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M.Sc. programme in
Coastal and Marine Management

CoMEM

Coastal flood risk assessment and coastal zone management

case study of Seberang Perai and Kuantan Pekan in Malaysia

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Thesis work done at the University of Southampton

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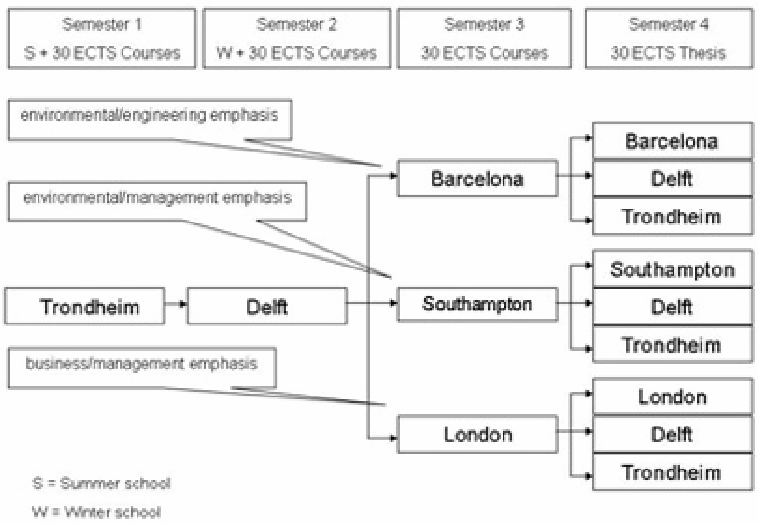

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SCHOOL OF CIVIL ENGINEERING AND THE ENVIRONMENT

COASTAL FLOOD RISK ASSESSMENT AND COASTAL ZONE MANAGEMENT – CASE STUDY OF SEBERANG PERAI AND KUANTAN-PEKAN IN MALAYSIA

JIANN CHYUAN HO

A dissertation submitted in partial fulfillment of the degree of
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ABSTRACT

The rise of sea level increases the risk of coastal flooding by increasing the probability of occurrence of flood event at a given height. The essence of coastal planning and management in the future relies on an accurate coastal flood risk assessment with regards to sea level rise. Through the set up of flood risk assessment model in Geographic Information System (GIS) using Shuttle Radar Topography Mission (SRTM) elevation data, flood height data, and sea level rise estimate based on IPCC high emission scenario, areas at risk of inundation at Seberang Perai (highly developed area) and Kuantan-Pekan (less developed area) in Malaysia were identified. Flood maps were produced subsequently. Damage costs associated with a given flood event were calculated through the identification land value of different land use categories. Four flood management tools had been utlisied in the study. They include "Do nothing", "Flood insurance", "No development" and "Hold the line". The cost-effectiveness of these flood management tools was evaluated over a course of 200-year based on a 1 in 200-year flood event for both study locations. Results from the study show that the effectiveness of flood management tools varies with location and land use pattern. However, in both locations, "Flood insurance" is concluded to be the most economically viable option for coastal zone management in Malaysia in the future as the damage cost incurred from a flood event is effectively reduced via the implementation of "Flood insurance" policy. Flood insurance is currently not a common practice in Malaysia. However, in order to reduce the uncertaities resulted from flood risk assessment, the study recommends more accurate elevation data to be captured for future analysis. Besides, it is also recognised that there is a need for Malaysia to maintain long term measurement of sea level.

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1. INTRODUCTION

Ancient communities along the Nile River, the Indus River, the Tigris-Euphrates Rivers, and the Ganges River relied on periodic flooding to replenish nutrients in deficit and to improve the fertility of soil for agricultural activities. However, in modern time, gone are the benefit of flooding and the primitive land use pattern. In recent centuries, coastal areas around the globe have undergone rapid modernisation and evolved into the most densely populated and economically vital areas on earth. And in many countries, such as the United Kingdom, the United States, China, India, Japan, Brazil, South Africa, and Australia, the largest economic centre centres are often located within the coastal zone and are expanding both landwards and seawards. The detrimental and adverse impacts to the living of mankind and the proper functioning of economic activities caused by flood event at any given height in these cities are beyond imagination. The nature of globalisation in today's business world also means disruption in a regional economic centre is equivalent to a global economic standstill.

Flood problem indeed is of global concern. Yangtze River Flood of 1935 (Wu, 2004), North Sea Flood of 1953 (Deltawerken, 2004) and Bangladesh Flood of 1991 (Hofer and Messerli, 2006) are examples of historic flood events at different parts of the world that had gobbled thousands of lives and had caused physical damages that worth millions. However, the bad news is the severity of coastal flooding problem is escalating over the last century and will continue to worsen in the future. The increasing settlement of inhabitants and the rocket speed of urbanisation process within the coastal zone and its conurbation are direct factors that contribute to the increase severity of coastal flooding problem. On the other hand, coastal flooding problem is also exacerbated by climate change factor, especially the rise of sea level (Nicholls, 2009). Increase in sea level causes flood at a given height to occur more frequently in the future than at present. Besides, the extent or the area at risk of inundation for floods at the same probability of occurrence also increases as the flood height increases in conjunction with sea level rise. In this study, the concept of coastal flood risk, where risk is a product of probability (of occurrence) and consequences is studied using a case study in Malaysia.

Located geographically outside the typhoon and earthquake zone, Malaysia is a considerably lucky country and is spared from these catastrophic natural disasters. Flooding, however, is considered as the most severe natural disaster experienced by Malaysia and it happens at a regular basis. It is estimated that the total flood prone area in Malaysia is about 29,800 km^2 or 9% of the total land area and flooding problem is estimated to affect approximately five millions or 21% of the total population (DID, 2007). Most floods occurred in Malaysia as a result of cyclical monsoons – the Northeast and Southwest monsoons – that normally bring heavy and regular rainfall in the country. Also, inadequate drainage system to curb with the excessive rainfall during monsoon seasons has also intensified flooding problem in Malaysia. However, a series of flood seen in Johor state of Malaysia in 2006 are believed to be extraordinary events that are closely related to new weather phenomenon and global climate change (Ministry of Natural Resources and Environment Malaysia, 2007). Nevertheless, work on the impact of climate change on the country have not been studied intensively, nor is there any establishment of regulations and guidelines designed for planning by taking into account the impact of climate change and the resultant sea level rise.

In Malaysia, the major issue related to coastal zone is the problem of erosion instead of flooding. From November 1984 until January 1986, the Malaysian government had carried out a National Coastal Erosion Study (DID, 2008). As a result of the study, Surat Pekeliling Am Bil. 5/87, or the General Circulation No. 5/87 was issued at 1987, aimed at reducing losses due to erosion and to eliminate costly protection works in the future (Midun, 1988). The government had also set up the Coastal Engineering Technical Centre within Department of Irrigation and Drainage Malaysia (DID) at the same year and charged the centre with task to implement coastal erosion control for the entire country. Subsequently, the government had carried out a National River Mouth Study in 1994 in an attempt to develop improvement programmes to alleviate coastal problem at river mouth area across the whole nation (DID, 2008).

The studies and improvement programmes carried out by the Malaysian government show that the focus of the government is concentrating heavily on coastal erosion problems. Although there have been studies on the impact of sea level rise in recent years, it is more as a subject of interest rather than a subject of necessity. In year 2007 saw a pilot study by DID to investigate the impact of sea level rise in Malaysia through the National Coastal Vulnerability Index (NCVI) Study (DID, 2007). However, as acknowledged in the NCVI study, the lack of long term sea level records has proven to be a major problem for an accurate estimation future sea level rise scenarios. It was also recommended that more studies are needed in the future to improve knowledge on sea level rise in Malaysia. Other than DID, National Hydraulic Institute of Malaysia (NAHRIM) has also shown interest in study pertaining to the impact of sea level rise in Malaysia. To date, however, coastal flood risk as a result of sea level rise has not been studied by the institution.

In view of the limited study pertaining to the impact of sea level rise on coastal flooding in Malaysia at present, there is a need to develop comprehensive flood risk management programme to reduce the risk of coastal flooding in the future. This should involve the production of flood risk maps that could facilitate coastal planners to base their decision making. This project attempts to develop a risk based simulation model by taking into accounts the rise of sea level, storm frequency and change in land use patterns in Malaysia. The objectives of this study consist of two major directions; the assessment of coastal flood risk and the management of coastal zone in conjunction with sea level rise scenarios. Specifically, the objectives of the project are:

- To identify data requirement for an accurate coastal flood risk study in countries with limited long term data record;
- To develop a generic approach for coastal flood risk assessment taking into consideration the impact of sea level rise that could be refined continuously with more accurate data input;
- To facilitate coastal planners and managers in Malaysia in decision making process by investigating the cost-effectiveness of different flood management tools using the approach developed above; and
- To investigate the cost-effectiveness of different flood management tools in coastal zone development in conjunction with changes in land use patterns.

The scope of work in this study include the data collection from Malaysia, the set up of simulation model in a GIS system to study the evolution of coastal flood risk caused by with sea level rise and land use patterns, the production of coastal flood risk maps indicating areas at risk of inundation, and to evaluate the long term cost-effectiveness of flood management tools, including construction of flood defences, flood insurance and setback development approach. The study period covers a length of 200 years as a means to provide a long term vision for coastal planners on the evolution of coastal flood risk in the future.

The structure of this report is organised as follows:

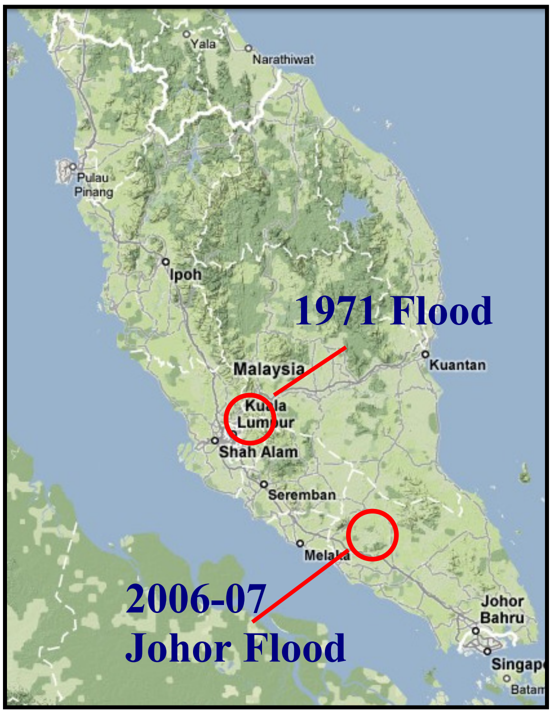
- Section 2 is the literature review pertains to background information study;
- Section 3 describes the data collected and the methodology developed in this study;
- Section 4 presents the results from simulations;
- Section 5 summarises and discusses the results presented in Section 4 follows by recommendations to improve future studies;
- Section 6 is the conclusion; and
- Section 7 lists the references used in this study.

2. LITERATURE REVIEW

In this section, coastal flood risk in Malaysia at present and in the future will firstly be studied. Thereafter, the existing flood risk management in the country will also be discussed. Lastly, case studies on flood management and planning for sea level rise in the United Kingdom, the United States and Australia are made. The aim for these case studies is to suggest possible flood risk management approaches that could be adopted in Malaysia in its planning for sea level rise. In this section, all monetary quotes are referred to the countries' respective currencies. For study in Malaysia, the Ringgit Malaysia (RM) is used where RM1 ≈ €5.00 or RM1 ≈ £5.50.

2.1 Coastal Flood Risk in Malaysia – Present Scenarios

Floods are the most disastrous natural hazard in Malaysia. Floodplains in Malaysia are estimated to cover an area of 29,800 square kilometres or 9% of the total landmass in the country (DID, 2007). The cost of damage resulted from undesirable flood events is expensive. The average annual flood damage is estimated at RM1bil (Abdullah, 2004). From the history of the cost of damage, a rising trend is observed. This is best manifested by comparing the cost of damage between the two most disastrous flood events in Malaysia – the 1971 Flood and the 2006-07 Johor Flood (Figure 2.1). The cost of damage for the 1971 Flood and the 2006-07 Johor Flood totalled at RM70mil (Chan, 1993) and RM1.5bil (Berita Harian, 2007) respectively. The escalating damage bill is attributed to uncontrolled development within the floodplains over the past decades. Major flood events normally occur during extreme monsoon seasons especially the Northeast Monsoon season which sees intense rainfall in the country. Kelantan, Pahang, Terengganu, Sabah and Sarawak states and other low-lying coastal region are often a victim of these extreme monsoon rains (Billa et al, 2006). Coastal flooding as a result of high tides meeting high river flow is prevalent at coastal cities such as Klang, Teluk Intan and several places in Penang. Penang is an area with the most intense coastal population and the pressure on land is greatly felt. The population density in Penang reaches 860 people per square kilometre and is comparable to the most densely settled parts of the Netherlands (DID, 2007). At present, more than 55% of the population live within the coastal zone which comprises only 9% of the total land masses in Malaysia (Lee and Teh, 2001).



Source: Google Map

Figure 2.1 Map indicating the location of 1971 Flood and 2006-07 Johor Flood in Malaysia

A study on the coastal flood phenomenon in Terengganu, Malaysia summarised that flood occurrence in Malaysia is the result of a combination of factors (Gasim et al, 2007). These factors include high intensity of rainfall which is also the primary cause of flood in Malaysia; low water current in river regime; back water phenomenon during high tides; and velocity and direction of wind that opposes the direction of river flow (ibid.). Flooding problem at Terengganu was also amplified by the nature of low terrain (ibid.). Although the coastal flood phenomenon in Terengganu was concluded to be a result of intense rainfall during monsoon seasons rather than sea storm, the change in global climate is expected to bring more intense rainfall and thus exacerbating coastal flood phenomenon in the future. In fact, the impact of climate change was experienced by Malaysia through the unprecedented 2006-07 Johor Flood (Ministry of Natural Resources and Environment Malaysia, 2007). Malaysia, despite located outside the typhoon zone, had seen extraordinary rainfall which is studied to be closely related to new weather phenomenon and Typhoon Utor (ibid.). In addition to natural causes, uncontrolled deforestation and rapid urbanisation development across the country are also important factors contributing to the risk (probability x consequence) of flooding Malaysia by increasing the consequences of flooding. The reduction in green area has resulted in surface runoff quantity and the flow velocity in urban area to increase significantly. Coupled by insufficient drainage provision, floods become more common nowadays (Abdullah, 2004).

Following the catastrophic 1971 Flood event, the Malaysian government had established a Permanent Flood Control Commission to study the short term preventive and long term flood mitigation in Malaysia. This commission is assisted by the Department of Irrigation and Drainage Malaysia (DID). Since then, DID has become the official governmental agency responsible for flood related issues in Malaysia. Under the collaboration of the Commission and DID, tremendous efforts had been poured into river basin studies, flood forecasting and warning system and the development of river basin management units to combat flooding problem in Malaysia (DID, 2007). Financial support from the government is also immense and continuous through the implementation of development plan, or more well known as the Malaysia Plan. The Malaysia Plan is an economic development plan to promote the welfare of all citizens and to improve the living conditions in rural areas (ibid.). Integrated in the many different versions of Malaysia Plan, DID has received handsome budget allocation from the government for river improvement and flood mitigation as a measure to reduce flood risk in the country (ibid.).

2.2 Coastal Flood Risk in Malaysia – Future Scenarios

As mentioned above, coastal flood risk in Malaysia is expected to increase in the future due to climate change. Climate change affects coastal flood risk in Malaysia in two possible ways: more intense precipitation during monsoon seasons and more frequent flood occurrence due to higher sea level rise. Although only the latter is taken into consideration in this study, the former factor will be briefly discussed in the following paragraph.

The Asian monsoon is governed by the distribution of Asian and Australian land masses and the surrounding oceans. Thus it is expected that global climate change will not disrupt the monsoon weather pattern in Malaysia in significant ways (Chan and Yap, 2001). However, based on a variety of global climate models, monsoon seasons in the future may see unexpected intense rainfall in Malaysia especially during the months from June to August (ibid.). As concluded from the coastal flood phenomenon study where intense rainfall during monsoon season is the primary cause of flooding (Gasim et al, 2007), higher intensity rainfall will inevitably increase the probability of coastal flooding in Malaysia.

Conversely, the impact of climate change-induced sea level rise is highly uncertain in Malaysia. The question on whether Malaysia is vulnerable to sea level rise currently remains unanswerable. This is mainly the outcome of the lack of long term sea level measurement in Malaysia. Under the auspices of Department of Survey and National Mapping Malaysia, a long term recording of sea level using automated instruments arranged in a network of observation throughout Malaysia only started in 1984. Therefore, only a total of 25-year measurement is ready for deployment at present. Nevertheless, a study based on these records has shown that no discernible significant long term trend of sea level rise could be observed (Lee and Teh, 2001). Nevertheless, it was observed that there was a 1.25mm/year change in sea level in Malaysia over the last 20-year (Zakaria et al, 2007).

Compared to global average estimates generated from Intergovernmental Panel of Climate Change (IPCC, 2001) and the observation that the region of Indonesia, Thailand and Bangladesh is experiencing an above average sea level rise (U.S. Environmental Protection Agency, 2009), the localised estimate is understated. Nevertheless, it is important to realise that projecting future trend of sea level rise based on measurements of only 25-year is highly inaccurate since it contains errors generated from spatial and temporal variability (Gornitz, 1994). Contrary to the aforementioned studies, geological evidence has shown that Malaysia is at least for the time being, not seriously threatened by sea level rise (Ong, 2001). Furthermore, it was concluded that with the current vertical sedimentation rate in Malaysia is sufficient to help maintain the sea level around the Malaysian coast if there is no tectonic change (ibid.). This sea level rise estimate issue will be dealt with in greater detail in Section 3.

Despite the uncertainties in sea level rise, several studies had attempted to estimate the likely impact of sea level rise in Malaysia. Nicholls and Mimura (1998) has concluded that one metre increase in sea level rise will cause 700 square kilometre (2.1%) of land loss and displaces more than 0.3% of the population in Malaysia. Moreover, one metre rise in sea level will also cause the loss of 180,000-hectare of agricultural land, 15%-20% of mangrove forests loss along the coastline, and possible relocation of shore-based power stations (Ministry of Science, Technology and the Environment, 2000). According to the National Coastal Vulnerability Index Study (DID, 2007), an average of 30% land loss is estimated at Langkawi Island and Tangjung Pia in Malaysia based on one metre sea level rise scenario.

