Pechong. Kes ini telah menyebabkan keperluan jumlah kolam yang paling minima (28,495.06 m3) apabila aliran air adalah terhad di alur keluar dan ia juga mempunyai peratusan tertinggi pengurangan aliran (kira-kira 46%) berbanding asal apabila simpanan kolam dikawal.

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ABSTRACT

Flood occurrences are becoming widespread all over the world as the level of urbanization has increased tremendously especially in the recent years. This problem is further aggravated by inappropriate urban drainage systems built in developing areas. The government of Malaysia has taken proactive steps to address these flooding issues as the country is envisioned to be a fully developed nation in 2020 by implementing the Urban Stormwater Management Manual for Malaysia (MSMA). One of the significant Best Management Practices (BMPs) identified in the MSMA was the construction of detention ponds for flood mitigation. Implementation of this structure has proven functional in alleviation of flood problems especially in areas downstream. However, the introduction of detention ponds may also cause adverse impact to upstream areas such as flooding. Therefore, there is an urgent need to evaluate the influence of ponds on the flow characteristics of the river from its upper stream to the lower stream reaches. This study was conducted in one of the contributing catchments of the frequently flooded district of Tanah Merah, Kelantan, namely Pechong catchment. The computational modelling was carried out using InfoWorks CS software. Both flow and volume control cases consisting of nine types of pond arrangements were considered in the simulation. From the results, it was found that the primary function of the pond to reduce peak flow at the catchment outlet was

achieved in all proposed pond scenarios. However, the proposed pond scenarios located at the upper stream and middle stream reaches have pronounced influence on the flow characteristics at upstream reach of the ponds. The water level in the river segment upstream of the pond increases significantly while the flow velocity at the same segment decreases. Such finding is vital for the design of the capacity of drains upstream of the ponds in order not to inundate these areas in the pursuit of controlling flow downstream. Among the nine cases of ponds investigated, Case 5, in which the pond is located at the junction of two incoming flows from upstream areas, is found to be the optimum pond scenario for the Pechong catchment. This case has resulted to require least pond volume (28,495.06 m^3) when flow was restricted at the outlet and it also has the highest percentage of flow reduction (about 46%) from the original case when pond storage was controlled.

CHAPTER 1
INTRODUCTION

1.1 Background

Flooding issues have become more rampant in the recent years as more population have been affected by its occurrences. Flooding claimed lives of thousands of people and caused severe destruction to properties by millions of ringgit. In a statistics of disaster taking place in Malaysia, flood contributes to the greatest percentage of reported people affected by disaster and subsequently it causes greatest amount of economic damages (UNISDR Preventionweb, 2010).

Malaysia experiences flood as its leading natural disaster in the country immersing more than 10% of the country's areas in floodwater (Chan, 2005). Primarily caused by the monsoon season, flooding in the flood-plain zones is also attributed to inadequate urban drainage system built in those areas which eventually causes flash flooding.

Flood damages to flood prone areas are also overwhelming. In Table 1.1, direct losses in Tanah Merah, Kelantan from floods of 2003, 204 and 2005 are enumerated (DID, 2007).

Table 1.1: Direct Losses in Tanah Merah Floods in years 2003, 2004 and 2005 (DID, 2007)

Year	Flood Victims	Lives Lost	Flood Damage (RM)
2003	681	-	26,300.00
2004	2,599	2	462,000.00
2005	1,613	1	346,000.00

Urbanization is another major factor that causes flash flooding in highly developed areas. When formerly vegetated region were transformed into impervious surfaces, water flows rapidly through the conveyances instead of infiltration into the ground and as a result, larger amount of water discharge at the downstream area is recorded during a rainfall event. Coupled with inadequate urban drainage system (Musa, 2010), hazards of flash flooding are bound to take place especially when no flood mitigating structures are built.

Demands for mitigation measures has risen progressively due to the immense nuisances brought about by the flooding. The government of Malaysia has taken a proactive step in resolving this matter by providing information and guidance as regards stormwater best management practices (BMPs) through publishing the Urban Stormwater Management Manual for Malaysia (*Manual Saliran Mesra Alam* Malaysia – MSMA), an endeavour undertaken by the Department of Irrigation and Drainage (DID).

Use of detention ponds in a given catchment is one of the BMPs recommended in the MSMA. Detention ponds are constructed primarily to manage peak flow and control velocity of stormwater and eventually reduce flooding and erosion downstream. Consideration in the design must be duly noted since retarding the peak flow in the upper areas of the catchment might result in its peak flow coinciding with that of downstream area which will create more flooding problem instead of providing solution.

