DEVELOPMENT AND STABILITY OF COASTAL SAND SPIT

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By

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Submitted to the Civil Engineering Programme
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CERTIFICATION OF APPROVAL

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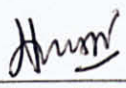
Approved by:



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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained here in have not been undertaken or done by unspecified sources or persons.

Azlina Binti Aminulla

ABSTRACT

Sand spit has created problems at the affected area including navigation problem, safety of the navigation boats and also the potential of flooding. All of these problems are critical if actions not been taken into account to overcome this problem. This research is focusing on the cause of the development of sand spit and the tidal prism. Comparison between sand spit occurrences are made to see the common features between the sand spit and to determine what are the effects towards its development. River mouth study is also conducted to study the characteristics of the critical river mouth. Comparison between sand spit occurrences are made to see the common features between the sand spit. The cause for its formation has always been the longshore sediment transport that carrying the sediment driven by the dominant wind and wave.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Total land area in Malaysia is estimated as 329,750 km^2 [1] and the total length of the coastline is 4,809 km [2] as shown in Figure 1-1. The rivers in Malaysia discharge their flow into the South China Sea, Straits of Malacca and Sulu Sea. There are siltation problem at most of the river mouth due to heavy sediment deposition from the upper stream coupled with longshore drift. This is a common and critical problem in Southeast Asia including Malaysia. The spits are among the common phenomenon that occurred at the river mouth entrance. There are many river mouths that are supposedly function as the shelter for fishing vessels have continuously suffered decreasing navigation depths which are caused by sedimentation. The decrease in navigation depth has caused the navigation down time and also increases the risk due to shifting of shallow sand bars and wave current interaction.

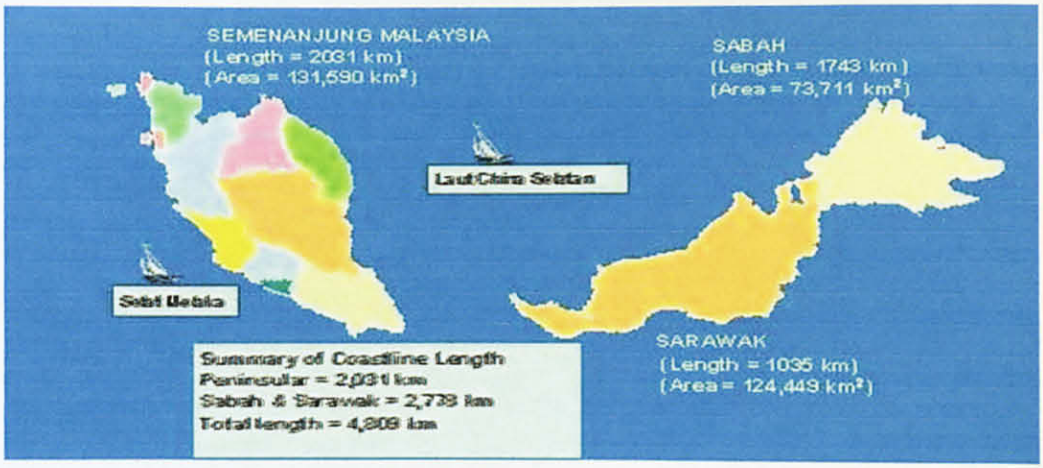

Figure 1-1 Malaysian Coastline [2]

Sand spit is defined as a deposition landform found off coasts. At one end, spits connects to land while at the far end they exist in open water. It is an area where the beach stretches out into open water across the mouth or bay of the estuaries [4]. Spits are ordinary morphological features on interrupted coastlines and typically found where the coast makes an unexpected change in its direction [5]. Spits formation can be affected by two factors which are the wave climate (environmental condition) and the geological setting of the area where the spits are formed.

Malaysia has a tropical climate with two monsoon seasons; North-east (NE), and South-west (SW) monsoon. Both are typically occurring from October to February for NE monsoon and April to October for SW monsoon. The NE monsoon season mostly affects the eastern states; Kelantan, Terengganu and Pahang while the SW monsoon affects the western states but not that intense as it is being protected by Sumatra. This monsoonal season affect the formation of sand spit as it is the main driver for the sediment transport and morphology of the river. As mentioned earlier, the geological setting of the area also affects the sand spit as the coastal process varies depending upon the orientation of the rivers.

A great understanding on the sand spit growth, its elongation and stabilization is required for the prediction of the barrier formation. The physical forces that affect the sand spit such as river flow, tides, waves, wave induced currents and others are also taken into account when dealing with sand spit formation.