In summary, although studies have shown that Malaysia has the possibility to suffer more intense rainfall and rising sea level as a result of global climate change, the vulnerability of Malaysian coastline and the risk of coastal flooding in the future remains uncertain. The uncertainty is concluded as a result of the lack of a long term sea level measurement and the generalisation of climate study using global climate models in future climate prediction. Despite studies have shown that the risk of coastal flooding in the future is anticipated to increase in accordance with sea level rise, there is no regulation and planning guideline specifically enacted to prepare the country for the impact of climate change at present.

2.3 Existing Flood Risk Management in Malaysia

Other than structural measures such as the construction of dams and levees, detention storage, diversions such as the Stormwater Management and Road Tunnel, or the SMART Tunnel constructed primarily to mitigate the recurring floods problem in Kuala Lumpur, the capital of Malaysia (SMART, 2009), flood risk management in Malaysia also sees the implementation of non-structural measures primarily focusing on the effort of real time flood forecasts and early warning system. The Department of Irrigation and Drainage (DID) has set up the infoBanjir national server to report real-time river levels, to provide river level forecasts for important flood assessment points and logistical support. Besides, the GEOREX flood system technology has also been developed in 2002 aiming to provide the Malaysian authorities with more efficient and reliable flood forecasting and monitoring system (Billa et al, 2004). The GEOREX system enables relevant authorities to undertake preventive measures to minimise the consequences of floods for local populations (ibid.).

Although the generation of flood warning well in advanced is crucial for an effective performance of flood relief works, flood management system relies heavily on the assistance of flood risk assessment in spatial planning. This can be achieved via the production of flood risk maps. At present, the development of flood risk maps in Malaysia is still a very slow process and is insufficient to be used for analysis. This situation is mainly driven by the lack of information especially ground elevation data and the infrastructure in floodplains (Mohd. et al, 2006). Nevertheless, acknowledging the need to plan and develop carefully within flood prone areas, attempts to produce flood risk maps has been started in Malaysia in recent years. One of the earliest efforts in the production of flood maps was the study aimed at a nation wide update on the condition of flooding through the National Register of River Basins programme, carried out alongside with the launch of the 8th Malaysia Plan (DID, 2003).

Lately, the production of flood risk maps has improved with the rapid development in spatial technology. Several studies on flood risk assessment integrating the use of Geographic Information System (GIS) have been carried out in the country. For instance, flood maps had been generated successfully for the river basin of Selangor River (Hassan et al, 2006) and Segamat (Mohd. et al, 2006) in Malaysia. In these two studies, it was concluded that by developing flood models using GIS, flood risk maps can be produced and used in decision support system to study the impact of human activities at catchment area of a river system (ibid.). The objective of this project is similar to these two studies where flood risk maps are produced using GIS models. However, this project focuses on coastal flooding instead of riverine flooding. Besides, this project also differs from the previous studies by integrating spatial planning policies into GIS models.

In order to study the impacts of sea level rise, the National Coastal Vulnerability Index Study (DID, 2007) was carried out collaboratively by DID and Universiti Teknologi Malaysia (UTM) in 2007. Although the study did not involve the production of flood risk maps, area at risk of inundation and the vulnerability of the Malaysian coastline to sea level rise from the aspects of geologic, coastal process, biological and socio-economic were studied at Langkawi Island and Tanjung Pia (ibid.). Instead of assessing quantitatively the risk imposed by sea level rise, the study identified qualitatively the risk at these two study stations by assigning appropriate indices to indicate the vulnerability of coastal zone to sea level rise.

Flood insurance as a non-structural flood risk management tool is not a common practise in Malaysia. The flood insurance industry is not well developed since floods are considered as the “Act of God” (Abdullah, 2004). Nevertheless, there are some private insurance companies that provide insurance against flood losses for a premium (Hiew, 1996). However, few property owners have subscribed to such coverage (ibid.). Furthermore, it is not a legal requirement to have flood insurance in Malaysia, neither is there any incentive from the government to promote flood insurance as an instrument for flood risk management in the country (ibid.).

2.4 Planning for Sea Level Rise

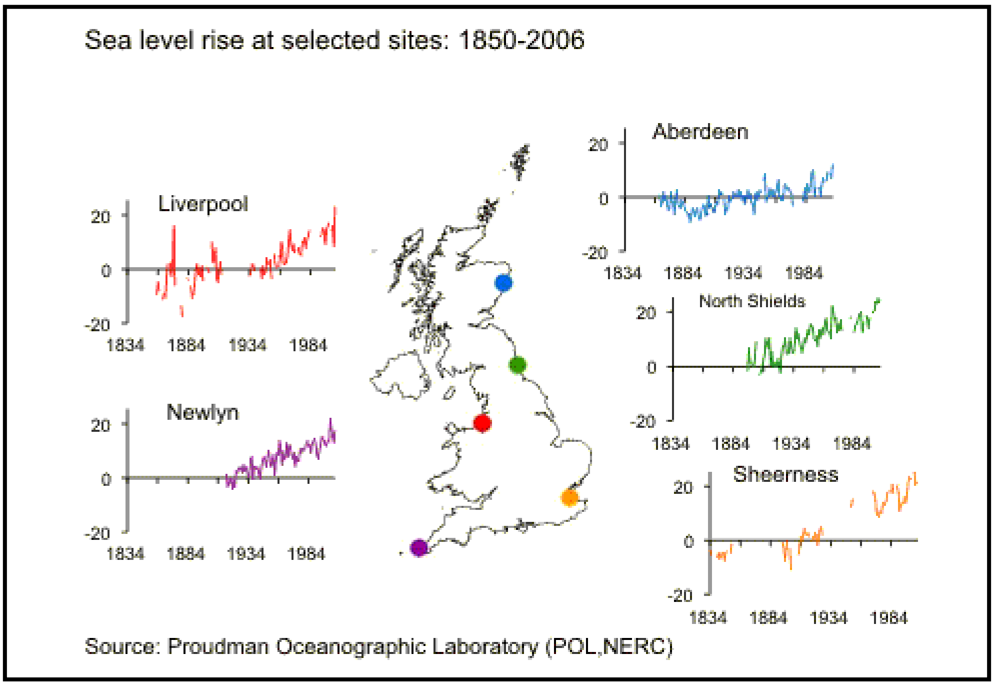
One of the main objectives of this project is to study the evolution of coastal flood risk in accordance with sea level rise and the associated risk assessment method is to facilitate coastal planners in their decision making. This objective is also known as planning for sea level rise. Proper planning based on careful study on the impacts of sea level rise will help avoid mistakes in spatial planning that require billions for rectification works at later stage. In this section, three case studies on planning for sea level rise in the United Kingdom, the United States and Australia will be studied.

2.4.1 Country Study 1 – United Kingdom

Protected by the 34,000km of flood defences, it is reported that over 5% of the United Kingdom (UK) population live in 12,200km^2 area that is at risk of riverine and coastal flooding (Hall et al, 2005). Several forms of flooding prevalent in the UK are river flooding due to water exceeding the river channel capacity, coastal flooding caused by storm surges and high tides, land flooding as a result from the inability of land to absorb intense rainfall in short duration, groundwater flooding as water levels rise above surface elevations, and flooding from sewers when sewer is overwhelmed by heavy rainfall (PPS25, 2006). The principal national government body responsible for flood and coastal erosion risk policies in England is the Department for Environment, Food and Rural Affairs (DEFRA) where as the principle regulator responsible for delivery of flood management strategy is the Environment Agency (EA). DEFRA funds most of EA's flood management activities in the UK.

In recent years, the availability of remotely sensed data and other national datasets have enabled flood risk assessment in England and Wales to be conducted at national scale. The EA has introduced a National Flood and Coastal Defence Database (NFCDD) in 2002 and provided an inventory of flood defence structures and their overall condition in a digital database (Hall et al, 2005). And recognising the need to improve the performance of flood defences as a system and not single entity at any location in the UK, the Risk Assessment of Flood and Coastal Defence for Strategic Planning (RASP) was launched jointly by DEFRA and EA in order to develop balanced, integrated risk management strategies for dealing with systems of flood defences (Hall et al, 2003). At present, the government is drafting new legislation, the Floods and Water Management Bill, for managing flood and coastal erosion risk in England and Wales. The bill sees the creation of Regional Flood and Coastal Committees that will advise the EA and local authorities on flood and coastal erosion approaches (DEFRA, 2009). Other than flood defences and legislations, insurance also plays an important role in the flood risk management in the UK. An informal partnership that is based on the division of responsibilities is developed between the government and the insurance companies (Lin et al, 2007). Insurance companies have to provide relatively cheap flood insurance regardless of the risk level while the government has to undertake adequate flood defences and control over development at floodplains (ibid.).

Despite the uncertainties in sea level rise projection, the UK has seen significant incorporation of climate change factor, especially sea level rise for planning purpose at national level (DEFRA, 2008). Referring to Figure 2.2, based on the five longest sea level records in the UK covering a period of 150-year, the rate of sea level rise in the UK is observed to fall within a range between 0.6mm/year to 2.0mm/year (ibid.). Through the study of climate change scenarios and the projection of sea level rise in the next century under the United Kingdom Climate Impacts Programme (UKCIP) and Foresight Futures project, DEFRA has promoted policy guidance, or more specifically the Flood and Coastal Defence Appraisal Guidance (FCDPAG3), that enables Operating Authorities to take climate change impacts into account in planning, appraisal, decision making and operations (DEFRA, 2006). The guidance acknowledges the uncertainties in climate change predictions and thus suggested higher allowances for flood and coastal risk management and planning. The range of net sea level rise suggested in FCDPAG3 for 2085-2115 time slices is between 13 to 15mm/year, significantly higher compared to historical trend of sea level rise (ibid.). On the other hand, a new management strategy has also been developed under the title of "Making Space for Water" by DEFRA with increasing emphasis on ecological enhancement and non-structural solutions. These include managed realignment and wetland creation (DEFRA, 2005).



Source: DEFRA 2008

Figure 2.2 Long term British Isles sea level records

2.4.2 Country Study 2 – United States

In the United States (US), the most highly desirable and rewarding sites for most kinds of human activities are concentrating at coastal and riverine floodplains. However, eight out of ten costly disasters in the US history were widespread flooding resulted from hurricane (Lin et al, 2007). The damage cost caused by flooding is estimated to be more than USD2 billion and thus make flood the most hazardous natural disaster in the US (ibid.). Coastal flooding in the US is primarily caused by the hurricanes. Other causes include winter storms, tsunamis and rising sea level (FEMA, 1992). Like many other activities in the US, floodplain management is carried out within a structured framework that sees different roles played by the federal, state and local governments, regional entities and also the private sectors. The leading organisation formation is at the federal government level where the Federal Emergency Management Agency (FEMA), an independent agency that reports directly to the President of US, is charged with the tasks to respond to, planning for, recovering from, and mitigating against flood disaster (ibid.).

In general, four core strategies have been adopted in the US to reduce flood damage. The effectiveness of floodplain management using these four strategies is deemed difficult to be assessed. However, the needs for more specified goals and the need for comprehensive database for better flood management were acknowledged in an assessment (FEMA, 1992). The four core strategies are:

- Modify susceptibility to flood damage and disruption by avoiding dangerous, undesirable, uneconomic and unwise use of floodplains;
- Modify flooding via the provision of structural means such as dams, reservoirs, dikes, levees, floodwalls and shoreline protection works to alter the flood itself;
- Modify the impact of flooding on individuals and the community by helping communities to prepare and recover from floods thorough the dissemination of information and education; and
- Restore and preserve the natural and cultural resources of floodplains by setting aside floodplains from development.

Under the third strategy, it also sees the initiation of National Flood Insurance Programme (NFIP) in 1968. Under the NFIP, it is mandatory for residents of high risk areas to acquire flood insurance (Official site of NFIP, 2009). High risk areas are defined as areas have a 1% or greater chance of flooding in any given year (ibid.). Through the development of flood maps by the government, the American insurance industry has been able to assess risk and estimate damage well. However, the cost of providing flood insurance still remains high in the US especially after the occurrence of Hurricane Katrina (Lin et al, 2007). Besides, the assured financial assistance from the federal government in the event of flooding has also reduced the inclination of property owners to invest in flood insurance (ibid.).

At present, no specific measures has been taken by most of the organisations in the US to prepare for sea level rise. Recently, however, possible response options have been assessed by many public and private organisations. The Coastal Zone Management Act enacted by the federal government has started to include sea level rise in the list of hazards that states should address since 1990 (Titus, 2009). This congressional mandate has resulted two largest coastal related organisations in the US, the National Oceanic and Atmospheric Administration (NOAA) and the US Army Corps of Engineers (USACE) to include the prospect of sea level rise in their studies and planning guidance. At state level, the implications of sea level rise have been considered by state governments in a number of states. For example in Maryland and Florida, currently there have been programmes in place for acquiring vulnerable coastal areas (Cooper et al, 2005). And in New Jersey, through the enactment of Garden State Preservation Trust Act, one million acres of open space, farmland and historic land will be preserved by 2009 (ibid.). On the other hand, a few local governments have considered the implication of sea level rise for roads, infrastructure and floodplain management. For instances, ways to decrease the impacts of storm surge by construction of flood walls has been looked by the New York City Department of Environmental Protection (Titus, 2009). Meanwhile, Miami-Dade County is Florida has also start developing maps to indicate areas at risk of inundation to study the vulnerability of the county to sea level rise (ibid.).

2.4.3 Country Study 3 – Australia

Floods are the most expensive natural hazard experienced in Australia and the average annual flood damage cost mounts up to AUD350 millions (Bretnall, 2000). The most severe flood problems occur in the states of New South Wales and Queensland where the combined average annual damage cost is over AUD270 millions (ibid.). Similar to the United States, the responsibility of flood management lies on the shoulders of all levels of government and the different departments and agencies within the government (McLuckie, 2008). Guidelines are set at the national level while the power of planning is given at state level. In Australia, the production of flood maps is typically the remit of the local councils and thus the style and content of the maps differ from region to region (ibid.). At national level, the formation of the National Flood Risk Advisory Group (NFRAG) provides advice to the Australian Emergency Management Committee (AEMC) and its other committees on flood risk management. Besides, NFRAG also provide national guidance on flood risk management through an update of the Australian Emergency Manuals on flood management published by Emergency Management Australia (ibid.).

Flood management in Australia is a combination of structural and non-structural measures. Structural flood mitigation measures include levees that protect existing development from flooding, detention basins, and flow capacity expansion works in the floodplain (ibid.). Besides, flood forecasting and warning, assistance in flood response and availability of infrastructure critical in response to and recovery from flood events are ensured by the governments (ibid.). Regarding non-structural measures, flood insurance is seen as an important tool for the recovery of communities after a flood event by the government. However, the government has adopted hands-off policy on flood insurance provision and thus causing the insurance scheme fails to work well (Lin et al, 2007). Generally, insurance cover is not readily available in Australia and comprehensive flood insurance is deemed financially unfeasible due to weak demand (ibid.).

In view of the impacts of climate change, planning in many States has seen a trend to incorporate the likely impact of sea level rise. However, the question of what amount of sea level rise should be assumed for planning purpose remains as the most debated topic amongst these States. Similar to flood management in Australia, planning for sea level rise sees a divided responsibility between the national and state level governments. National guidelines has identified marine climate change and its effect on the coastal zone and has set out the priorities in research for coastal and ocean engineering in Australia (Institution of Engineers, Australia, 2000). On the other hand, at state levels, although all local councils in Australia has included sea level rise in their planning schemes at present, the recent adoption of statutory planning schemes in a number of States indicates a change in the local planning environment (Walsh et al, 2004). For example, the definition of coastal hazards in the New South Wales Coastline Management Manual has taken into account the impacts of sea level rise. Besides, the state coastal plan of Queensland also states that the impact of climate change must be addressed in coastal management plan (ibid.).

2.4.4 Conclusion

Dealing with the issue of planning for sea level rise, the United Kingdom has shown that the responsibility of the enactment of relevant regulation and guidelines rests on the shoulder of federal government. In the United States and Australia, however, it is the remit of state government to establish planning guidelines and thus resulted in guidelines in different forms that are tailored for individual states. Nevertheless, all three countries show that flood insurance is a crucial flood management tool in reducing the risk of flooding in these countries. However, the implementation of flood insurance has varied degree of success in these countries. In Malaysia, neither the planning guideline prepares the country for sea level rise, nor has the implementation of flood insurance been adopted by the government. Comparing to these three countries, flood risk management in Malaysia inclines towards curative approaches and relies heavily on structural measures.

3. DATA AND METHODOLOGY

3.1 Locations of Study

Two locations were selected for this study. The first location is the Seberang Perai (also known as Province Wellesley in English) coastline bounded between Sungai Perai and Sungai Junjung of the state of Penang. The second location is the Kuantan-Pekan coastline bordered by Sungai Kuantan and Sungai Pahang of the state of Pahang. Both study locations are located within the Peninsular Malaysia. Seberang Perai is situated at the west coast where sea climate is generally mild as it is sheltered from the Southwest monsoon by Sumatra Island of Indonesia. Sediment along the west coast is mud dominated. On the other hand, Kuantan-Pekan coastline is located on the east coast. The east coast is exposed to South China Sea and thus is generally more susceptible to rough sea climate especially during the Northeast monsoon season. A sandy coastline is prevalent along the east coast. Figure 3.1 depicts the locations selected for this study.

Source: Google Earth images

Figure 3.1 Seberang Perai (left) and Kuantan-Pekan coastlines depicting different level of development; Locations of study area in Southeast Asia Region (insert)

It is the aim of this study to evaluate the impact of coastal flooding at areas with different levels of development at present and in the future. Therefore, these two locations were selected as they represent different land use patterns. Seberang Perai is a highly developed industrial and residential area whereas agricultural activity is the main occupation along the Kuantan-Pekan coastline. Nevertherless, for Kuantan-Pekan, an exception in the general land use pattern is seen in the vicinity of Kuantan city where urban and commercial areas are prevalent. The Kuantan-Pekan coast is also a study area recommended in the National Coastal Vulnerability Index (NCVI) Study of Malaysia (DID, 2007).

3.2 Data

3.2.1 Elevation Data

An accurate elevation data is the fundamental requirement in this study because all flood heights and sea levels were derived in relation to land elevation. Flood scenarios are simulated using an accurate digital terrain model (DTM). Therefore, it is crucial to procure the most accurate elevation data for the production of an accurate DTM. It is noteworthy that DTM is terrain model of the bare earth where vegetation, buildings and flood defence structures are digitally removed. Three elevation data options suited for Geographic Information System (GIS) work environment were considered in this study. These include DTM released by Department of Survey and Mapping Malaysia (JUPEM), Light Detection and Ranging (LiDAR) data captured specifically for the purpose of this study, and Shuttle Radar Topography Mission (SRTM) elevation data. It was decided to utilise SRTM data in this study after attempts to obtain DTM released by JUPEM and LiDAR data were challenged by both authorisation and cost factors. However, the major issue in utilising SRTM data is the low level of accuracy of the data.