With the advent of high technology, computer modelling has been a valuable method in urban drainage system analysis. Infoworks Collection System (Infoworks CS) version 8.5 developed by Wallingford was used in the analysis of the urban drainage model in this research. Use of computer models has made engineers' tasks easier as tedious calculations are done simultaneously and accurately by the software, thus, generating greater savings in time and money. With full modelling capacities of backwater effects, reverse flow, open channels, trunk sewers, complex pipe connections and ancillary structures, Infoworks CS allows users to produce fast and accurate hydraulic modelling of any complex urban collection system network (Innovyze, 2011).

In this study, various locations and sizes of ponds were outlined in the study area, Pechong subcatchment (Figure 1.1), which is located in one of the frequently flooded district in the country, namely, Tanah Merah, Kelantan. The effect of introducing pond on the river system was investigated using the Infoworks CS software.

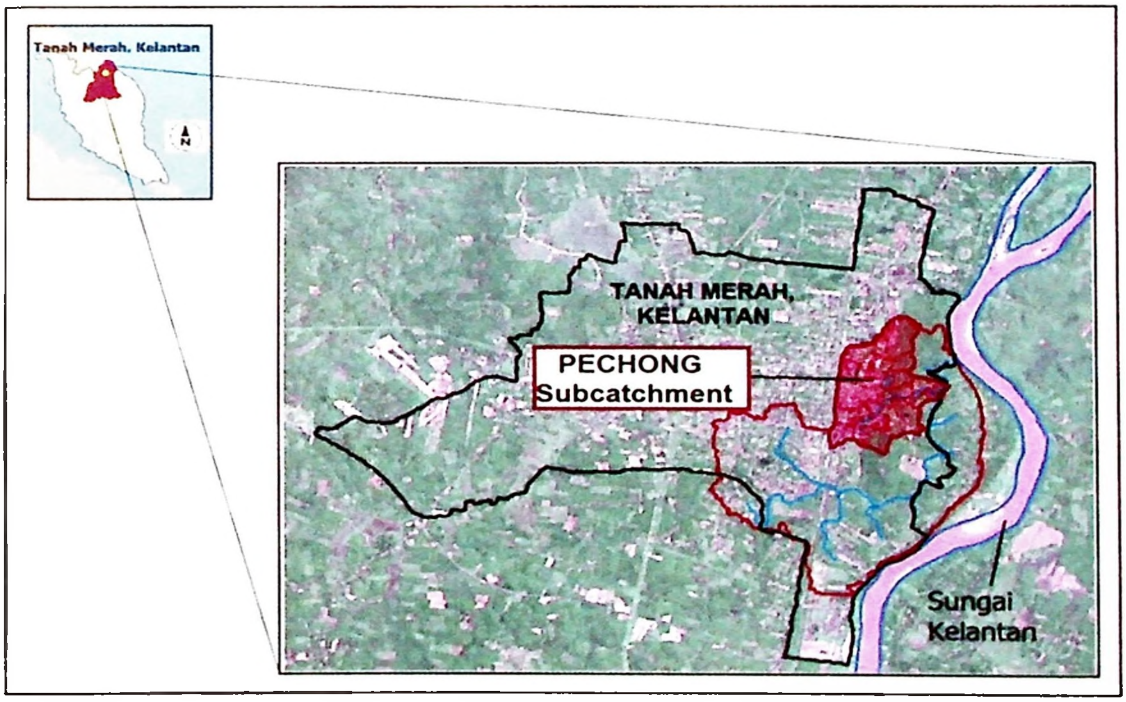

Figure 1.1: Location map of Pechong subcatchment, Tanah Merah, Kelantan

1.2 Problem Statement

The district of Tanah Merah has been experiencing floods primarily due to bank overflowing of Sungai Kelantan (external flooding) during monsoon season. The district is located right at the west bank of the river, hence regular flooding is expected. Moreover, the study area, Pechong subcatchment is located adjacent the Sungai Kelantan (as shown in Figure 1.1) while the rest of catchments in the district are at a distance. This close proximity makes the area more vulnerable to frequent flooding compared to the other catchments in the district, hence immedidate action for flood mitigation is needed.

Internal flooding also takes place in Tanah Merah due to internal drainage problem. Drainage system built in the town areas is ineffective to contain and convey stormwater thus causing stormwater to be spilt onto the main streets during heavy rainfall (DID, 2010). These exacerbate the suffering endured by the residents in the district when they take place on a regular basis and no flood mitigation measures are in place.

One of the possible solutions to flooding in the study area is to provide detention pond in the drainage system. However, the effect of introducing detention pond to the drainage system may not be known. Therefore, this study is carried out to investigate various sizes and locations of ponds within the drainage system in order to optimize their inclusion in the system for flood mitigation.