1.2 Problem Statement

The government of Malaysia has been working out to find the solutions for this problem by dredging and constructing breakwaters. Unfortunately, these ways are not always practical due to different morphological features in every inlet.

The development of sand spits near the east coast of Malaysia is quite worrisome. The navigation route and safety of the nearby area is affected by the sand spit formation. Fishermen are amongst the most affected due to this phenomenon. They have to take longer time in order to go to the sea as the usual way has been blocked by the spit. This increase the travel time and cost of their monthly expenses as they have to fill up more fuel in order to fish.

Besides that, the safety of the navigation boat is also affected at the area covered by the spit. This is due to the shallower water been created behind the spit formation and thus, affects the flow of the water. This may create problems for the fishing boats to move as navigation capability is now reduced. As the spits continue growing, the ecosystem in the created lagoon behind the sand spit may also change. This may lead to changes in the living flora and fauna due to the adjustment in the water quality

Another problem that has been faced around the sand spit area is the potential of flooding. Since the opening of the river mouth or estuaries are blocked and narrowed due to the spit formation, the flushing capacity through the river mouth will be hindered. During monsoon seasons, the area will be susceptible to flooding since the opening of the river mouth or estuaries are being blocked. Therefore, proper studies are required in order to overcome these problems.

1.3 Objectives

The objectives of the study are:

i. To investigate the cause of the sand spit formation and its growth factors.
ii. To study the relationship between tidal prism and the channel stability

1.4 Scope of study

In this project, factors affecting sand spit occurrences were studied and researches were done to study in more detail of the formation and development. Comparison of the sand spits characteristics at several different locations were done to identify the common features that contribute to its formation. Besides that, river mouth characteristics studies and review on previous reports were also conducted in order to achieve the objectives.

CHAPTER 2
LITERATURE REVIEW

There are several studies that have been conducted to asses the formation of sand spit all around the world. The shape, size and growth rate of the accumulated sand spits were studied by a theoretical and experimental approach. The growth rate, shape and size of the spit are affected by the geological and a number of physical parameters.

In previous study in Denmark, they studied on the accumulating sand spit phenomenon which is considered due to the constant supply of sediment coming as longshore transport along a long straight stretch of coastline [5]. The wave climate is taken to be constant and the incoming wave is from one direction only. The spit is formed as the addition of the updrift coastline without varying its shape. The process of the spit movement is shown in Figure 2-1.

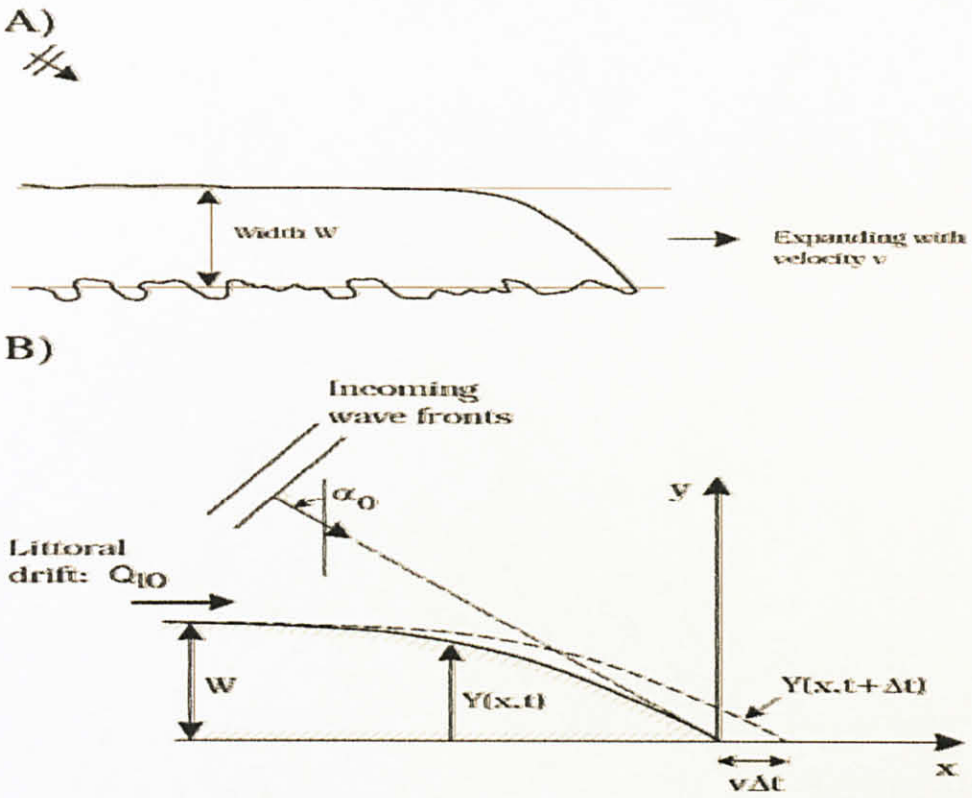

Figure 2-1 (A) The direction and width of the spit's expansion. (B) Sketch of a growing spit with Y at time t + dt is indicated by the dotted curve [5]