Shuttle Radar Topography Mission (SRTM) Elevation Data

Shuttle Radar Topography Mission (SRTM) is an international project pioneered by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA) in the United States (US) to obtain elevation data on a near global scale. SRTM data was obtained during an 11-day mission in February 2000 by circulating a specifically modified radar system that flew onboard the Space Shuttle Endeavour. The radar system utilised dual Spaceborne Imaging Radar (SIR-C) and dual X-band Synthetic Aperture Radar (X-SAR) configured as a baseline interferometer, acquiring two images at the same time. This technique is known as Interferometric Synthetic Aperture Radar (USGS, 2004). The SRTM digital elevation model obtained for this study is the Seamless SRTM Finished 3 arc-second data. As the name suggests, it has a horizontal resolution of 3 arc-second (approximately 90m). According to the US Geological Survey which hosts the National Map Seamless Server for SRTM data downloads, the absolute horizontal and vertical accuracies of SRTM Finished 3 arc-second are 20m (circular error at 90% confidence) and 16m (linear error at 90% confidence) respectively (ibid.). However, it was reported by the same institution that the vertical accuracy is actually significantly better and is closer to +/- 10m. The horizontal and vertical datums for SRTM data are both based on the World Geodetic System 84 (WGS84).

The major concern in utilising SRTM data in flood analysis is the level of accuracy of the data. Flood events often distinguish amongst each other in just 0.01m height difference. The aforementioned vertical accuracy of SRTM data at +/- 10m is therefore clearly insufficient for the purpose of this study. In a study to assess the vertical accuracy of SRTM data, Miliaresis and Paraschou (2004) had however concluded that the vertical accuracy of SRTM data was found to be terrain class dependent and that SRTM data has a propensity for showing greater inaccuracy at sloping regions than at plane ones. A further study by Miliaresis (2007) attempted to investigate the influence of slope had further strengthened the theory that the vertical accuracy of SRTM data reduces with increasing slope. Since coastal regions are normally plane rather than sloping, it can thus be concluded that the use of SRTM data for flood analysis will not see a vertical inaccuracy as much as +/- 10m. However, it should be borne in mind that although studies had shown that SRTM data has a higher vertical accuracy at plane regions, the magnitude of error is still in the order of a metre.

In order to verify the accuracy of SRTM data, a direct comparison between SRTM and LiDAR data obtained for the Solent region, United Kingdom was carried out in this study. LiDAR elevation data which was used as a reference in this exercise was obtained by utilising optical remote sensing technology that measures the properties of scattered light to find the range of a distant target. The accuracy of the LiDAR data obtained for the Solent region is +/-0.15m (Therry, 2008). A total of 300 elevation test points were compared for three locations – Southampton, Portsmouth and Exbury – of 1 square kilometre each. As recommended by Miliaresis (2007), test points should be well distributed and representative of the terrain. Thus, these locations were selected as they represent different land use patterns and levels of development in the Solent region. Test points with differences in elevation exceeded 4m were deemed "noises" and were filtered out during the analysis. The summary of the analysis is shown in Table 3.1 and detailed result.

Table 3.1 Results for direct comparison between LiDAR and SRTM data

Location	Mean Difference (m)	Standard Deviation (m)
Exbury	0.43	2.17
Portsmouth	0.12	1.79
Southampton	0.16	1.79
Average	0.22	1.91

The mean and standard deviation of the difference in elevation between SRTM and LiDAR data obtained from the verification study are 0.22m and 1.91m respectively. It can thus be concluded that the vertical accuracy in flat area is relatively small compared to the accuracy range reported by USGS. The result conforms with the literatures that SRTM data has a higher vertical accuracy at plane regions. However, the standard deviation of the differences found in this study is large for a satisfactory flood risk analysis since flood heights normally differ from each other in the order of centimetre. Therefore, in order to compensate the low level of accuracy of the SRTM data, it was decided that for the purpose of flood scenario simulations, two additional flood levels, +/- 2.0m (rounded up from 1.91m average standard deviation) from a targeted flood height were included in simulations. This practice will allow the generation of a range of possibility surrounding a flood at given height at slightly more than the 70% confidence level. The horizontal spatial resolution of the downloaded SRTM data (approximately 90m) was deemed ineffective for flood scenario simulations as the elevation of the topography has been averaged out within an area of approximately 8000-square metre. Therefore the data was resampled using a bilinear option in the GIS work environment to smaller cell sizes in order to improve the nature of topography represented by the dataset. The resampled data has a cell size of 5m and this cell size was used throughout the entire study for different data set in order to maintain consistency.

3.2.2 Sea Level Rise

According to the National Coastal Vulnerability Index (NCVI) Study of Malaysia, local sea level rise estimates had been derived from tidal observations at two pilot stations situated at the northern and southern most of Peninsula Malaysia. Tidal records from these stations for the past 10 and 20 years were studied. The rates of sea level rise were estimated at 0.18mm/year and 1.25mm/year respectively (DID, 2007). However, the reliability of sea level rise estimates that are based purely on tide gauge records for duration of only 10-20 years is questionable. This is mainly due to the problems with data quality and physical processes that introduce a high level of spatial and temporal variability. Variations in winds, river runoff, ocean currents and vertical earth movements are examples of the sources of uncertainty in sea level data (Gornitz, 1994). In a study attempted to interpret global sea level change, Douglas (1995) had also concluded from a series of literature review that if tide gauge data alone is used for sea level rise analysis, a continuous sea level record of at least 50 years is an absolute minimum. Besides, the rise and fall of sea level is significantly affected by the 18.6-year nodal tidal cycle. Therefore, it is recommended that sea level rise projection should take into account the effect of nodal tidal cycle by including multiple nodal tidal cycles in the computation of sea level trends (Gratiot et al, 2008). Nevertheless, it is recommended in the NCVI study that a longer period of observation is indeed needed in order to estimate in higher precision the rate of sea level rise in Malaysia in the future (DID, 2007).

Four sea level rise scenarios were considered in this study. Conforming to the need for a long term tidal records in sea level rise analysis, only localised estimate generated from 20 years record (1.25mm/year) was considered in the following section. This is the first of four scenarios, hereafter localised scenario. The other three scenarios generated from the Third Assessment Report (TAR) of Intergovernmental Panel of Climate Change (IPCC) are global low emission, global average emission, and global high emission. The rates of sea level rise for these scenarios are 3mm/year, 5mm/year and 9mm/year respectively (IPCC, 2001). All four scenarios are illustrated graphically in Figure 3.2.

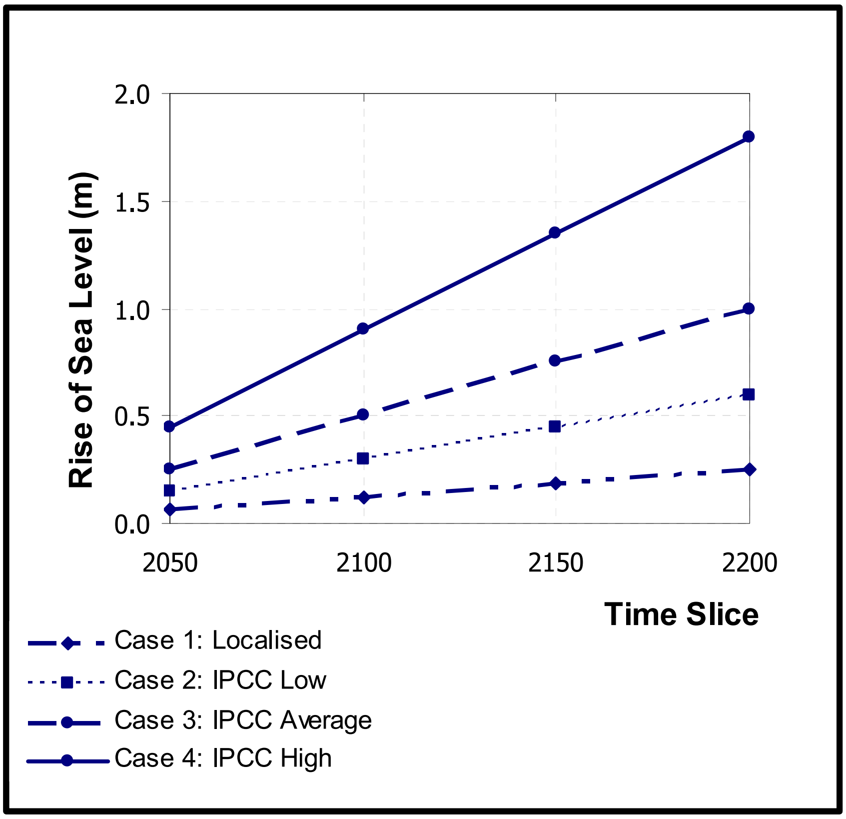


Figure 3.2 Four scenarios of sea level rise considered in this study

From Figure 3.2, the stark differences amongst the four scenarios considered in this study are evident. Since the objective of this study is to develop a generic approach for coastal flood risk assessment, only one of the four rates of sea level rise was taken into consideration. The IPCC high emission scenario was selected in this study based on the following reasons:

- The localised sea level rise estimate was generated based on very short recording period (10 to 20-year) and thus is error prone. Sources of error include problem with data quality; spatial and temporal variations which have not been taken into account; and the record covers only one nodal tidal cycle and thus had captured significant variation in the measured sea level;

- The rate of sea level rise is expected to accelerate in the future due to rapid global climate change. However, this acceleration factor was not considered in this study and rate of sea level rise remains constant throughout the study. Thus higher rate of sea level rise was used to compensate this simplification;
- It is reported in IPCC Fourth Assessment Report (AR4) that countries such as Indonesia, Thailand and Bangladesh are experiencing above average sea level rise (IPCC, 2007). Since Malaysia is located in the same geographical region, a higher rate of sea level rise is therefore considered;
- The sea level rise projection in IPCC covers only until the 2080s. However, the study period used in this project is further into the future until 2200. In order to allow for uncertainties beyond year 2080, higher rate of sea level rise is therefore chosen for the study; and
- As mentioned in Section 2.4.1, although the historical trend of sea level rise observed in the United Kingdom is between 0.6 to 2.0mm/year, DEFRA has suggested that sea level rise allowances of up to 15mm/year for the coming century should be used in flood risk management and planning. Since this project also serves as a tool for planning and management purpose, higher rate of sea level rise is therefore selected.

3.2.3 Flood Height Data

The frequency of a flood event occurs at a particular height (probability) determines the associated risk (probability x consequences) of the flood event at an area. Ideally, the probabilities of occurrence at different heights are estimated via probability distribution analysis where recorded extreme high water events for a minimum of past 30 years are used. A record of this length is also necessary to estimate a 1 in 100-year flood event at any degree of accuracy. However, observed tidal records were not successfully obtained during the analysis period of this project. Therefore, it was decided to use the XTide tide prediction server (Flater, 1998) in this study. XTide is an online server that generates tide and current predictions for various locations around the globe. For the purpose of this study, Penang and Kuantan were selected. The major drawbacks for using XTide to generate hindsight predictions are:

- The algorithm used for tides prediction in XTide is the same as the one used by the National Ocean Service in the U.S. and thus predictions tend to be more accurate for the U.S than for other locations in the world. Besides, the accuracy of the prediction is also depends on the changes of topography;
- Although it is technically viable to generate hindsight prediction tides with XTide, the predictions are unverifiable; and
- Tidal levels generated by XTide are only predictions and not actual extreme high water events. Actual recorded extreme high water events serve as important information for the determination of flood recurrence interval. However, this issue could be resolved if observed tidal levels were used in the analysis in future.

The XTide predictions were utilised since no better dataset was available during the analysis period. However, it is strongly recommended that observed tidal levels in the past should be obtained from Department of Survey and Mapping Malaysia in order to improve the accuracy of the study. Or at the very least, a study of the hindsight predictions by XTide should be verified before they are used.

In this study, the probability of occurrence for present flood scenario was calculated using Weibull equation,

$$P = R / (N+1) \qquad \text{Equation 3.1}$$

where R is the rank number and N is the total number of observations. A total of 38 annual maximum water levels for year 1971-2008 were used in this exercise. The probability curve for present scenario was then plotted onto a Normal distribution chart and floods at different probabilities of occurrence can be estimated from the chart. In addition to the present sea level, sea level rise scenario at year 2150 based on estimates generated using IPCC high emission scenario selected in Section 3.2.2, were also plotted to depict the impact of sea level rise on flood height in the future. It could be seen from these charts that flood at any given height will occur more frequently in the future (higher probability of occurrence) due to the rise of sea level. These plots are as shown in Figure 3.3.

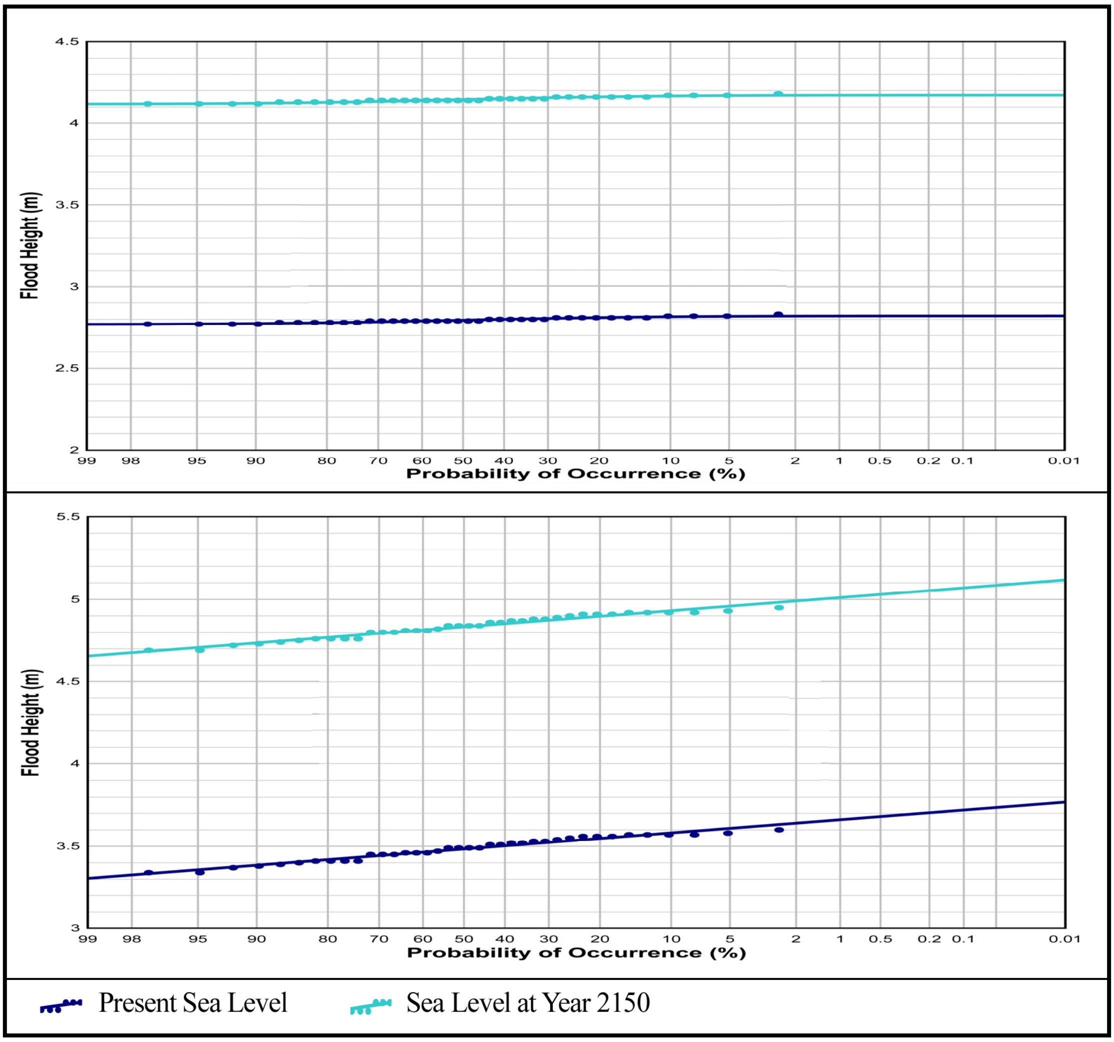


Figure 3.3 Probability of flood occurrence at Seberang Perai (above) and Kuantan-Pekan at present and at year 2150 when sea level rise is considered

Based on Figure 3.3, future estimates of flood height at different recurrence intervals were estimated for four time slices at 50-year steps. These estimates are summarised in Table 3.2.

Table 3.2 Future estimates of flood height at given recurrence interval

(a) Seberang Perai (Highly Developed Area)

Recurrence Interval (yr)	**Flood Height at Different Time Slices (m)**				
	Present	**2050**	**2100**	**2150**	**2200**
1 in 2	2.79	3.24	3.69	4.14	4.59
1 in 5	2.81	3.26	3.71	4.16	4.61
1 in 10	2.82	3.27	3.72	4.17	4.62
1 in 50	2.83	3.28	3.73	4.18	4.63
1 in 100	2.84	3.29	3.74	4.19	4.64
1 in 200	2.84	3.29	3.74	4.19	4.64
1 in 1000	2.85	3.30	3.75	4.20	4.65

(b) Kuantan-Pekan (Less Developed Area)

Recurrence Interval (yr)	**Flood Height at Different Time Slices (m)**				
	Present	**2050**	**2100**	**2150**	**2200**
1 in 2	3.48	3.93	4.38	4.83	5.28
1 in 5	3.55	4.00	4.45	4.90	5.35
1 in 10	3.58	4.03	4.48	4.93	5.38
1 in 50	3.64	4.09	4.54	4.99	5.44
1 in 100	3.66	4.11	4.56	5.01	5.46
1 in 200	3.68	4.13	4.58	5.01	5.48
1 in 1000	3.72	4.17	4.62	5.07	5.52

3.2.4 Land Use and Damage Values

Land Use

In modern city planning, portions of land are assigned to different categories such as commercial, residential, industrial, agricultural and natural reserve. In the context of the flood damage, it is evident that for the same area of land, the value of industrial area is higher than agricultural area as industrial area is occupied by equipment plants that are worth significantly higher than crops. In addition, developed cities also tend to be the hubs for key infrastructures and facilities such as hospital, electricity stations and telecommunication centres. The purpose of this study is to identify the risk associated with coastal flooding where risk is the product of probability and consequences (value of damage). Therefore it is crucial that different land use patterns are clearly identified and are valued appropriately. Using the flood damage values obtained from the report of National Register of River Basin Malaysia (DID, 2003), the major land use patterns in this study were classified as industrial, residential and agricultural. A total of ten sub-categories of land use were identified in this study and are depicted in Figure 3.4. Three sub-categories were assigned to both urban and rural residential areas in order to depict the density of housing in these areas. The definition of housing density is as given in Table 3.3. However, it is noteworthy that to base housing density on the number of dwellings per hectare is only for the purpose of simplicity and it can lead to a skewed result in risk analysis. This is because in the case of a flood event, only the ground level of a high number of dwellings tower block will be affected and not the entire building. Besides, housing definition based on density of houses doesn't discriminate individual worth of houses but is generalising the value of properties. Thus, the value of damage maybe overestimated or underestimated. Therefore, if the precise calculation of the value of damage is required, it is recommended that building density is expressed in term of remedial cost required for repair after a flood event. Similarly to residential area, three sub-categories were also assigned under the umbrella of agricultural area. These are paddy field, tree crops and mixed crops field.