1.3 Research Objectives

This research utilizes Infoworks CS version 8.5 software by Wallingford to model the drainage system in the study area. The objectives of this research are as follows:

1. To investigate the effects of the proposed ponds on the existing river system;
2. To evaluate the effectiveness of proposed detention ponds in various locations and sizes for flood mitigation;
3. To propose the ideal detention pond location and size for Sungai Pechong catchment.

1.4 Scope of Research Study

This research study focuses on determining the effectiveness of proposed ponds with various sizes in various locations in the Pechong catchment of Tanah Merah, Kelantan for flood mitigation purposes. Detention ponds were outlined at various locations in the catchment and in another set, with varying sizes in order to determine which of them proves effective and eventually propose for an optimum pond layout in the Pechong catchment.

Pechong River is the main waterway within the cathcment. It is approximately 1.4 km in length and receives runoff flow from the Pechong catchment area of about 172.54 ha.

The modelling reach of the study is limited to the existing main drains and proposed ponds of the Pechong catchment. The simulation measures the performance of ponds in its quantitative aspect only.

Hydrologic and hydraulic data of the catchment were extracted from the Stormwater Management Masterplan Study on Tanah Merah, Kelantan completed in 2007 by REDAC, USM.

1.5 Significance of the Study

The results of this study may help to optimize planning for future development in the study area. Where the ponds are in its optimum location and size, the urban drainage system in the area is expected to function in a more sustainable fashion. Optimized location and size of ponds in the catchment will not only eliminate nuisances caused by flood but will also advance economic growth in the Tanah Merah district.

The damages wrought by floods are increasing by the year as shown in Table 1.1. Unless a straightforward measure to mitigate the floods is in place, the study area and its surroundings will still be faced with increasing amount of damages year by year and inevitably, the district's economy will be negatively affected.

One of that measure is the inclusion of pond in the urban drainage system. However, construction of ponds will necessitate giving up a considerable area of land and also the cost of construction will have to be taken into account. In this case, if the benefits derived from the construction of this structure can be maximized while spending minimal amount, then it would be to the best interest of the government and townsfolk in general.

1.6 Thesis Content

This thesis is divided into five chapters. Chapter 1, the introduction, presents the background of the study, problem statement, research objectives, scope of research study and significance of the study. Chapter 2 focuses on a review of literature as regards the research topic. The first part gives definition and types of flood and cites incidences of flooding around the globe. It also highlights the history of flood occurrences in Malaysia. It is followed by flood mitigation measures applied in Malaysia which is categorized into two: structural measures and non-structural measures. Some structural solutions to flooding problem applied in Malaysia include flood control dams, canalization and related works, flood diversion channel or tunnel and ponds. This chapter also discusses the urban stormwater management in Malaysia which includes the construction of detention ponds. Detention ponds were categorized into two: dry detention ponds and wet detention ponds. Discussion about computer modelling which highlights approaches to stormwater quantity modelling follows suit. These approaches are classified into two: empirical models and deterministic models. Deterministic models are categorized further into hydraulic and hydrologic models. Past studies that relates to this research are also presented, which include optimal location of infiltration-based BMPs by Perez-Pedini et al., optimal control of urban wastewater systems by Butler and Schutze, optimization of regional stormwater management systems by Behera et al. and modelling urban river catchment: a case study in Malaysia by Leow et al. This chapter is then concluded by a summary and research gap. Chapter 3 presents research methodology which pertains to the processes undertaken to complete the research. It begins with introduction to the study area and general research methodology. Thereafter, discussions on secondary data collection and design rainfall used in the study follow. The computer model of the study area is presented next. This involves discussion about InfoWorks CS environment which consisted of a network, nodes, links and subcatchment. Afterwards, land uses before and after development of the study area are discussed. Subsequently, scenarios/cases proposed for the study area are presented. There are two sets of scenarios considered in the study: set A refers to scenarios where the control is downstream flow while set B is pond volume control. Each of the set consists of nine cases, the first of which being the control case, where there is no pond involved. The rest of the cases include proposed pond/s in the catchment. Chapter 4 presents the results and discussions for both of the sets. And finally, chapter 5 gives the conclusions and recommendation for future similar study.

CHAPTER 2
LITERATURE REVIEW

2.1 Floods

Flood, defined as an increased level of a water body spilling over an area of land which was previously not immersed in floodwater (Smith and Ward, 1998), usually results from an excessive rainfall that takes place within a short period of time (Sanyal and Lu, 2004). Such rainfall or snowmelt exceeds the absorptive capacity of soil and flow capacity of waterways causing inundation onto the lowland areas (Ward, 1978).