A laboratory experiments on spits had been conducted to study the formation and migration of the sand spit. In the experimental set-up, fully turbulent flow condition was assumed. The dimension of the laboratory wave basin were taken as follow; 7 m wide, 16 m long and 0.5 m at the uniform stretch of coast. The stretch of coast was 2 m wide and 5 m long with an initial slope of 1:10. The bed was raised up to 0.12 m above the bottom of the wave tank (the water depth was kept at 0.25 m) and the sketch of the experimental set-up is shown as in Figure 2-2 [5].

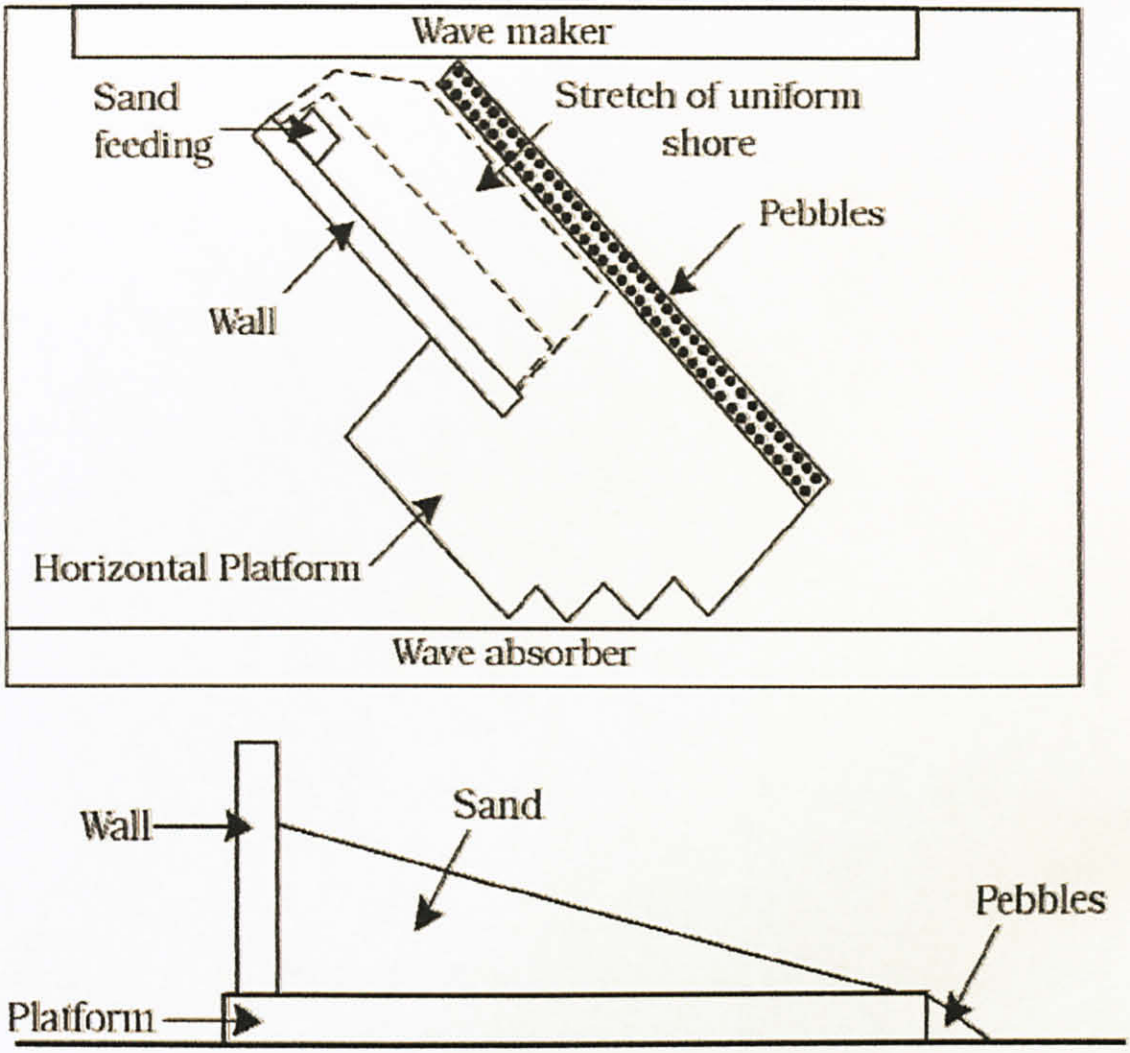

Figure 2-2 Experimental set-up sketch [5]