Table 3.3 Definition of housing density for both urban and rural residential areas

Categories of Housing	Dwellings/Hectare
High Density	100
Medium Density	50
Low Density	35

For the identification of land use categories, Google Earth images were downloaded for both study locations. A total of 30 images were used for Seberang Perai (highly developed area) whereas 180 images were used for Kuantan-Pekan (less developed area). The size of one image downloaded was 1280x706 pixels. Images for both study locations were downloaded at different zoom levels depending on the resolution of images for a satisfactory identification. For the case of Kuantan-Pekan, the resolution of the images downloaded from Google Earth was deemed insufficient for land use identification as the images were partially blocked by clouds. This problem was overcome in this study by assuming land use pattern based on adjacent land use category. It is concluded in this study that Google Earth images are not the ideal dataset for the purposes of land use identification. It is recommended that the identification of land use patterns from the most recent topographic maps is more preferable. The utilisation of topographic maps in this study was ruled out by the challenge to obtain the maps from the Mapping and Survey Department of Malaysia.

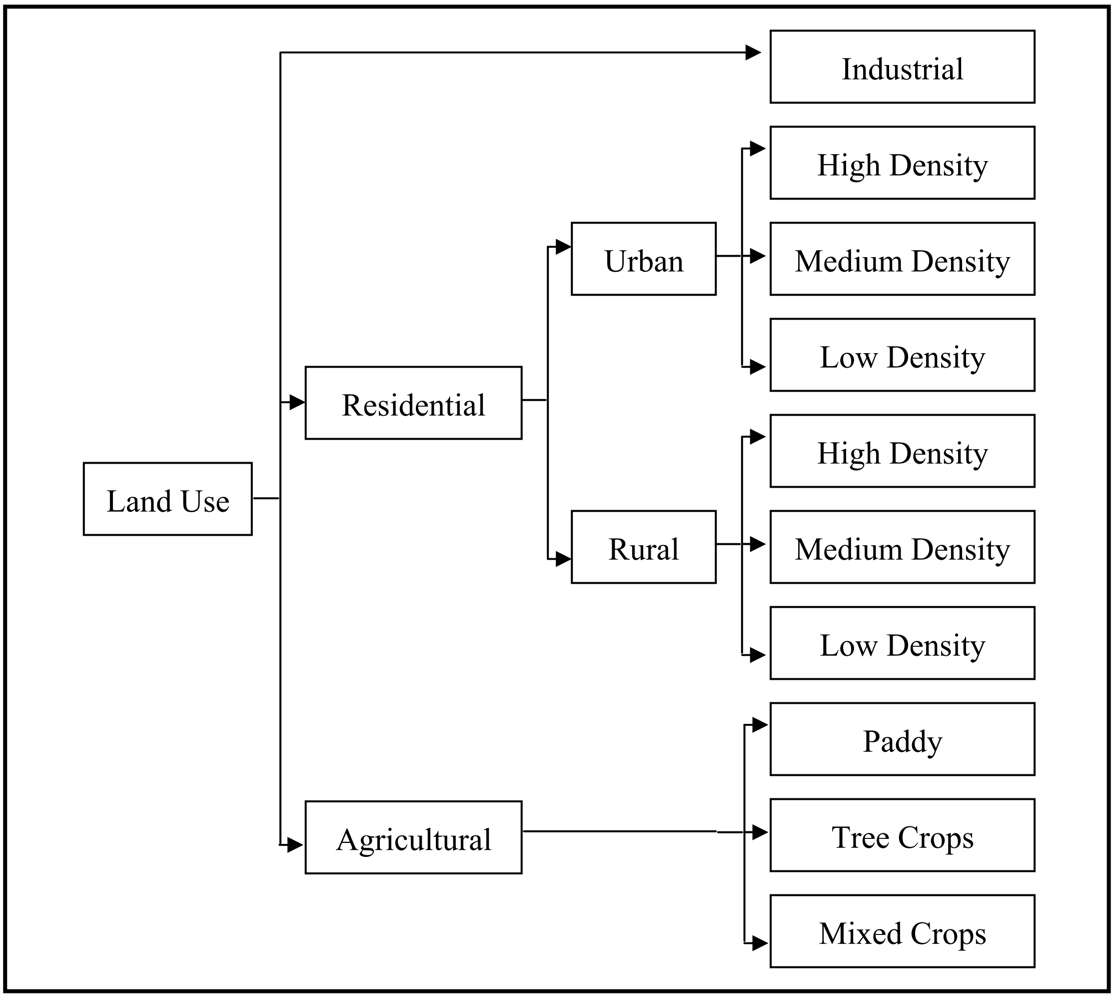


Figure 3.4 Land use classification used in this study

Damage Values

The estimation of damage cost in a flood event in Malaysia was achieved using the report of National Register of River Basin (DID, 2003), as shown in Appendix. The cost estimation was subdivided into two major categories – building/properties and crop production. Cost estimation from studies conducted in year 1982 and 2002 were compared in the report and a significant escalation in the damage value from year 1982 to year 2002 was observed. Various damage factors were also incorporated in the cost estimation based on the depth and duration of a flood event. It could be seen from the report that the values tabulated are more suitable for post-flood investigation where details of damage, for examples, number of households and area of land affected had been obtained. However, the objective of this study is to estimate the cost of damage prior to an actual flood event. Therefore, with reference to the report, the following decisions were made in this study:

- The considerable amount of major face-lifting developments as a result of rapid economic development between the period of 1982 and 2002 in Malaysian is unlikely to be repeated in the future. The difference between these studies at year 1982 and 2002 was therefore disregarded and only findings generated from study of year 2002 was adopted throughout the entire study;

- Different cost estimations for urban and rural housing in the report were maintained in this study. However, instead of considering damage value incurred by individual houses in a flood event, the housing density concept (as shown in Table 3.3) mentioned previously was introduced;

- In the report, the cost of damage between industrial and residential areas was not clearly distinguished where the cost of damage incurred on industrial facilities is only taken as 10% of damage to urban houses. Since industrial and residential areas are exclusive of each other in this study, assumptions were made to the cost of damage of industrial properties and facilities at both study locations. The assumptions made are shown in Table 3.4. The difference between the assumptions at the two locations was decided based on the different natures of industrial activity found at these locations – heavy industry at Seberang Perai and light industry/commercial at Kuantan-Pekan; and

Table 3.4 Assumed value of damage for industrial properties and facilities

	Assumed value of damage	
	Properties (%)	Facilities (%)
Seberang Perai	150	10
Kuantan-Pekan	130	10

Note: Percentage shown in this table is with reference to the total value of damage for urban houses and urban household articles at high density urban housing area.

- Crop production values obtained from the report had been simplified to only three major groups which are paddy, tree crops and mixed crops. Tree crops field is defined as an area with either rubber, oil palms or coconut plantation whereas mixed crops field is a plantation area with either mixed horticulture or other crops. This step was necessary because visual separation of the crop types based on Google Earth images was impossible during the study. However, this issue can be easily resolved if topographic maps or remote sensing spectral data are used in the study.

As part of the scope of study, an Excel worksheet had been developed for the calculations of the value of damage for flood events of different heights simulated in this study.

3.3 Methodology

Figure 3.5 depicts the workflow in this study. Although study for both Seberang Perai (highly developed area) and Kuantan-Pekan (less developed area) were carried out individually, they shared the same workflow pattern. The workflow can be summarised in four major work scopes and is explained in the following sections.

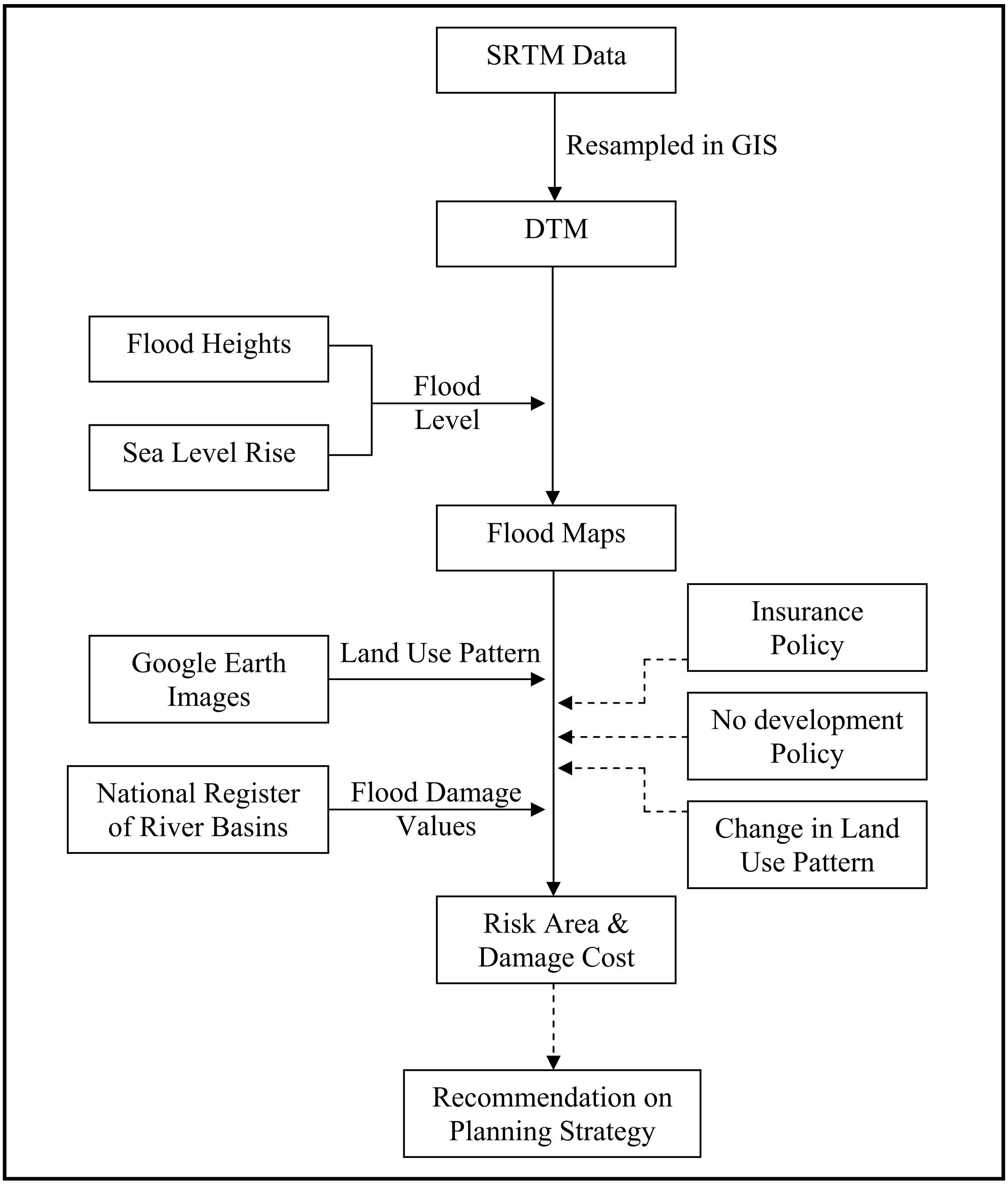


Figure 3.5 Flowchart depicting the methodology adopted in this study

3.3.1 Model Setup

To setup the model, SRTM data was first projected in ArcGIS software using the Universal Transverse Mercator (UTM) 47N coordinate system, which is the zone designation for both study locations. The UTM coordinate system was used because it was the same coordinate system for which land use images downloaded from Google Earth was used. As mentioned previously, the cell size of SRTM DTM was large for an effective flood scenario simulation due to the averaging of land elevation across a wide area. Thus, the SRTM DTM was first resampled from 90m to 5m cell size using the bilinear resample method in ArcGIS software. 5m cell size was selected for the analysis because it was small enough for an effective flood scenario simulation and was not too small to magnify the process time and workload in ArcGIS software. It is recommended that no smaller cell size should be chosen as significant modification to original data will reduce the accuracy of analysis.

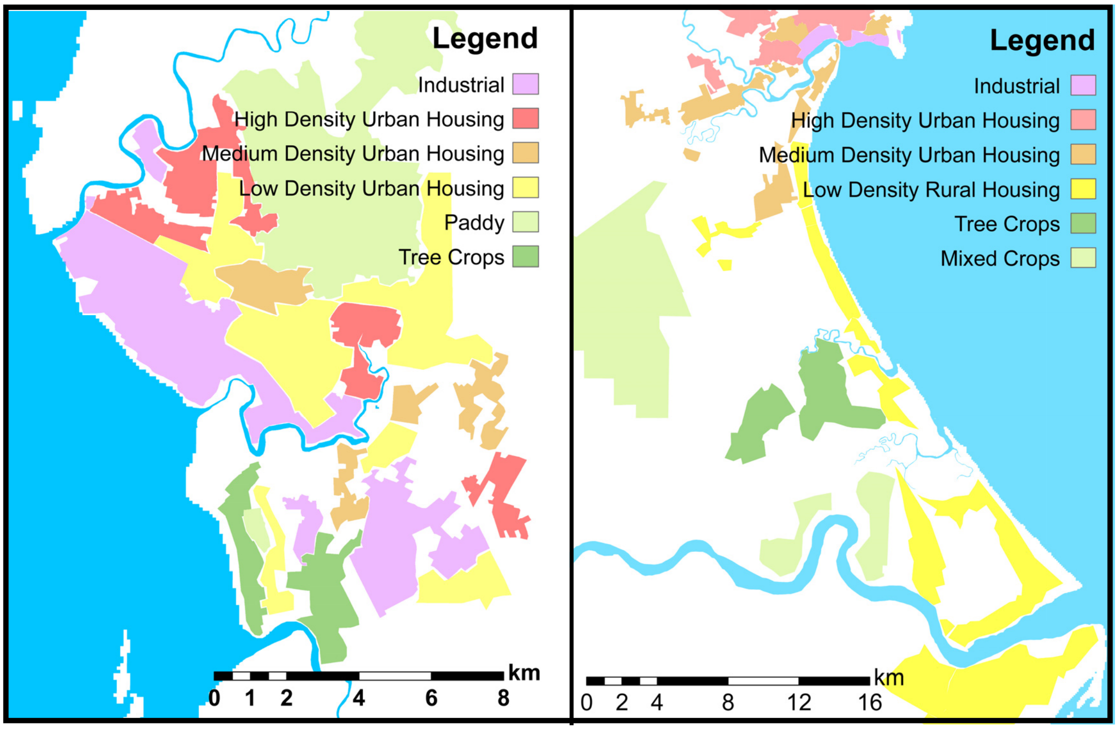


Figure 3.6 Models setup for Seberang Perai (left) and Kuantan-Pekan

As part of the model setup, Google Earth images were downloaded in tiles format and were georeferenced in ArcGIS software by inserting four control points onto individual tile image at known latitude and longitude geographic coordinates. Different land use pattern, as classified in Section 3.2.4, was then identified from the combined image and was mapped out in ArcGIS software via visual observation. In the model, land and sea were classified according to their elevation values. Non-zero data was classified as land area and zero data was classified as sea. The final products of model setup for both study locations are as seen in Figure 3.6.

3.3.2 Simulated Scenarios

After the models were setup, flood simulations were carried out. The simulation process was divided to two stages during the analysis. A first stage simulation was carried out before flood height data was obtained whilst second stage simulation was performed after the data was obtained. The first stage simulation was more general compared to the second stage. During the first stage, seven flood scenarios ranging from one to seven metres were simulated at one metre interval. Flood simulation was performed until this height firstly due to the need to run simulations at +/- 2m (approximately one standard deviation from the mean difference between SRTM and LiDAR data). Secondly, simulation until this height will help generate an idea of the severity of extraordinary flood events or tsunami. On the other hand, the second stage simulation was performed to study long term evolution of coastal flooding. A 1 in 200-year flood event at different time slices was selected as the base event for the second stage simulation. By applying different flood management tools explained in Section 3.3.4, the areas affected by a 1 in 200 year flood event were identified.

3.3.3 Calculation of Area at Risk of Inundation

Although the flood events were simulated to occur instantaneously during both stages of the analysis, the duration of flood was incorporated into the calculation of damage cost. The area at risk of inundation was identified by overlaying flood maps generated from simulations onto the base model. When an area at risk intersected with a region of specified land use, the cost of damage caused by the flood event on that particular region was calculated. Figure 3.7 shows an example of this approach for Seberang Perai (highly developed area) where industrial area at risk of five-metre flood was identified and highlighted. The total damage cost (subsequently damage index) caused by a flood event was calculated by summing damage costs incurred on every region of specified land use. By calculating the damage index (the consequences of a flood event), the indication of risk (probability x consequence) could be derived.