Smith and Ward (1998) categorized floods into two main types: river floods and estuarine or coastal floods. River floods occur mostly on floodplains as a result of flow exceeding the capacity of the stream channels and overspilling the natural banks or artificial embankments. Riverbank flooding in matured river is due to increased return frequency that results to inundation in flood plains (Herschy, 2002). In urban areas, flooding often results from surface ponding and when urban stormwater drains become surcharged and overflow.

Coastal flooding on the other hand, involve the inundation of land by brackish or saline water. Brackish-water floods result when river water overspills embankment in coastal reaches as flow into the sea is impeded by high-tide conditions. Direct inundation by saline water floods may occur when exceptionally large wind-generated waves are driven into semi-enclosed bays during severe storm or storm-surge conditions, or when so-called 'tidal waves', generated by tectonic activity, move into shallow coastal waters

(Smith & Ward, 1998). Coastal flooding disasters are linked to meteorological events and not the rise in sea level; sometimes they take place in combination with extreme luni-solar tide conditions (Herschy, 2000).

Most river floods result directly or indirectly from climatological events such as rain, snow and icemelt, combined rain and icemelt, ice jams, landslides and failure of dams and control works. Estuarine and coastal floods alternatively are usually caused by coastal storm surges, which result from severe cyclonic weather system, earthquakes and estuarine interactions between streamflow and tidal conditions.

2.1.1 Global Flooding

Flooding in the global sense has created more serious problem in the recent years as it posed multiple risks to human health (Jonkman, 2005; Few et al., 2004). It has become one of the major natural hazards worldwide. Deaths, damage to properties and economic losses are the major destruction brought about by flooding, the most serious of which is the loss of human lives from drowning in flash floods. As such, there are concerns for the need for global methods of flood damage modelling (Jongman et al., 2012). Listed in Table 2.1 are the major flood occurrences around the world and their corresponding number of fatalities and amount of damages from year 1988-2012.

Table 2.1: Major flood occurrences around the world from 1988 until 2012 and their corresponding number of fatalities/amount of damages (Information Please, 2010; Zeigler et al., 2012; Natural Disasters Association, 2012; reliefweb, 2012)

Year	Date	Country	Flood Description	Fatalities/Damages
1988	August – September	Bangladesh	Heaviest monsoon in 70 years	- killed more than 1,300 -floods inundated ¾ of the country leaving 30 million homeless - estimated damage: $1 billion
1993	June – August	Illinois, Iowa, Kansas, Kentucky, Minnesotta, Monsanto, Nebraska, North Dakota, South Dakota, Wisconsin (USA)	Flooding of Mississippi river and tributaries.	- 50 deaths - $12 billion estimated damage - almost 70,000 left homeless
1997	December 1996 – January 1997	US West Coast	Torrential rains and snowmelt produced severe floods in parts of California, Oregon, Washington, Idaho, Nevada and Montana	- 36 deaths - about $2-3 billion in damage
	April	North Dakota, South Dakota and Minnesotta	Grand Forks, North Dakota and surrounding area devastated as the Red River swelled 13 ft above flood level	- 11 deaths
	Summer	Central and Northeast China	Heavy flooding of Yangtze River	- killed more than 3,000 - left 14 million homeless - estimated damages exceeded $20 billion
1999	Summer	Asia	Torrential downpours and flooding in South Korea, China, Japan, Philippines and Thailand.	- more than 950 dead - millions homeless
	October	Southwest Mexico	Heavy rains resulted in mudslides and flood waters	- killed at least 360 people
	November and December	Vietnam	-	- $285 million in damage - killed more than 700 people
	December 15-16	Northern Venezuela	Heavy rain caused catastrophic flooding and mudslides	- killed an estimated 5,000 to 20,000 people
2000	February	Southeast Africa	Weeks of rain resulted in deadly floods in Mozambique and Zimbabwe	- killed 700 people - left 280,000 homeless

Table 2.1: Major flood occurrences around the world (continued)