Based on the experimental results, they have found that the spit is expected to attain an equilibrium shape for a constant wave forcing. From the model output, it was found that the growth rate is inversely proportional to the width of the spit and it was predicted to be infinitely narrow at the one that emerges [5].

In another studies conducted at Shamrock Island, Texas it was found that the sand was supplied to the spit by the circulation current within the nearby bay and waves generated by the northerly winter storms [6]. The linear expansion of the coastline with a constant width of the spit is clearly shown in the aerial photograph. The mapping of the aerial

photography has been used to monitor the long-term rates of shorelines migration [6]. For example, the aerial photography of Shamrock Island at the year of 1952 is taken to see the geographical changes along its coastline as shown in Figure 2-3.

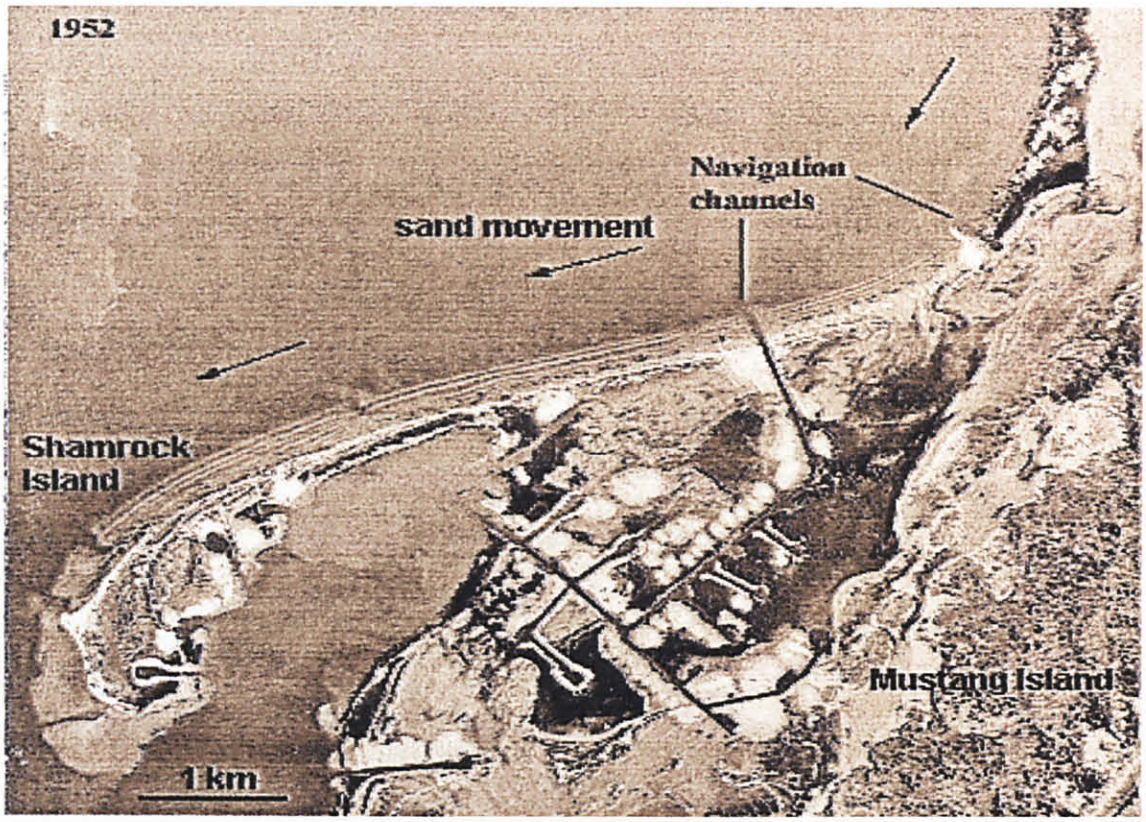

Figure 2-3 The aerial photograph of sand spit at Mustang Island in 1952 [6].