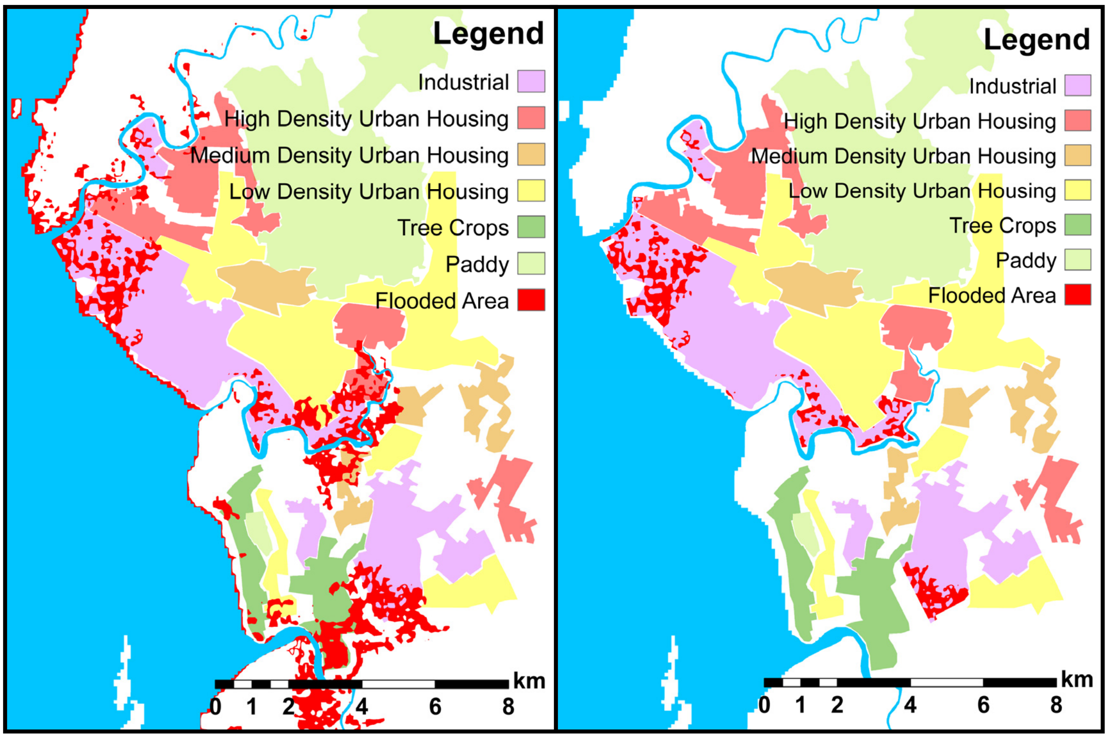


Figure 3.7 Total area (left) and industrial area (right) at risk of inundation by five-metre flood at Seberang Perai

3.3.4 Flood Management Tools and Change in Land Use Pattern

Other than identifying risk of flooding at different flood heights, an addition to the methodology used in this study was to study the evolution of flood risk in conjunction with the implementation of different flood management tools and change in land use pattern. The economic viability of the three scenarios explained in the following sections was then measured against the "Hold the line" policy. "Hold the line" policy is where seawall will be constructed along the coastline to protect the coastal area against the threat of 1 in 200-year flood event at different time slices. The following scenarios were considered in this study:

Flood Insurance Policy

As mentioned in Section 2.3, flood insurance is not a common flood management tool in Malaysia. However, it has been proven in countries like the United Kingdom, the United States and Australia that by incorporating flood insurance as a non-structural flood risk management tool, the risk of flooding could be reduced. The potential benefits of the implementation of flood insurance are two-fold. Firstly, flood insurance can help ease a government's fiscal burden for flood prevention and relief by involving individuals and insurance providers. Automated transfer of payments from non-affected persons to flood victims who are covered by the same insurance programme would also be allowed. Second, an individual's locative decision would be potentially influenced by flood insurance since the cost of living at flood prone area increases for individuals if flood insurance is made mandatory. In other words, flood insurance creates a counter incentive for people to migrate into or establish business in flood prone areas (Lin et al, 2007). Under this scenario, flood insurance was made mandatory for properties enclosed by area at risk of inundation up to two-metre height at Seberang Perai and three-metre height at Kuantan-Pekan at the present time. The insurance policy was set to change in accordance with rise in sea level and the policy will be renewed every other 50 years. The reduction of damage cost from the implementation of flood insurance at each time slice was calculated by excluding the damage cost incurred by properties enclosed by area where flood insurance is made mandatory. Table 3.5 lists the requirements used for properties to acquire flood insurance based on flood height at different time slices. It is assumed to be mandatory for properties at risk of inundation within the flood height limits to acquire flood insurance and the government will not pay any compensation for flood damage in these areas.

Table 3.5 Requirement for properties to acquire flood insurance based on flood height at different time slices

Location	**Flood Heights Necessitate Flood Insurance (m)**				
	Present	**2050**	**2100**	**2150**	**2200**
Seberang Perai	2.00	2.45	2.90	3.35	3.80
Kuantan-Pekan	3.00	3.34	3.90	4.35	4.80

No Development Policy

For both Seberang Perai and Kuantan-Pekan, area within 200m from the coastlines is setback and remains free from any form of development under the "No development" policy. By creating a buffer zone 200m from the coastline, the areas affected under this policy were identified. Similarly to the “Flood insurance” policy, reduction of damage cost from implementing the “No development” policy was also calculated.

Changes in Land Use Pattern

One of the objectives in this study is to evaluate the change of coastal flood risk in conjunction with the change of land use pattern. During the analysis, the land use pattern of a stretch of coastline south of Kuantan city was modified. It was assumed that this selected strip of coastline will be transformed into a tourism area where beach resorts (industrial/commerce) will be constructed. In view of the expected influx of migrants due to the rising employment opportunity from this new development, area behind the proposed beach resorts site was also modified from low density rural housing to medium density urban housing. The risk of flooding before and after the change of land use pattern was then studied. Besides, by implementing the “Flood insurance” and “No development” management approaches, the risk of flooding was studied once again. The change of damage cost resulted from the new development based on the different scenarios described above was calculated. Figure 3.8 shows the difference between land use pattern before and after land use modification for Kuantan-Pekan coast.

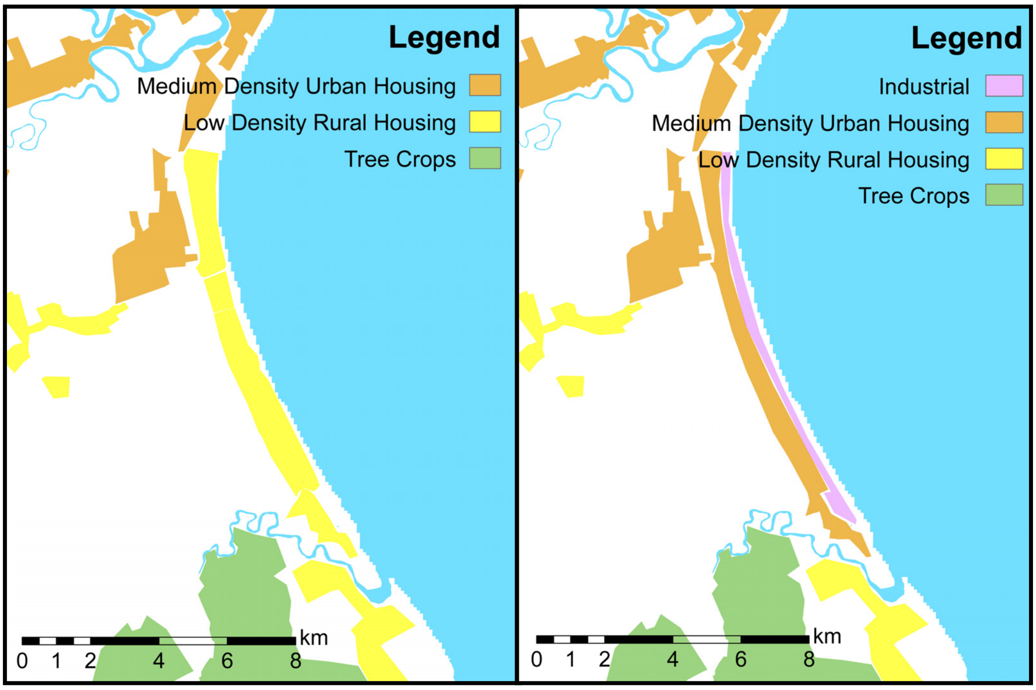


Figure 3.8 Kuantan-Pekan coast before (left) and after change in land use pattern

3.3.5 Outputs

Outputs generated from the analysis are:

- A series of flood maps indicating area at risk of flooding at different flood heights;
- Associated damage indices for individual flood events; and
- The evolution of coastal flood risk in conjunction with the implementation of flood risk management tools and change in land use pattern.

Based on the outputs generated from the analysis, a series of recommendation will be made for coastal planners for future coastal zone planning and management.

4. RESULTS

This chapter presents the results from the analysis described in Section 3. The first part deals with first stage simulation where floods ranging from one to seven-metre were simulated. Areas at risk of inundation were identified at this stage and flood maps were produced. The total damage cost (hereafter "damage index") was calculated. It is the sum of individual damage cost incurred on different land use category at risk of inundation. The damage cost is represented in the currency of Malaysia, the Ringgit Malaysia (RM), where RM1 ≈ €5.00 or RM1 ≈ £5.50.

The second part uses the flood simulation results generated from the implementation of i) "Flood insurance" policy, ii) "No development" within 200-metre from the coastline policy, and iii) change in land use pattern along the Kuantan-Pekan coastline, for a 1 in 200-year flood event using the IPCC high emission scenario. Damage index incurred from the implementation of these flood management tools or changes in land use pattern are compared against the cost of seawall construction and maintenance, also known as "Hold the line" policy.

4.1 Coastal Flood Risk

The first stage involved simulations of flood events based on seven different flood heights. Flood maps were then produced. The flood heights used range from one to seven-metre at one metre interval. As mentioned in Section 3.3.2, flood simulations were run up to a height of seven-metre for two purposes. Firstly, it is a measure to compensate the low level of accuracy of SRTM data. Secondly, it helps generate an idea of the severity of flooding due to extreme events and tsunami. Mean sea level was assumed at 0m. For each land use category, the damage cost was calculated by multiplying the total area affected by flood at a given height with damage value the particular land use category represents, as described in Section 3.3.3. The damage index for flood at a given height, as defined in the beginning of this section was calculated subsequently. In the analysis, it was assumed that both study locations are not protected by any coastal defence structures at present.

4.1.1 Seberang Perai (Highly Developed Area)

Seberang Perai was selected as it represents a highly developed and densely populated area. Table 4.1 shows the total area at risk of inundation and the associated damage index for floods at different heights. Flood maps for floods from one to six-metre heights are shown in Figure 4.1.

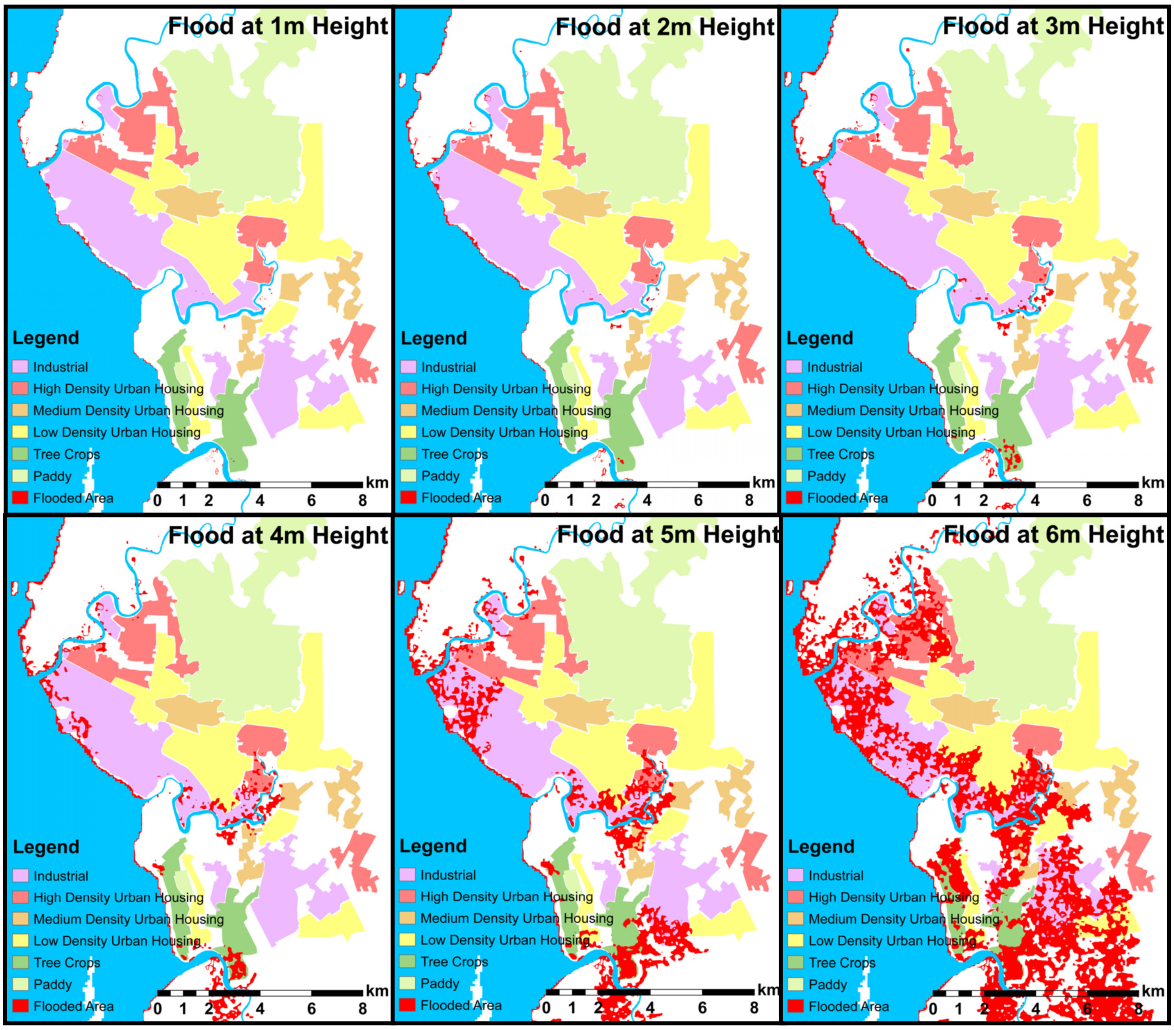


Figure 4.1 Flood maps for floods from one to six-metre height at Seberang Perai

Table 4.1 Area at risk of inundation and associated damage index at a given flood height at Seberang Perai

Flood Height (m)	Area at Risk of Inundation (ha)	Damage Index (RM mil)
1	4	4
2	12	11
3	57	57
4	212	466
5	699	1796
6	2153	5314
7	6250	8542

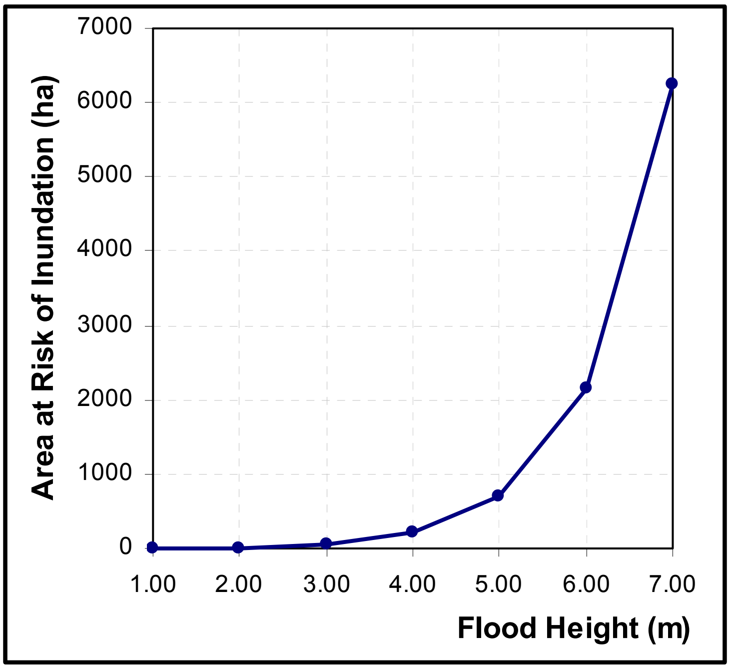


Figure 4.2 Plot of area at risk of inundation versus flood height at Seberang Perai

Figure 4.2 shows the relationship between flood height and total area at risk of inundation. For floods at height greater than four-metre, the total area at risk of inundation shows an escalating trend. Comparing flood maps shown in Figure 4.1 and taking into consideration the rising trend of area at risk of inundation in Figure 4.2, it can be inferred that the topography at Seberang Perai close to the coastline rises sharply before it becomes a generally flat land behind the coastline. This explains why area at risk of inundation becomes significantly larger at greater flood height because flood water can travel across wider area. However, it is worthwhile to consider if this inference is caused by the low level of accuracy of SRTM data and not by the topography. In other words, a single cell size in the original SRTM data is wide (approximately 90m). Therefore, the observed flat land behind the coastline might be a result of the averaged land elevation within one cell in SRTM data and does not necessarily represent to the real topography.

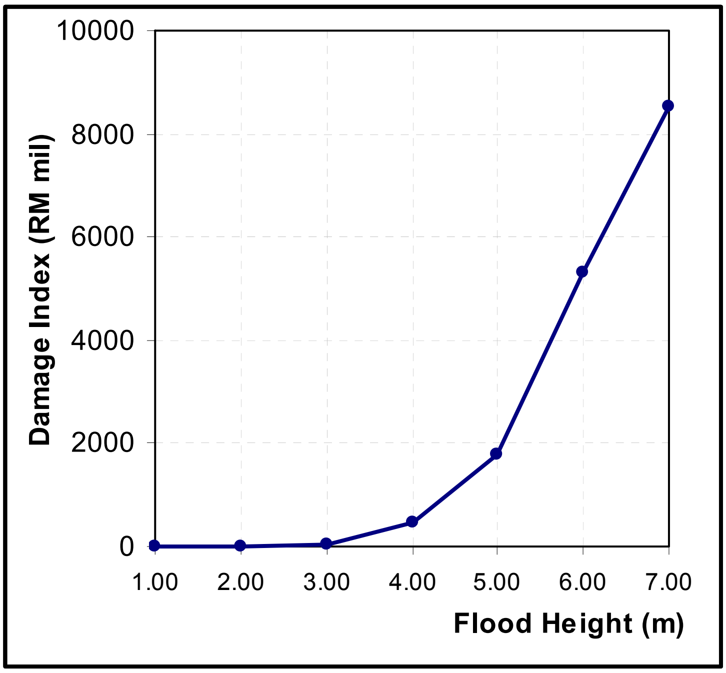


Figure 4.3 Plot of damage index versus flood height at Seberang Perai

As shown in Figure 4.3, an escalating trend for floods with height higher than four-metre is also observed between damage index and flood height. Although the damage index rises with increase in area of inundation, land use category affects the changes in damage index greatly. Industrial area is area with the greatest damage cost in a flood event. At Seberang Perai, an industrial area is located next to the coastline where it also is a flood prone area (low topography). Thus, the damage index at Seberang Perai rises sharply with higher flood height. Refer to Table 4.1, the increase in the area at risk of inundation is 1500-hectare from flood at five to six-metre height and is 4000-hectare from flood at six to seven-metre height. The increases in damage index are identical and are RM35mil and RM32mil respectively. This shows that the additional area at risk of flooding at higher flood heights is located outside the industrial zone where land value is significantly lower. It confirms that land use pattern does indeed affect greatly in the changes of damage index.