Year	Date	Country	Flood Description	Fatalities/Damaged
2000	Mid-September	Thailand, Cambodia, and Vietnam	Rising flood waters from the Mekong River and its tributaries	- destroyed crops and livestock - left at least 235 people dead and 4.5 million homeless. - damages were estimated at $50 million in Cambodia and $24 million in Thailand.
2002	June – August	Asia (China, India, Nepal, Bangladesh)	Annual monsoon floods	- 2,000 deaths
	August	Europe	Flooding across Central and Eastern Europe	- 108 people killed - billions of dollars of extensive infrastructure damage and deforestation
2004	May 18-26	Dominican Republic and Haiti	Torrential rains overflowed the Soliel River, causing floods and mudslide	- killed more than 2,000 persons
	June – August	South Asia	Annual monsoons	- left 5 million homeless - more than 1,800 dead in India, Nepal, and Bangladesh
2005	January – February	South East Asia	Extreme winter weather including cold, snowfall, avalanches, and flooding in Afghanistan, India, and Pakistan	- killed more than 800 people
	July 26	Mumbai, India	A record of 37 in of rain in a 24-hour period and a week of monsoon rains	-1,000 dead in Western India.
2007	June 18	Gainesville, Texas	-	- killed 4
	June 24	Karachi, Pakistan	-	- 226 reported dead
	July 8	West Bengal, India	-	- 660 people dead - more than a million stranded
	August 14	North Korea	One week of heavy rain in Central and Suthern North Korea caused severe flooding	- hundreds are reported dead or missing - huge areas of farmland were washed away, provoking fears that North Korea's food crisis could worsen
	Mid-August	Midwest and Plains states	-	- more than 20 people are killed
2008	March 17-19	Arkansas, Illinois, Kentucky, Missouri, Ohio (USA)	- major floods that stretch from Texas to Pennsylvania	- 13 people died - hundreds of people are evacuated from their homes

Table 2.1: Major flood occurrences around the world (continued)

Year	Date	Country	Flood Description	Fatalities/Damaged
2008	June 9–18	Indiana, Iowa, Illinois, Missouri, and Wisconsin (USA)	Severe flooding from storms cause already swollen rivers and lakes to flood. Cedar River is 17 feet above flood stage, the worst flooding Cedar Rapids has ever seen	- 10 people killed - 3 dams broke - thousands to evacuate their homes - at least 90 roads are closed.
	June 17	Southern China	The worst flooding in 50 years	- over 60 people killed - destroys 5.4 million acres of crops - 13 people missing in nine southern Chinese provinces
	July 27	South-eastern Europe	Five days of heavy rain caused major flooding in the Ukraine and Romania	- killed 18 people - caused at least $300 million in damages
	August 28–September 1	India	-	- killed at least 75 people - displaced over 2 million - at least half a million people are stranded, while half a million others are living in unsanitary relief camps
2009	August 7	Philippines	-	- at least 22 tourists on Mount Pinatubo were trapped and killed when heavy rain caused flooding and landslides
2010	May 3	Tennessee, USA	-	- at least 24 killed
	June 11	Arkansas, USA	Caddo and Little Missouri Rivers reportedly surcharge 20 ft. due to flash floods	- 18 persons killed
	July 30	Pakistan	-	- killed over 1,600 people - left millions homeless
	August	China	-	- killed several thousand - evacuated more than 15 million people
	September	Mexico	-	- killed at least 11
2011	April – May	Mississippi river flood	Comparable in extent to the major floods of 1927 and 1993. Two major storms and springtime snowmelt lead to swelling of Mississippi river including its tributaries.	- fourteen people were killed in Arkansas, with 392 killed across states: Illinois, Missouri, Kentu cky, Tennessee, Mississi ppi, Memphis and Louisiana. - thousands of homes were ordered evacuated

Table 2.1: Major flood occurrences around the world (continued)

Year	Date	Country	Flood Description	Fatalities/Damaged
2011	September	Pakistan	-	- total of 88 people have been killed and about eight million people have been affected
	October – November	Thailand	Flooding of Chao Phraya River was the country's worst since 1942	- damaged properties worth 45 billion US dollar - more than 500 lives lost
	November 25	Columbia	Worst flooding in 40 years. Region of Bolivar is said to be the worst affected including the city of Cartagena	- nearly 500 people have been killed - 595 people injured and 43 missing - 16,200 houses were destroyed by floods and landslides - more than 550,000 houses damaged - thousands of people left homeless
	November 29	Australia	Severe rains lead to River Mehi flooding	-1 person killed, 60 displaced -hundreds of farms and rural properties in Moree and Wee Waa have been flooded and left isolated. -several roads were flooded and lead to their closure
	November – December	Uganda	-	- 15,000 people affected and left homeless - several crops have been flooded
	December	Philippines	Rains from Typhoon Washi caused rivers to burst their banks in the night which caused severe devastation. Areas worst hit were Iligan and Cagayan de Oro where entire villages were washed away.	- 1,000 dead and with many reported missing -10,000 homes have been damaged.
	December 13	Kenya	-	- 24 people killed - 98,000 people displaced - Bridges destroyed in Western Kenya
	December 20	Tanzania	Floods were caused by the heaviest rainfall the country has witnessed since 1961.	- killed 20 people, left hundreds homeless. - at least 5,000 people displaced by floods
	December 22	Sri Lanka	Heavy rain and floods affected the low lying district of Ki"linochchi	- 11,000 people displaced - political condition of the country caused victims of floods to suffer further

Table 2.1: Major flood occurrences around the world (continued)

Year	Date	Country	Flood Description	Fatalities/Damaged
2012	April 2012 – Early 2013	Great Britain and Ireland, United Kingdom	-	- at least 9 fatalities - 1.2 billion euros worth of damages
	July 9	Russia	Torrential floods hit Krasnodar region. Officilas fail to give warnings to residents The town of Krymsk, home to around 57,000 people, was worst hit, with residents describing how a five-metre (16ft) wave swept through homes in the middle of the night, turning the town into a mudbath	- 150 killed, many of which were elderly - left thousands homeless
	August	Philippines	Relentless rain submerged at least a third of the sprawling capital of Manila The deluge, the worst to hit Manila since 2009 (when hundreds died in rampaging flash floods), was set off by the seasonal monsoon that overflowed major dams and rivers in the city and surrounding provinces	- 9 killed in landslides - at least 60 have dies from drowning - tens of thousands of residents affected - residents were under waist or neck-deel waters at one point.
	August	Pakistan	Heavy to intense monsoon rains caused widespread loss of life, livelihoods and infrastructure across southern Punjab, northern Sindh and northeastern Balochistan	- 5 million people, 14,270 villages and 1.1 million acres of crops were affected by flooding.
	December	Sri Lanka	Heavy rains battered Sri Lanka since middle of December 2012 causing floods and landslides	- killed 36 people and affected over 300,000

2.1.2 Flooding in Malaysia

Malaysia is not spared by menaces of floods. Flood has become one of the major natural disasters that afflict the country and it has actually emerged as a major subject for critical discussion among government, researchers and private industries in the recent years (Toriman et al., 2009).

Accounts of flooding in Malaysia are mainly brought about by heavy rainfall due to the monsoon climate which occurs annually during the north-east monsoon season between Novembers to March. This climate apparently causes major floods in the east coast and southern parts of Peninsular Malaysia, Sabah and Sarawak, estimated to be over 10% of the regions' area (Chan et al., 2004). A south-west monsoon from April to September is also observed which also generates rainfalls but lesser in intensity compared to the north-east monsoon. Inter monsoon occurs during the transitional periods (September – November) when convectional thunderstorm are frequent and it usually causes localised "flash" floods in the western part of the peninsula (DID, 2010). Flood prone areas in Malaysia are mapped in Figure 2.1.

Major floods that the country had experienced in the past resulted in severe damages to life and properties alike. As early as 1886, the state of Kelantan was severely flooded with wind outbursts which caused extensive damages in the state (DID, 2000a). In 1926, the flood which was called "the biggest flood in living memory" affected almost the entire parts of Peninsular Malaysia and resulted to extensive damages to property, road systems and agricultural land and crops (Chan, 2012; DID, 2000a). The 1967 floods rushed through river basins of Kelantan, Terengganu and Perak with death tolls of 55 lives. The catastrophic flood in 1971 swept across several parts of the country.