4.1.2 Kuantan-Pekan (Less Developed Area)

Compared to Seberang Perai, Kuantan-Pekan is a relatively less developed area except for Kuantan city at the north. Similar to the analysis carried out for Seberang Perai, Table 4.2 summarises the area at risk of inundation and the associated damage index at different flood heights. Figure 4.4 shows flood maps for floods from one to six-metre heights.

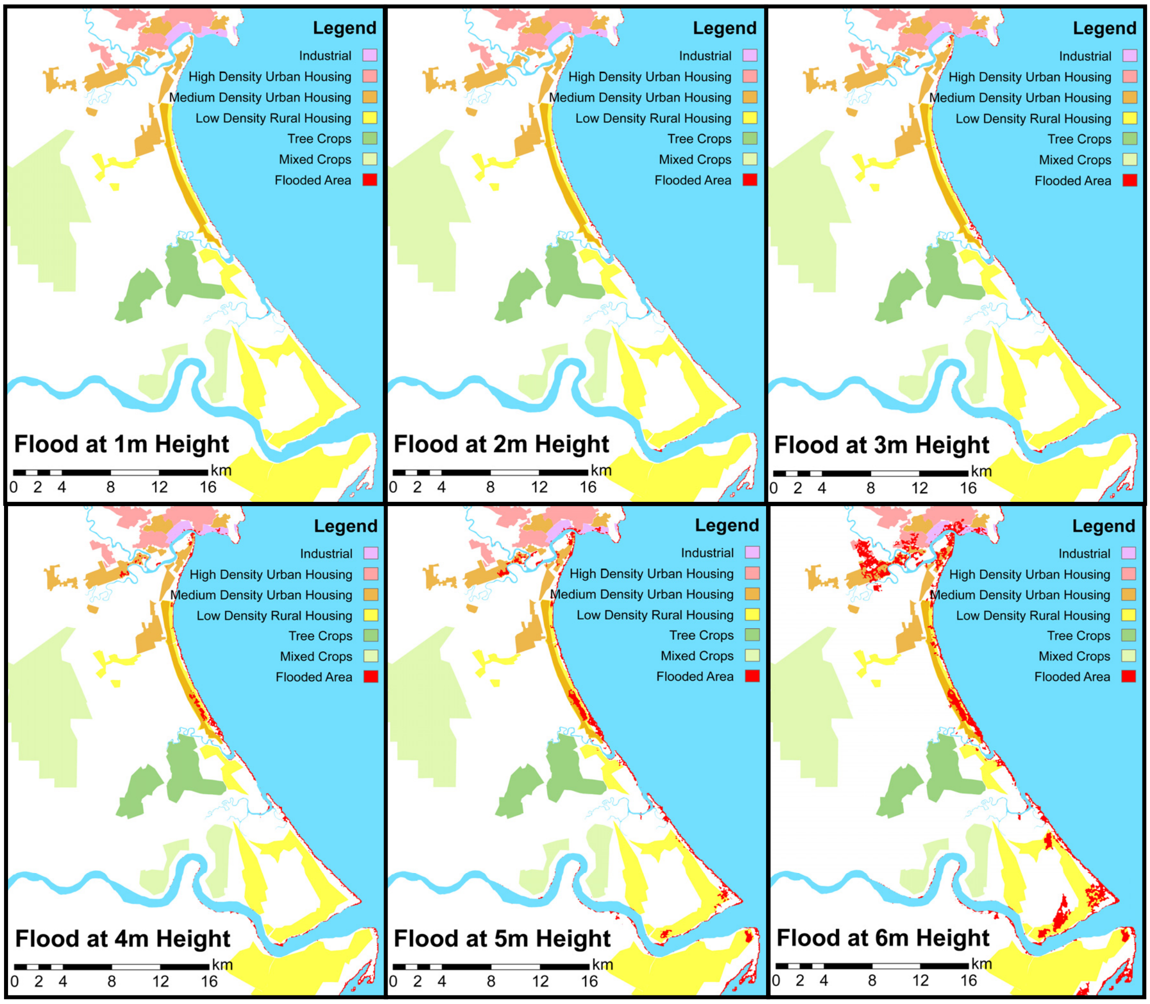


Figure 4.4 Flood maps for flood at one to six-metre flood heights at Kuantan-Pekan

Table 4.2 Area at risk of inundation and associated damage index at a given flood height at Kuantan-Pekan

Flood Height (m)	Area at Risk of Inundation (ha)	Damage Index (RM mil)
1	2	1
2	5	4
3	16	18
4	128	152
5	355	381
6	1172	1514
7	3033	3347

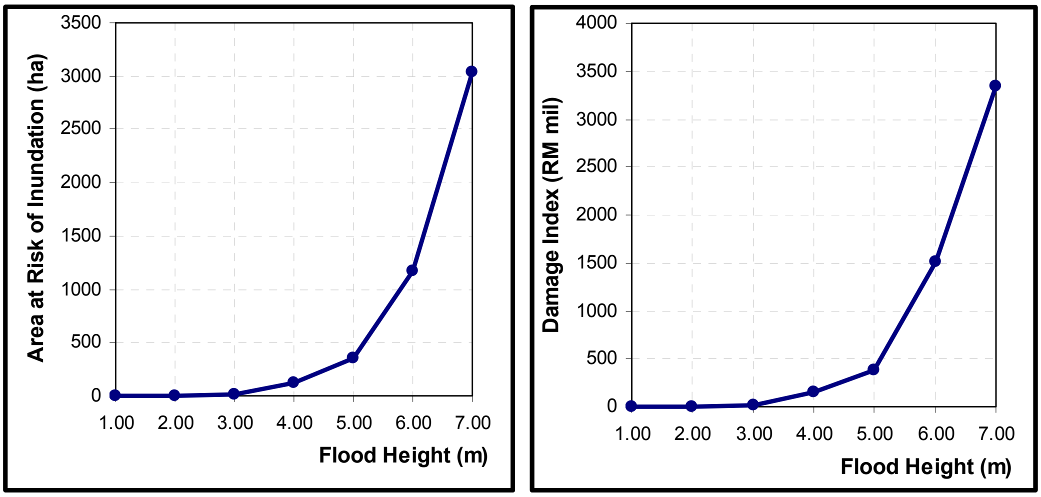


Figure 4.5 Plot of area at risk of inundation versus flood height (left); and plot of damage index versus flood height at Kuantan-Pekan

Similar to Seberang Perai (refer to Figure 4.5), the area at risk of inundation and the damage index at Kuantan-Pekan also shows a drastic increase for flood events at five-metre height or higher. Therefore, similar inference pertains to the nature of topography is also applicable to Kuantan-Pekan. However, if the damage index per square metre is considered, it is clear that Seberang Perai has a higher damage index than Kuantan-Pekan. The calculated damage indices per square metre for Seberang Perai and Kuantan-Pekan are shown in Table 4.3.

Table 4.3 Damage index per square metre

Flood Height (m)	Damage index / square metre (RM)	
	Seberang Perai	Kuantan-Pekan
1	79	63
2	86	78
3	101	117
4	220	120
5	257	108
6	247	129
7	137	111

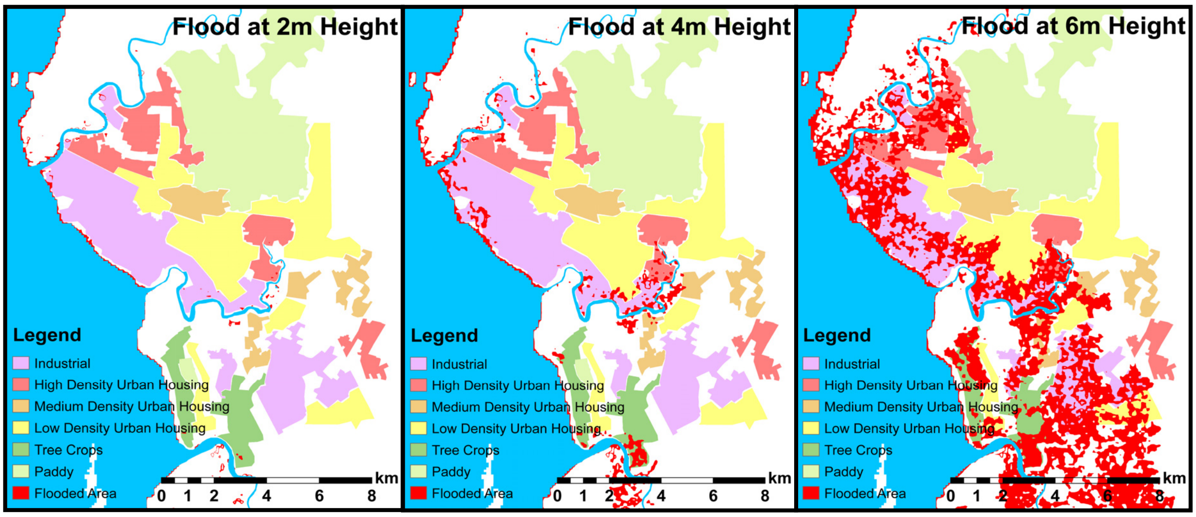
Evidently, land use is the main reason that contributes to the difference. And as mentioned in previous section, Kuantan-Pekan is less developed and less populated compared to Seberang Perai. Based on the concept of risk (probability x consequences), it can be concluded that Seberang Perai has a higher risk of flooding than Kuantan-Pekan because the consequences of coastal flooding is higher.

4.1.3 Range of Possibility of Flood at a Given Height

In order to compensate for the low level of accuracy of SRTM data used in this study, two additional flood levels at +/- 2m (approximately one standard deviation from the mean difference between SRTM and LiDAR data) from a given flood height were simulated. The reason behind this approach is to generate a range of possibility of flood events at a given height at slightly more than 70% confidence level. Figure 4.6 shows an example of the result using this approach at Seberang Perai and Kuantan-Pekan. A flood event at four-metre height was considered in this example. The uncertainties contained within the range of possible scenario are stark as the differences in area at risk of inundation differ greatly from one flood event to another. Thus, the output is not helpful for coastal planner to base their decision making. Therefore, it is concluded that an accurate elevation data is extremely crucial for an accurate flood simulation and subsequently an accurate coastal flood risk assessment.

In Table 4.4, the range of possibility for flood events at five different heights is shown. For flood events at one and two-metre height, the lower bound limit for area at risk of inundation and damage index are set to be zero. It is clear from these tables that the range of possibility for any flood event is very broad and thus raises the concern regarding the reliability of these estimates. In conclusion, an accurate elevation dataset is crucial for accurate flood simulations for coastal planners to base their decision making.

(a) Seberang Perai (Highly Developed Area)



(b) Kuantan-Pekan (Less Developed Area)

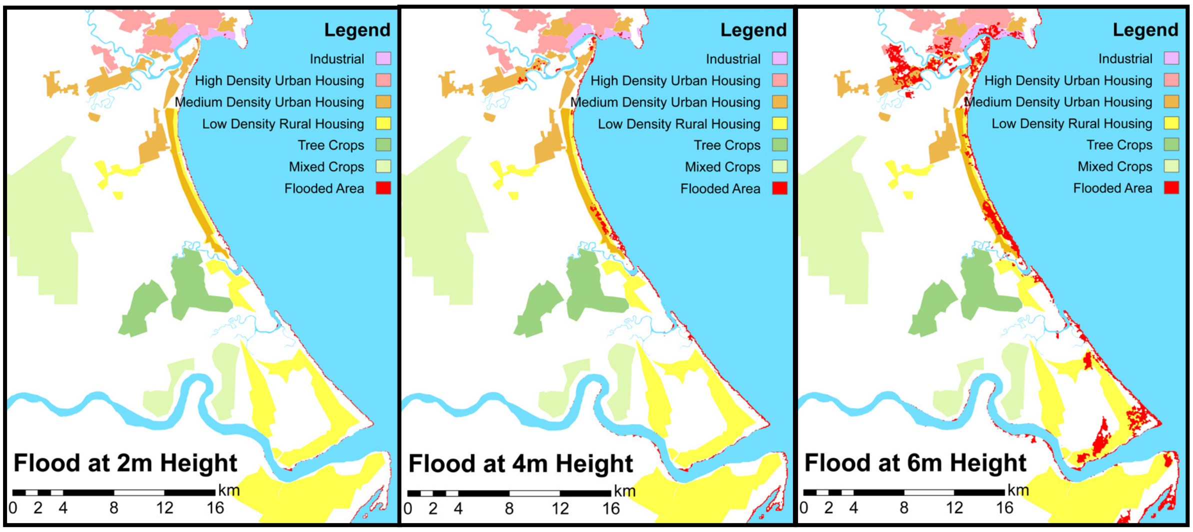


Figure 4.6 The range of possible scenario for flood at four-metre height

Table 4.4 The range of possibilities for flood at different heights

(a) Seberang Perai

Flood Height (m)	Range of Possibilities	
	Area at Risk (ha)	Damage Index (RM mil)
1.00	0 – 57	0 – 57
2.00	0 – 212	0 – 466
3.00	4 – 699	4 – 1796
4.00	12 – 2153	11 – 5314
5.00	57 – 6250	57 – 8542

(b) Kuantan-Pekan

Flood Height (m)	Range of Possibilities	
	Area at Risk (ha)	Damage Index (RM mil)
1.00	0 – 16	0 – 18
2.00	0 – 128	0 – 152
3.00	2 – 355	1 – 381
4.00	5 – 1172	4 – 1514
5.00	16 – 3033	18 – 3347

4.2 Flood Management Tools to Reduce Risk

This section describes the impacts resulted from the implementation of "Flood insurance" and "No development" tools. Throughout the analysis, a 1 in 200-year flood event using the IPCC high emission scenario was used. The 200-year study period is chosen in order to study the long term evolution of coastal flood risk in conjunction with the implementation of these flood management tools. Firstly, the damage indices for a 1 in 200 year flood event before the implementation of these tools were calculated. Thereafter, the changes in damage indices after the implementation of these tools were identified. The aim of this section is to evaluate the effectiveness of different flood management tools in reducing coastal flood risk in the long term. All cases discussed in the succeeding sections assume no defence at present.

4.2.1 1 in 200-year Flood

1 in 200-year flood events over the course of 200-year were simulated at both study locations. The flood heights used in the simulation were determined by applying a rate of sea level rise at 9mm/year (IPCC high emission scenario) on the base flood height derived from the plot of probability (Figure 3.3). The area at risk of inundation and the associated damage indices were calculated and were summarised as shown in Table 4.5. The damage indices presented in these tables is referred as "No defence" and will be used later for cost comparison with the implementation of different flood management tools. Figure 4.7 shows flood maps at Seberang Perai and Kuantan-Pekan for 1 in 200-year flood event at present and at year 2150.

Table 4.5 Area at risk of inundation and associated damage index for 1 in 200-year flood event

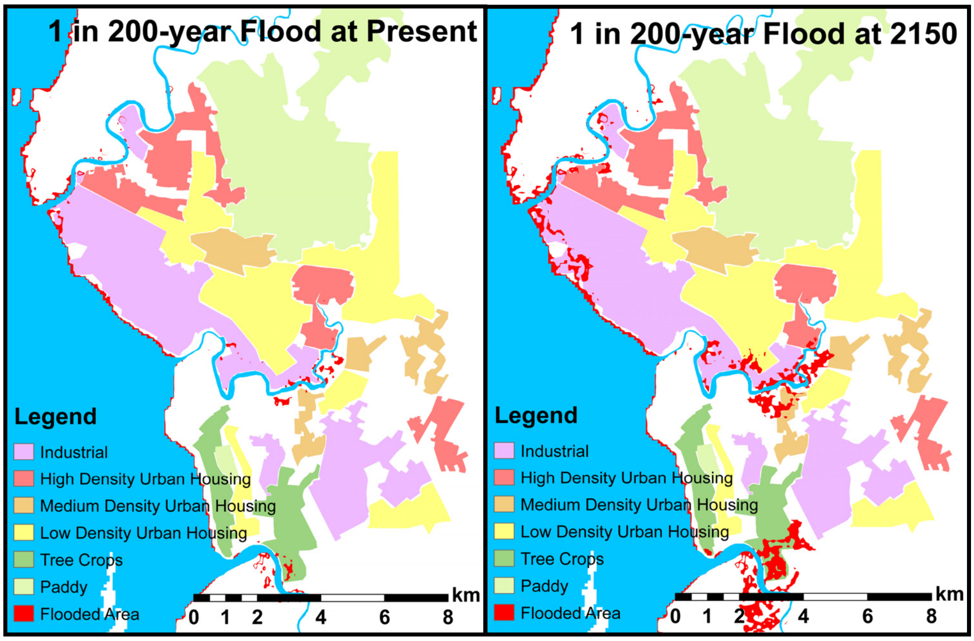
(a) Seberang Perai (Highly Developed Area)

Time Slice	Flood Height (m)	Area at Risk of Inundation (ha)	Damage Index (RM mil)
Present	2.84	4	38
2050	3.29	12	124
2100	3.74	57	212
2150	4.19	212	442
2200	4.64	699	1029

(b) Kuantan-Pekan (Less Developed Area)

Time Slice	Flood Height (m)	Area at Risk of Inundation (ha)	Damage Index (RM mil)
Present	3.68	82	98
2050	4.13	142	171
2100	4.58	199	240
2150	5.03	281	335
2200	5.48	687	707

(a) Seberang Perai (Highly Developed Area)



(a) Kuantan-Pekan (Less Developed Area)