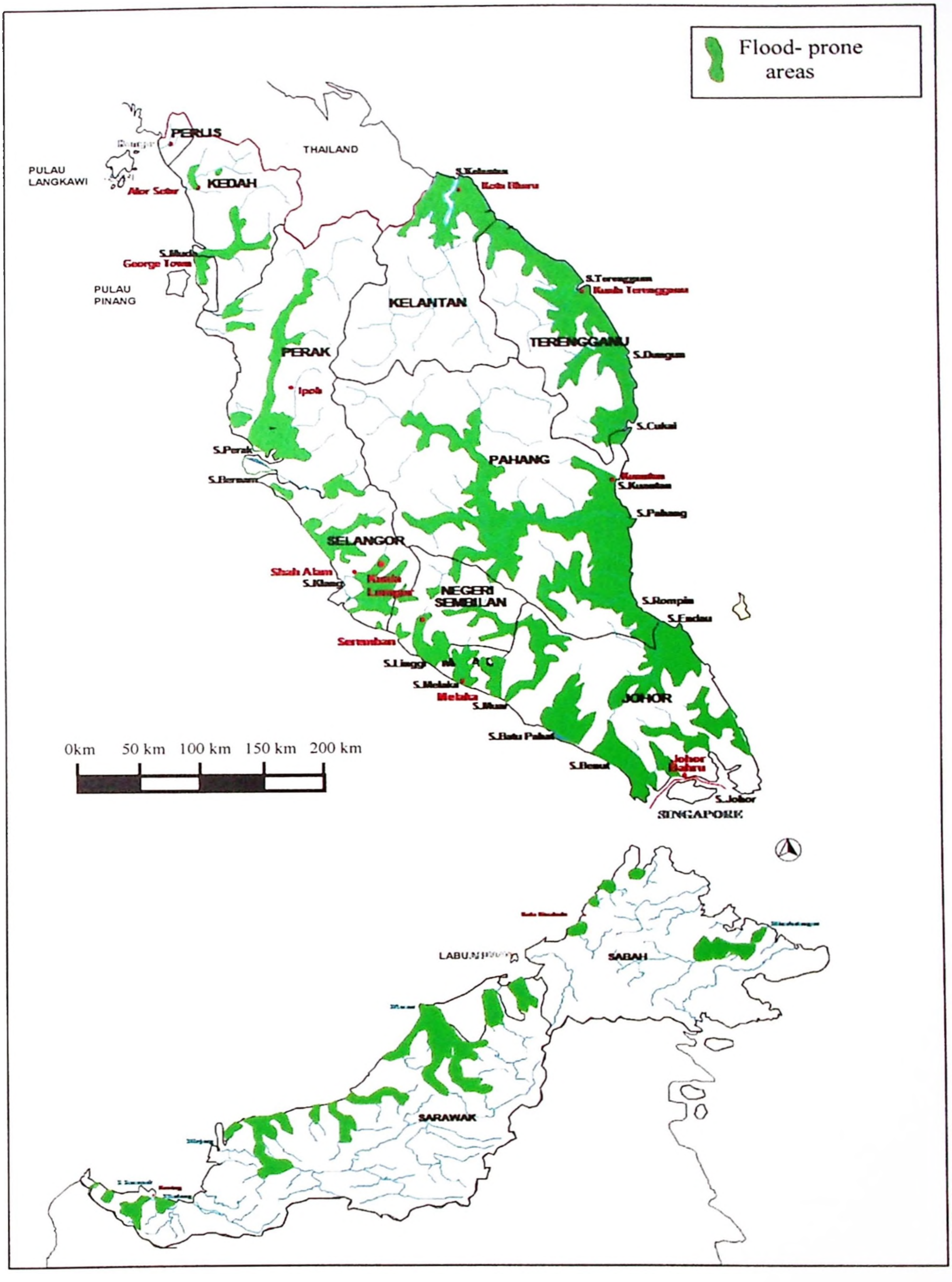

Figure 2.1: Flood prone areas in Malaysia (DID, 2011)

with the state of Pahang suffering the greatest loss in terms of economy, properties and crops. It also claimed 24 lives (DID, 2011). In 1996, Tropical Storm Greg brought floods in Keningau, Sabah claiming 241 lives and incurring 97.8 million dollars damages (Chan, 2012). In 2000, heavy rains cause floods once again in Kelantan and this time included Terengganu and killed 15 people and displaced over 10,000 people in the northern Peninsular Malaysia (Chan, 2012). In Johore, its worst flooding in 100 years was experienced in December 2006 as its first wave and January 2007, its second wave, which displaced some 312,386 population (Badrul Hisham, 2007). In 2010, floods have gravely affected transportation in states of Kedah and Perlis. Railways and roads have been closed including North-South Expressway including the airports. An estimated 8.476 million dollars worth of damages were incurred, four people wre killed and more than 50,000 people evacuated in both states (Chan, 2012). Even during the recent years, flooding across the country's flood prone areas is experienced. Some of the images of the flood occurrences in the country are shown in Figure 2.2 to Figure 2.4.

Incidences of flood are getting more common specially in rapidly urbanizing cities/towns. In a natural forest ecosystem, unlike urbanized areas, rainfall passes through several processes of infiltration, storage, and seepage which absorb part of the rainfall and retard its flow towards the river. During the urbanization process, formerly vegetated areas are converted into impervious surfaces. This adversely affects the whole hydrological process in that instead of infiltration, storage and seepage, stormwater flows are speedily conveyed towards downstream area and eventually cause flash flooding especially when excessive amount of rainfall takes place.

Other causes of flooding as listed in the DID's Flood Mitigation Publication on Managing Flood Problem in Malaysia (2010) are loss of flood storage as a result of development extending into and taking over flood plains and drainage corridors; inadequate drainage systems or failure of localised drainage improvement works extended insufficiently downstream; constriction at bridges and culverts that are either undersized or partially blocked by debris build-up or from other causes; siltation in waterway channels from indiscriminate land clearing operations; localised continuous heavy rainfall; tidal backwater effect and inadequate river capacity.