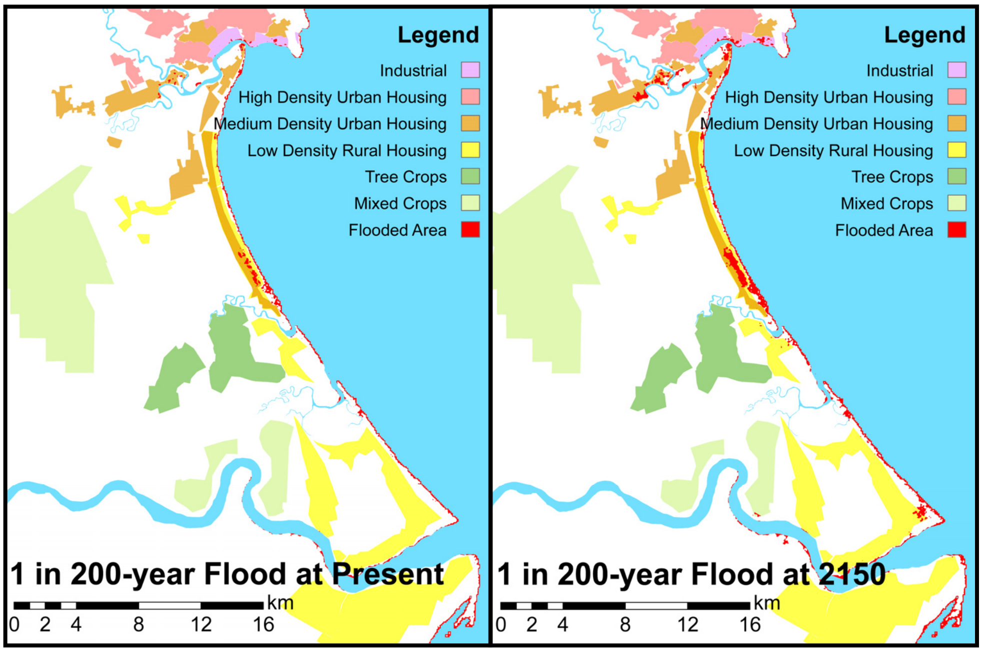


Figure 4.7 Flood maps showing a 1 in 200-year flood at present and at year 2150

4.2.2 Effects of a Mandatory Flood Insurance Policy

As mention in Section 2.3 and Section 3.3.4, flood insurance as a flood management tool is not a common practice in Malaysian currently. The utilisation of a “Flood insurance” tool sees flood insurance as a mandatory requirement for properties at risk of flood up to two-metre and three-metre heights at Seberang Perai and Kuantan-Pekan at present respectively. By possessing flood insurance, any damage incurred to these properties due to a flood event will be reimbursed by the insurance companies and not the government. Therefore, the overall cost of damage for a flood event is reduced. By excluding the damage cost within the insured region, new set of damage indices were derived and are summarised in Table 4.6. Also presented in the table is the percentage cost reduction resulting from the implementation of the mandatory flood insurance policy. The reductions are the differences between the initial (before the implementation of mandatory flood insurance policy) and the newly derived damage indices (after the implementation of mandatory flood insurance policy). It is noteworthy that the damage indices at different locations presented in this table shouldn’t be compared directly as they represent different types of land use and are derived from different flood heights.

Table 4.6 Damage indices and reductions in damage cost for “Flood insurance” policy

Time Slice	Seberang Perai		Kuantan-Pekan	
	Damage Index (RM mil)	Cost Reduction (%)	Damage Index (RM mil)	Cost Reduction (%)
Present	27	28.1	79	18.6
2050	96	22.7	100	41.2
2100	165	22.1	120	50.1
2150	301	31.9	130	61.1
2200	802	22.1	426	39.8

From Table 4.6, it is observed that reductions in damage cost from the implementation of the “Flood insurance” policy is fairly consistent throughout the course of study period at Seberang Perai (highly developed area) whereas it shows a fluctuating trend over time at Kuantan-Pekan (less developed area). Reductions in damage cost for Kuantan-Pekan are seen to be approximately twice the differences at Seberang Perai. This scenario could be explained by saying that area where flood insurance is mandatory in Kuantan-Pekan falls largely on urban area (high value land) concentrated at Kuantan city and not low density rural area (low value land).

4.2.3 Effect of a No Development Policy

Under "No development" policy, any form of development within the area 200-metre from the coastline is prohibited. By excluding the damage index incurred within this coastal trip, new damage indices were derived. Similarly to the "Flood insurance" policy, reductions in damage cost resulted from the implementation of "No development" policy at different time slices were calculated (Table 4.7). For both study locations, the "No development" policy shows a downwards trend in the reduction of damage cost. This is a result of a fixed no development zone over the course of study period. Thus, the reduction in damage cost remains constant over time. At Seberang Perai, the reduction of damage cost through "No development" policy (33.8%) is higher than "Flood insurance" policy (28.1%) at present. Approaching the end of the study period, the "No development" policy at both locations shows significantly low reduction (less than 5%) and is lower than "Flood insurance" policy. At Kuantan-Pekan, the derisory amount of reduction at all time slices is a result of the negligible amount of the development within 200m along the coast at present.

Table 4.7 Damage indices and reductions in damage cost for "No development" policy

Time Slice	Seberang Perai		Kuantan-Pekan	
	Damage Index (RM mil)	Cost Reduction (%)	Damage Index (RM mil)	Cost Reduction (%)
Present	25	33.8	97	0.8
2050	96	22.5	170	0.8
2100	177	16.7	238	0.7
2150	400	9.6	335	0.6
2200	979	4.9	705	0.4

4.2.4 Comparison of "Hold the line" with Previous Options

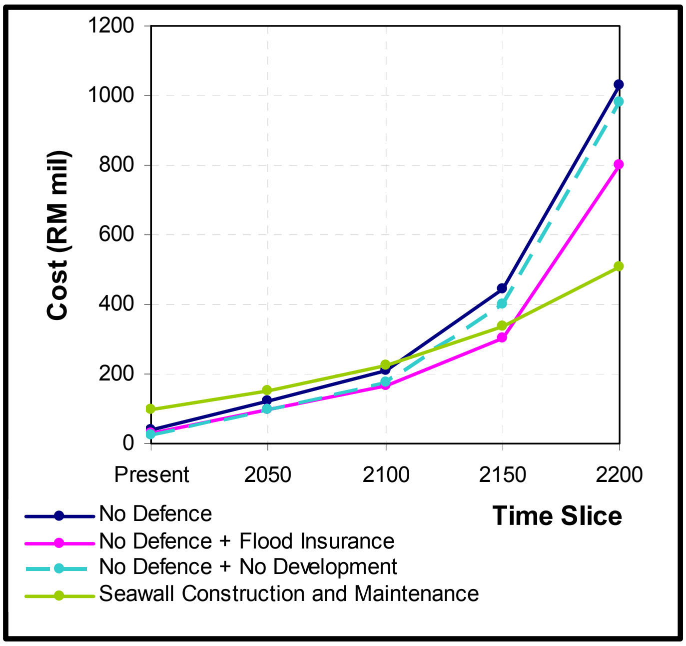
In this section, the two flood management tools are compared with another management tool; to construct and maintain seawall to protect the coastline, also known as "Hold the line" policy. From a personal communication via email with personnel from the Department of Irrigation and Drainage Malaysia (DID), the cost of construction for coastal defence structure is approximately RM4mil per kilometre. According to the same source, the maintenance cost of such structure is very site specific and depends on the extent of maintenance works required (Wong, 2009). In this study, the maintenance cost at 50-year interval is assumed to be 50% of the initial construction cost. The total lengths of coastline for Seberang Perai (highly developed area) and Kuantan-Pekan (less developed area) are 25-kilometre and 57-kilometre respectively. The costs involved in the construction and maintenance of seawall were calculated and are summarised in Table 4.8. Figure 4.7 compares graphically the damage indices amongst i) No defence as presented in Section 4.2.1; ii) No defence and implementation of flood insurance as presented in Section 4.2.2; iii) No defence and no development as presented in Section 4.2.3; and iv) Hold the line as presented in Table 4.8, over the course of study period (200-year).

Table 4.8 Cost of seawall construction and maintenance

Time Slice	Work Scope	Cost (RM mil)	
		Seberang Perai	Kuantan-Pekan
Present	Construction	100	228
2050	Upgrade & Maintenance	150	342
2100	Upgrade & Maintenance	225	513
2150	Upgrade & Maintenance	338	770
2200	Upgrade & Maintenance	506	1154

The objective of this comparison is to evaluate the economic viability of different flood management tools in reducing long term coastal flood risk. Figure 4.8 shows that the mandatory "Flood insurance" policy is more economically attractive compared to the "No development" policy. The "Flood insurance" policy also shows a significant amount of reduction in damage cost if compared to the "No defence" policy. However, if compared to the "No Defence" policy, the "No development" policy shows insignificant differences, or insignificant cost reduction. Quantitative figures pertaining savings could be referred to Table 4.6 and 4.7.

(a) Seberang Perai (Highly Developed Area)



(a) Kuantan-Pekan (Less Developed Area)

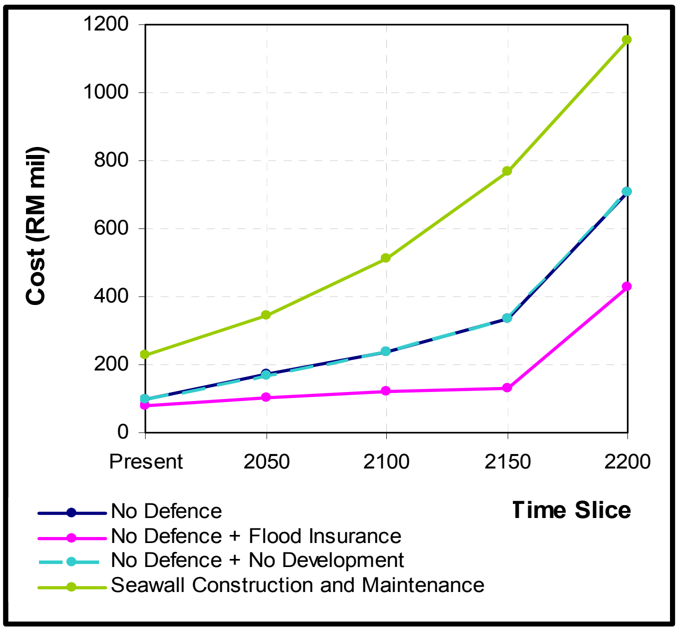


Figure 4.8 Cost comparison for a 1 in 200-year flood at Seberang Perai and Kuantan-Pekan

On the other hand, the "Hold the line" option shows a higher cost over the course of the coming century at both locations. Although the option becomes beneficial at Seberang Perai from year 2100 until year 2200, it remains as the costliest option at Kuantan-Pekan over time. Therefore, it can be concluded that the benefit of "hold the line" option is location sensitive. It may have long term benefit at one location but is completely unattractive at the other location.

4.3 Impacts of Changes in Land Use Pattern

One of the objectives of this study is to evaluate the impact of land use changes on coastal flood risk. As mentioned in Section 3.3.4, the land use pattern along the Kuantan-Pekan coastline was assumed to change due to development and the impact resulted from this modification was studied. The damage index remains the same before year 2050 as it requires time for development. Table 4.9 compares the damage indices before and after the change in land use pattern. It is noteworthy that the total area at risk of inundation is assumed to remain the same before and after the change in land use pattern. The increase in damage index is thus solely a result of increase land value at flood prone area.

Table 4.9 Damage indices before and after the change of land use pattern

Time Slices	Damage Index (RM mil)	
	Before Change	After Change
Present	98	-
2050	171	290
2100	240	396
2150	335	527
2200	707	956

4.3.1 Land Use Changes and Flood Management Tools

The "Flood insurance" and the "No development" management approaches were applied onto the new land use pattern. The resultant damage indices and the percentage of reduction in damage cost were studied and are presented in Table 4.10.

Table 4.10 Damage indices for the implementation of policies on new land use

Time Slice	Flood Insurance		No Development	
	Damage Index (RM mil)	Cost Reduction (%)	Damage Index (RM mil)	Cost Reduction (%)
2050	161	44.5	288	0.6
2100	176	55.6	394	0.5
2150	184	65.1	525	0.5
2200	492	48.5	953	0.3

Compare reduction in damage cost in Table 4.10 (after change) with Table 4.6 and Table 4.7 (before change), only minor differences in the percentage of cost reduction are observed. In general, the "Flood insurance" policy shows a significantly higher cost reduction and thus is more attractive than the "No development" policy. For the "No insurance" policy, the average cost reduction after change in land use pattern is approximately 5% higher than before change. However, it is 0.2% lower for the "No development" policy. It can be concluded that the use of these flood management tools is not greatly affected by the changes in land use pattern. Figure 4.9 shows that despite costly construction and maintenance, the protection afforded by seawall increases with increased land value. It can thus be concluded that the prospect for "hold the line" policy increases if massive development is set to take off in the future.

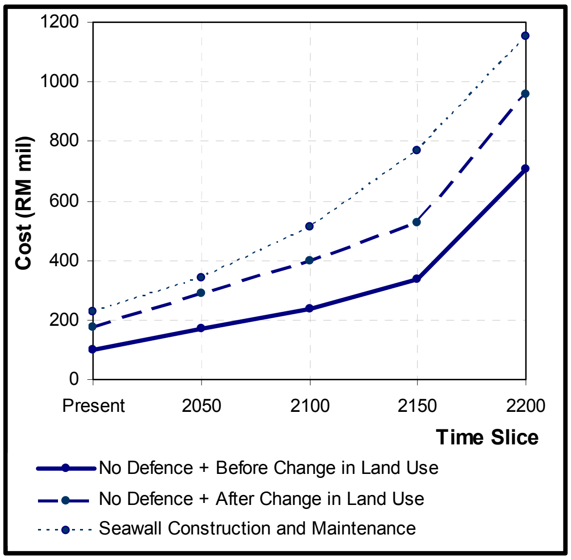


Figure 4.9 Cost comparison between seawall construction and changes in land use

4.4 Summary

The area at risk of inundation and the associated damage index at Seberang Perai (highy developed area) and Kuantan-Pekan (less developed area) increase gradually for floods less than four-metre height but show an escalating trend thereafter. It could be inferred that the nature of topography, where land rises sharply within short distance from the coast and turns to a vast flat land area behind the coastline, is the main reason for this. The other possibility is due to the low level of accuracy of SRTM data used in the analysis. Land elevation in SRTM data has been averaged across a cell size of approximately 90 metre and thus has eliminated the possible hilly topographic nature.

On the other hand, from the analysis using the two management tools – “Flood insurance” and “No development”, the “Flood insurance” policy reduces the damage cost more than the “No development” policy. In fact, damage costs reduced from “No development” are derisory and are less than 1% at all times. And when compared with “Hold the line” policy, the construction of a seawall shows greater reduction in damage cost than “No development” as it reduces the damage cost to zero. In the case of “Hold the line”, it is observed that the reduction in cost varies with locations. In this study, it is cost effective in the long term at Seberang Perai but remains as the costliest option throughout the course of 200 year considered at Kuantan-Pekan. When all three flood management tools – “Flood insurance”, “No development” and “Hold the line” – were utilised after the change in land use pattern, it is found out that no significant changes in the reduction of cost (less than 5%) were observed. Thus, it is concluded that land use changes do not affect significantly the cost effectiveness of the implementation of these management tools. However, with greater land value, the option of seawall construction does become more attractive as it offers greater protection in case of a flood event. The reduction in damage cost was found to reach almost RM1000mil at year 2200.

5. DISCUSSION AND RECOMMENDATIONS

There were two main objectives this study. Firstly, it aimed to develop a generic approach assessing coastal flood risk and to identify the data requirement for an effective and reliable assessment. Through the identification of flood prone areas and subsequently the production of flood risk maps, it improved the preparedness of public and authority to potential flood events. Second, through the utilisation of different flood management tools, it facilitated coastal planners and managers in their decision making for coastal development in the future. In this section, the issues concerning flood risk assessment and coastal zone planning and management are discussed.

5.1 Coastal Flood Risk Assessment

As discussed in Section 2, assessment of coastal flood risk is a new field of research in Malaysia. Attention given to flooding problems tends to focus on riverine flooding rather than coastal flooding in this country as the former poses a more dangerous threat than the latter at present. However, the rise of the sea level as a result of global climate change is expected to inevitably increase hazard posed by coastal flooding to a significantly higher level.

In the first part of the study, the issue of coastal flooding was dealt with by simulating flood scenarios using flood heights from one to seven-metre at Seberang Perai (highly developed area) and Kuantan-Pekan (less developed area). Simulations were run until seven-metre height to compensate low level of accuracy of SRTM data used in the study, and also to indicate the possible devastation caused by a tsunami type flood. Flood prone areas were identified via flood maps produced from the results of the analysis. The damage indices at different flood heights were also calculated and were presented. The findings demonstrated that a generic approach could be developed to assess coastal flood risk regardless of the study location, and through the production of flood maps, public and authority will be able to study area at risk of inundation. Thus, the first objective of this study has been fulfilled.

However, the reliability of findings at these two particular locations was challenged by the low level of accuracy of the data, especially the elevation data used in this study. Section 4.1.3 revealed the range of possibilities for flood event at any given height. The example of flood at four-metre height at Seberang Perai was studied and the areas at risk of inundation range from 12 to 2153-hectares, and the associated damage indices range from approximately RM10mil to RM5300mil. Quantitatively, the differences between the upper and the lower bounds for area at risk of inundation are huge. The inference from these figures is the high degree of uncertainty generated from the findings.

The objective of flood risk assessment is to facilitate subsequent preparation and mitigation works. Flood preparation and mitigation works are costly and the budget for these works is not unlimited. The selection of the type of mitigation works is location sensitive and depends largely on the area and the associated damage cost involved should there be a flood event. As identified in Section 4, areas at risk of inundation and the associated damage cost varies according to the topographic nature and the land use pattern. It is evident that an economically viable solution for a flood prone area worth RM5300mil will be excessive and unreasonable for a flood prone area worth only RM10mil. Therefore, it is crucial that the extent of flood prone area and the associated damage cost should be assessed as accurately as possible by using the most accurate data in the analysis. Only by producing reliable analysis then can coastal planners optimise the limited resources available for coastal protection works. In conclusion, in order to improve the accuracy of flood risk analysis, dataset with high level of accuracy is recommended to be used.