Figure 2.2: Muslims on small boats leave a mosque in floodwaters after Friday prayers in Tumpat, Kelantan state, Malaysia, Friday, Nov. 25, 2011 (Sulekha.com, 2011)

Figure 2.3: Flooding at the north-eastern town of Kuantan, Malaysia taken on December 24, 2012 (ABC Radio Australia, 2012)

Figure 2.4: Flash flood in Georgetown, Penang on 6th April 2013 (SAYS, 2013)

2.2 Flood Mitigation

In the pressing need to alleviate the nuisances brought about by flooding phenomena, mitigation measures for flood occurrences have been sought out by authorities and common folks as well. Knight and Shamseldin (2006) listed some of the basic principles in flood alleviation as follows: (a) reduction of flooding using structural measures, which involve construction of dams, flood detention basins, river training, high flow diversions among others; (b) reduction of susceptibility to damage which consists of mainly non-structural measures such as physical and mathematical models, flood forecasting and warning, floodplain development regulations and flood proofing of buildings; (c) reduction of impact of flooding which consists of disaster preparedness, education, insurance, improve emergency response and post flood recovery and (d) restoration of natural resources which also involve zoning, permanent evacuation, tax structure and national flood insurance scheme.

In general, flood mitigation measures can be broadly categorized as structural measures and non-structural measures.

2.2.1 Structural Measures

In the recent years, structural solutions to flooding problems were given more attention to the exclusion of non-structural measures. Structural measures are hard engineering solutions which aimed at controlling the flood. Increase in river capacity to accommodate excess runoff from drainage systems through channel upgrading is one form of such measure. Common practices in developed areas also include construction of dams, reservoirs, embankments, levees, retention ponds and diversion channels.

Following are few of the structural measures constructed for flood control purposes in Malaysia (DID, 2010).

2.2.1.1 Flood Control Dams

Constructed to retain flood water, these dams (Figure 2.5) function to protect areas downstream. Usually, dams were constructed for multiple purposes, such as water storage, water supply and flood detention. Dams have several contributions to further human advancement by means of making available reliable sources of drinking water and irrigation, hydropower, recreation, navigation and income (Brown et al., 2009). Furthermore, negative impacts brought about by climate changes such as flooding may be alleviated by controlling flows onto the flood prone areas by these flood control dams.

However, there have been concerns over physical, ecological and social impacts of the contruction of large dams. Aside from relatively high cost of dam construction, several social issues need to be taken into consideration before even starting the contruction such as transfer and resettlement of displaced inhabitants and disturbance of social, cultural and economic life in neighbourhood affected by the dam (Tilt et al, 2008).

Furthermore, there is this another concern for dam flooding which occurs when reservoir elevation breach the maximum level (Diman & Tahir, 2012). As a result, dam flooding takes place which aggravates flooding in river networks. Worse, lives and properties of inhabitants downstream of the dam are directly affected by these destructive floods.

Hence, construction of dams must take into extensive consideration the cost and benefits.

Figure 2.5: Flood control dams in Timah Tasoh, Perlis (Diman & Tahir, 2012)

2.2.1.2 Canalization and Related Works

Canalization (Figure 2.6) comprises of widening and deepening of waterways and lining of its banks and beds. Such works accommodate for greater amount of flows in the waterways thereby reducing vulnerabilities of neighbouring households from flooding. Undersized structures such as bridges are also replaced as the flood flows from urbanizing areas are increased. Canalization is usually applied together with dredging and construction of levees. However in urban areas, concrete embankments are usually constructed due to the restrained nature of river banks (Merriman and Brownitt, 1993).

Caution must be duly taken for this certain work as fluctuations of tidal water levels are imminent effects of estuarine waterways deepening (Niemeyer, 1998). Changes in the water levels begin right away after the deepening works and continue after dredging for a certain period of time until the balance between estuarine geometry and tide is reached. High priority is given to this quantitative changes of tidal peaks and tidal ranges due to deepening in order to determine its environmental impacts which are necessary for purposes of planning.

Figure 2.6: Canalization and related works (DID, 2010)

2.2.1.3 Flood Diversion Channel or Tunnel

Where widening or deepening of rivers are not feasible due to rigorous development along both river banks, such as rivers found in the major city centres, the viable solution to contain the increasing flood discharges is either to retain excess flood water downstream in storage ponds or divert these floods through a diversion channel or tunnel. This is already being undertaken under the Stormwater Management and Road Tunnel (SMART) Project in Malaysia. It aims to assuage flooding in the Kuala Lumpur City Centre by rerouting volumes of flood water to the constructed tunnel. The tunnel also functions not only as a stormwater channel but also a motorway, which is likely to ease traffic jamming at the southern gateway to Kuala Lumpur. Figure 2.7 shows the flood diversion tunnel in Malaysia.