5.2 Coastal Zone Planning and Management

Flood risk assessment at the first stage simulation is an extremely useful tool for coastal management as it anticipates well in advance area at risk of inundation at different flood heights. The usefulness of the assessment for coastal planners was demonstrated in two ways. Firstly, through the utilisation of different flood management tools, including flood insurance, setback development and construction of flood defence structure, the most appropriate and cost effective flood management approach could be designed for a flood prone area. Second, by studying the evolution of coastal flood risk in conjunction with the change in land use pattern, coastal managers can decide more prudently if a proposed development would increase coastal flood risk in the future. This will help avoiding development within flood risk zone and thus helps to avoid unnecessary and costly mistake in spatial planning. In other words, develop coastal area with a long term vision.

5.2.1 Flood Risk Management

In general, there are three ways to adapt or manage costal flooding problem in conjunction with sea level rise – to protect, to accommodate, and to retreat. Protect and retreat approaches had been dealt with in this study. The protect approach was manifested through "Hold the line" policy where seawall is constructed and maintained. No damage (no consequence) is anticipated behind seawall and thus the risk of flooding (probability x consequences) is zero. However, residual flood risk should also be accounted for when adopting this approach. Residual risk is defined as the portion of risk that remains after the construction of flood defence structures (Carter, 2005). Residual risk includes the risk of structural failure and the likelihood of flood surpasses protection designed in flood control structures (ibid.). Often when a structure fails, or the design is surpassed by flood's intensity, the resulting damage is catastrophic.

On the other hand, the options for retreat are i) the "Do nothing", also known as the "No defence" option. This is the option with the highest risk since area at risk of inundation receive no protection of any form in a flood event; ii) the "No development" policy that prohibits new development within 200-metre from the coastline; and iii) the mandatory "Flood insurance" for properties at risk of flooding. Unlike "Hold the line", the mandatory "Flood insurance" and "No development" policies do not reduce flood risk to zero although the risk of is reduced. These options are compared and presented in Figure 5.1.

The cost comparison exercise shows that the cost-effectiveness of shoreline management approach varies with location. This is best manifested with the example of the "Hold the line" policy. At Seberang Perai (highly developed area), seawall construction is more economically viable than the "No development" policy after year 2100. It then went further to take over the "Flood insurance" policy and became the most beneficial flood management approach by year 2200. However, the "Hold the line” policy remains as the costliest amongst all approaches considered for the entire study period at Kuantan-Pekan (less developed area).

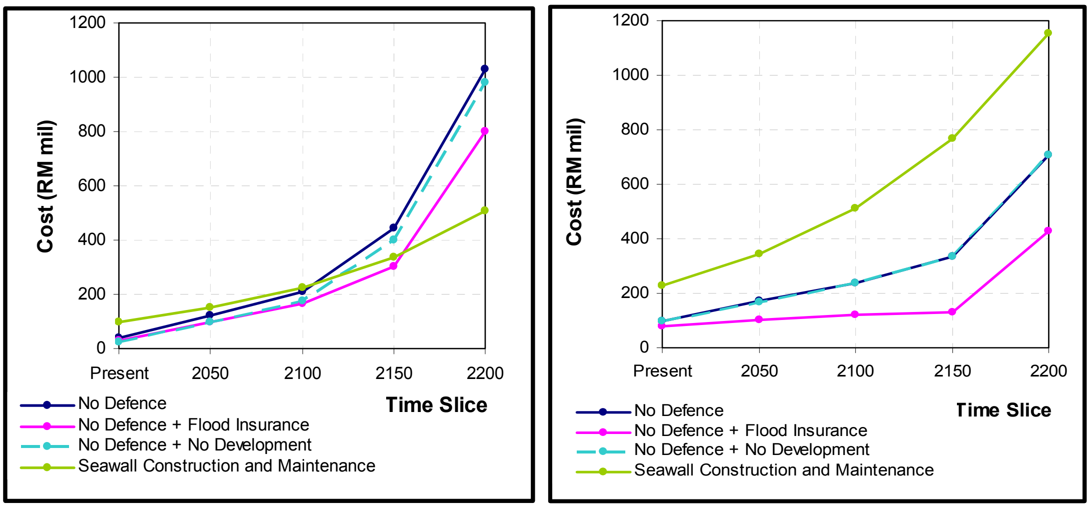


Figure 5.1 Cost comparison amongst different flood management options for a 1 in 200-year flood at different time slices at Seberang Perai (left) and Kuantan-Pekan

The essence of this cost comparison exercise is for coastal planners to select the most cost-effective flood management tool to reduce the intermediate and long term risk of coastal flooding. It helps to avoid the adoption piecemeal solution that is only beneficial in the short term but detrimental in the long run. From this study, it is clear that there is no one-size-fits-all solution when it comes to coastal flood management. In fact, location and land use pattern are sensitive factors and they affect the selection of the most suitable management approach.

5.2.2 Planning and Development

Through cost comparison, the selection of the most appropriate flood management tool could be easily determined. However, planning for future is a more complicated issue. Coastal flood risk (probability x consequences) increases with coastal development. To avoid “risky” development, the potential risk posed by a new development has to be assessed carefully. This projects studies the impacts of new development on coastal flood risk at Kuantan-Pekan coastline. Through the incorporation of flood management tools, the feasibility and economic viability of the new development were reassessed. This exercise aimed to address two issues – i) The risk of permitting new developments without adaptive measures; and ii) The viability of permitting new developments with adaptive measures.

From the study, if new development is permitted without any adaptive measures (the "Do nothing" option), the risk becomes higher due to the significant increase in land value. The differences between the damage costs incurred before and after change in land use pattern are shown in Table 4.9. Thus, the answer to the first issue is "No", new development shouldn't be allowed without adaptive measures.

The use of flood management tools has seen cost reduction benefit. Compare between the implementation of mandatory "Flood insurance" and "No development" policies, the former saw a higher cost reduction after change in land use pattern than the latter. However, it is important to realise that higher cost reduction is not equivalent to lower flood risk. As the land value behind the coastline (consequence) increases, the risk of flooding remains higher even with the utilisation of flood management tools. On the other hand, "Hold the line" policy becomes more cost effective with increased land value. This is because the immediate protection afforded by the construction of seawall becomes higher whilst the risk of flooding is maintained at zero level. Thus, it can be concluded that with the right type of adaptive measures, new development can be viable.

Undoubtedly, with identical investment in flood defence, the "hold the line" policy offers greater benefit with increased development. However, it is risky to permit new development based on this criterion solely. Ironically, costal area protected by any form defences often becomes more attractive for human settlement and new business. Thus, the prospective increase in the risk of coastal flooding as a result of the increase in consequences (higher land value) should be taken into account. Furthermore, as discussed previously, residual risk following the construction of flood defence structures also need to be accounted for. Beside, coastal area is a very sensitive region. Addition of artificial structures along the coastline will indirectly alter the sedimentology process and subsequently the wave regime at nearshore region. The ecosystem along the coastline may be disturbed thereafter. In addition, erosion problem is also commonly observed at the toe of flood defence structures due to scouring effect. Thus, the need for additional protective measures to mitigate erosion problem should also be considered.

In conclusion, coastal planning and management shouldn't be assessed solely via the cost-effectiveness of a project. A coastal planner needs to be visionary and take into account every aspect that can potentially influence new coastal development proposal. However, the analysis approach discussed above is a very useful tool for coastal planners as it helps generating an overall idea for coastal planners in their decision making process.

5.3 Recommendations

The limitation in this study is the lack of accurate data and it has become the largest source of error in the analysis. In this study, accurate data were not accessible either due to the cost involved in data collection or the required data simply does not exist. The latter is also a common problem amongst less developed countries where long term records are often not kept by relevant authorities. Based on the experience of this study, the following recommendations are advised for the improvement of flood risk assessment in Malaysia:

- More accurate elevation data should be obtained coastal area in Malaysia. An accurate elevation data will increase the reliability of flood risk assessment by reducing the uncertainties, which is the range of possibility at a given flood height resulted from the use of SRTM data that has been brought up in this study. Collection of accurate elevation data such as LiDAR data along the coastline of Malaysia is recommended in order to facilitate flood risk analysis at nationwide scale;
- This study considered the IPCC high emission scenario and used a constant rate of sea level rise at 9mm/year throughout the entire analysis. However, rate of sea level rise is nonlinear and the use of global sea level rise estimation is too general for a specific study location. Furthermore, allowance for relative sea level rise due to local land adjustment was not considered in the estimate of sea level rise. Therefore, it is recommended that future study should incorporate these factors in order to allow a more

realistic analysis. Besides, it is advised that long term sea level observation in Malaysia should be established since this record is currently lacking in the country;

- Flood height data used in this study is based on hindsight prediction using XTide online prediction server rather than actual sea level observation from the past for a sufficient length period. Therefore, actual extreme water levels were not considered in this study and thus resulted in a lower flood height estimates. The differences amongst flood heights at different recurrence intervals were also observed to fall within a narrow range because of this reason. Thus, it is recommended that historic tidal observations are to be procured from Department of Survey and Mapping Malaysia in order to estimate the flood level at the study locations more accurately. Similarly to the problem faced in the estimation of sea level rise, it is advised that recording of long term sea level should be set up;
- It is recommended that up-to-date topographic maps are used when digitising the land use pattern. In this study, Google Earth images were used. The accuracy of digitisation was reduced due to the low image resolution of Google Earth images at Kuantan-Pekan (less developed area). Although Seberang Perai (highly developed area) was not affected by this problem, the different agricultural activities remained hardly distinguishable amongst each other from the images. Thus, the identification of more land use categories for more accurate calculation of damage index had been limited;
- Although damage values data obtained for this study covers a comprehensive range of land use categories, the model used in the study has been simplified by only applying uniform land value on limited number of land use categories. In order to increase to accuracy in the estimate of damage index, a database of the individual property with its associated damage index would be required. Thus, it is recommended that a national properties database to be established;
- The housing and population densities used in the analysis were assumed to remain constant, and subsequently the associated cost. However, it is unlikely that these variables will remain constant over a long period of time

in reality. Thus, it is recommended that the trend of population growth and the increase of housing density to be studied and incorporated in the model;

- Flood events are assumed to occur instantaneously in the model. This simplification has understated the complicated flow of water over floodplain topography. To reduce error generated from this simplification, it is recommended that the GIS model is used in conjunction with mathematical model for open channel flow so that the flow of flood water could be simulated more accurately; and
- This study adopted the approach to increase development along the coast in order to evaluate the cost effectiveness of flood management tools in coastal planning and management. It is recommended that approaches, for example, managed realignment where existing towns are relocated to hinterland area, could be studied. This suggestion offers coastal planners a greater range of options for planning and management purposes.

Although the model has been limited by the aforementioned limitations, the model developed in this study is said to have fulfilled the aim to develop a generic approach for flood risk assessment that is capable for continuous refinement should more accurate information and data are available in the future.

6. CONCLUSION

The following objectives were identified in this study:

- To identity data requirement for an accurate coastal flood risk study in countries with limited long term data record;
- To develop a generic approach for coastal flood risk assessment taking into consideration the impact of sea level rise that could be refined continuously with more accurate data input;
- To facilitate coastal planners and managers in decision making process by investigating the cost effectiveness of different flood management tools using the approach developed above; and
- To investigate the cost effectiveness of different flood management tools in coastal zone development in conjunction with change in land use pattern.

This study has addressed the above objectives and is explained as follows:

- In order to carry out coastal flood risk assessment, the most accurate elevation data should be procured as it helps reduces the uncertainty in risk assessment. Besides, it is also identified that long term sea level records for a minimum of 50-year is essential for the future sea level rise estimate and also the probability of occurrence of flood at any given height. Thus, it is recommended that it is necessary to establish long term measurement of sea level for countries with limited historic records. Up-do-date topographic maps are also required for the setting up more accurate model;
- A model has been set up in this study and was used as a base model for flood simulation at Seberang Perai (highly developed area) and Kuantan-Pekan (less developed area). By incorporating sea level rise and flood height data into the model, flood prone areas were identified and flood maps were produced. By applying appropriate land damage value onto different land use categories that intersected with areas at risk of inundation, damage index was calculated for flood at any given height. It is observed that the risk of flooding differs from one location to another depending on the level of

development and the use of land. In the model, due to data collection problem, data with low level of accuracy was used. However, by using more accurate data as suggested in Section 5.3, the simulation output produced by the model is anticipated to improve greatly;

- "Do nothing", "Hold the line", "Flood insurance" and "No development" flood management tools were incorporated in the same model set up above. The economic viability of these tools were studied for a period of 200-year. By comparing the cost involved for different options, the most appropriate flood management approach at different time intervals was identified. Results from the analysis showed that "Flood insurance" strategy could effectively reduce coastal flood risk at both study locations. However, it was also observed that flood management strategy behaves differently at different locations. Therefore, by practising cost comparison at individual location, it allows coastal planners to design a long term and visionary flood management approach that is effective for a location of interest; and
- In the study, land use pattern along the coastline south of Kuantan city (less developed area) was modified from lower value development to higher value development. By incorporating the aforementioned flood management tools, the changes of the effectiveness of these tools in conjunction with the change in land use were studied. This method allows coastal planners to assess if a proposed development in future will significantly increase coastal flood risk and whether implementation of a particular flood management approach will help to reduce this increase risk.

In conclusion, long term risk of coastal flood increases with climate change and anthropogenic activities within the coastal zone. This risk could be assessed using the method developed in this study. Via careful study on the effectiveness of long term planning and management strategies in the coastal zone, costly mistake can be avoided during an attempt to reduce coastal flood risk.

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APPENDIX

Land Use Categories and Unit Values of Crops, Buildings and Household Articles Excerpted from the National Register of River Basins (DID, 2003)

TABLE 2.2: FLOOD DAMAGE FACTORS

Item	Flood Depth	Flood Duration	Damage Factor (%)		Remarks
Paddy (Production loss)	less than 0.5m	less than 2 days	30		
		3 to 4 days	37		
		5 to 6 days	40		
		more than 7 days	45		
	0.5 to 1.0m	less than 2 days	33		
		3 to 4 days	40		
		5 to 6 days	43		
		more than 7 days	49		
	more than 1m	less than 2 days	60		
		3 to 4 days	80		
		5 to 6 days	86		
		more than 7 days	96		
Rubber (Mortality of young tree)	more than 0.25m	less than 7 days	5		Assume 9% of total planted area to be subject to mortality
		8 to 14 days	15		
		15 to 21 days	60		
		more than 22 days	100		
Oil Palm/Coconuts Palm (Mortality of young tree)	more than 0.25m	less than 7 days	10		Assume 9% of total planted area to be subject to mortality
		8 to 14 days	20		
		15 to 21 days	70		
		more than 22 days	100		
Other Tree Crops (Mortality of young tree)	more than 0.25m	less than 4 days	10		Assume 10% of total planted area to be subject to mortality
		5 to 8 days	25		
		9 to 12 days	60		
		more than 13 days	70		
House/Building			*Urban*	*Rural*	
	less than 0.5m		3.5	3.5	
	0.5 to 1.0m		4.5	4.5	
	1.0 to 1.5m		6.1	6.1	
	1.5 to 2.0m		6.8	6.8	
	2.0 to 3.0m		11.2	11.2	
	more than 3.0m		17	17	
Household Effects	less than 0.5m		5.7	5.7	
	0.5 to 1.0m		9.6	9.6	
	1.0 to 1.5m		11.9	11.9	
	1.5 to 2.0m		13.5	13.5	
	2.0 to 3.0m		33.6	33.6	
	more than 3.0m		68.7	68.7	
Industrial Facilities	10% of damage to urban houses				
Public Facilities and Utilities	30% of damages to public buildings and private houses				
Indirect Losses	30% of direct losses				
Mining, Grasslands, Forests and Swamps	Minor damages and not estimated				

Table A4.1: Comparison of Unit Values used in KTAT 2002 Study and JICA 1982 Study.

1- Crop Production Values		Unit	2002 Study Value (RM)	1982 Study Value (RM)
Mix Horticulture		ha	4,700	2,900
Paddy	Perlis	ha	1,872	1,270
	Kedah		1,857	1,110
	Pinang		1,471	1,118
	Perak		1,500	860
	Selangor		1,911	900
	N. Sembialan		1,359	1,070
	Melaka		1,412	1,060
	Johor		1,197	1,010
	Pahang		967	760
	Terengganu		1,644	800
	Kelantan		1,519	620
	Sabah		1,409	1,130
	Sarawak		809	1,060
Rubber	(Mortality)	ha	5,200	2,880
	Production loss	/ha/day	23.50	12.83
Oil Palms	(Mortality)	ha	3,500	1,930
Coconuts Palms	(Mortality)	ha	6,200	3,440
Other Crops	(Mortality)	ha	6,400	3,540
2- Building / Properties				
Private Housing	Urban house	household	22,000	7,500
	Household effects	household	18,000	0
	Rural house	household	15,500	3,000
	Household effects	household	16,600	0
Public Buildings		per 10,000 population	3,780,000	2,000,000

Table A4.2: Comparison of Flood Damage Factors and Damage Values for Buildings and Household Articles

a) Urban

Depth of Flooding	2002 Study					1982 Study				
	Factor %		Damage (RM)			Factor %		Damage (RM)		
	Building	HA	Building	HA	Total	Building	HA	Building	HA	Total
less than 0.5 m	3.5	5.7	770	1026	1796	3	0	225	0	225
0.5 -1.0 m	4.5	9.6	990	1728	2718	5	0	375	0	375
1.0 - 1.5 m	6.1	11.9	1342	2142	3484	7	0	525	0	525
1.5 - 2.0 m	6.8	13.5	1496	2430	3926	11	0	825	0	825
2.0 - 3.0 m	11.2	33.6	2464	6048	8512	15	0	1125	0	1125
more than 3.0 m	17	68.7	3740	12366	16106					

b) Rural

Depth of Flooding	2002 Study					1982 Study				
	Factor %		Damage (RM)			Factor %		Damage (RM)		
	Building	HA	Building	HA	Total	Building	HA	Building	HA	Total
less than 0.5 m	3.5	5.7	542.5	946	1489	3	0	90	0	90
0.5 -1.0 m	4.5	9.6	697.5	1594	2291	5	0	150	0	150
1.0 - 1.5 m	6.1	11.9	945.5	1975	2921	7	0	210	0	210
1.5 - 2.0 m	6.8	13.5	1054	2241	3295	11	0	330	0	330
2.0 - 3.0 m	11.2	33.6	1736	5578	7314	15	0	450	0	450
more than 3.0 m	17	68.7	2635	11404	14039					

Remarks:

i) For unit values of Buildings and Household Articles(HA), refer to Table A4.1

ii) Flood Damage Factors in the 2002 Study are adopted from JICA 2000 Study: The Study on Integrated Urban Drainage Improvement for Melaka and Sg. Petani.