The study of erosion in that particular area was conducted by shoreline mapping where the aerial photographs were scanned using a high-resolution scanner and then imported to Adobe Photoshop to differentiate the shoreline. In this study, the development of the spit at Mustang Island was mapped as shown in Figure 2-4.

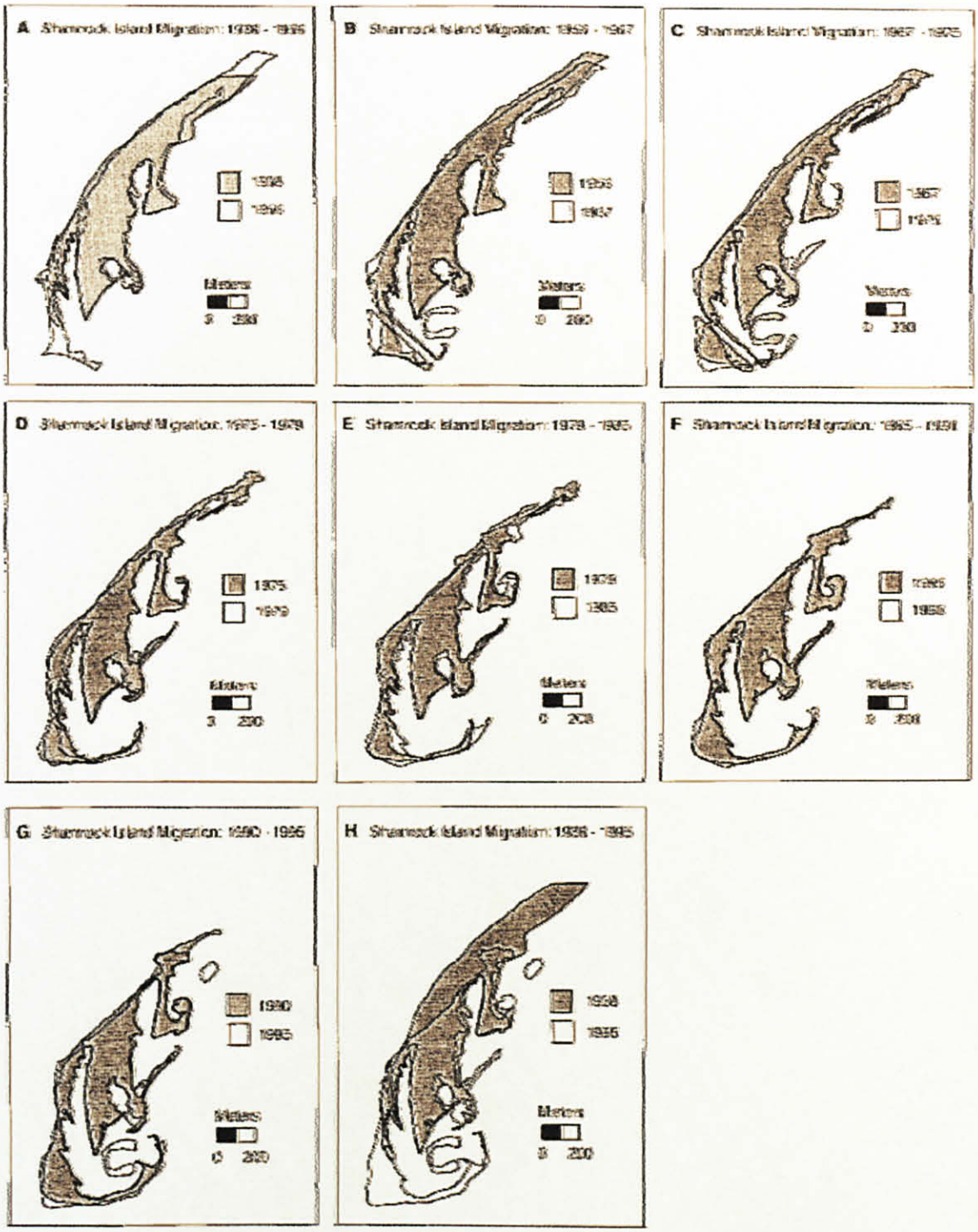

Figure 2-4 Development of sand spit from 1938 to 1995 [6]

The study of the stability of the sand spit due to dredging had also been conducted by the National Institute of Oceanography of India to study the sand spit at the Jatadharmaohan creek with different criteria. Various depths were dredged along the spit model and the results showed that the current increases as the depth is increased by 7.0 m [7]. The area of study and borehole locations is shown in figures below.

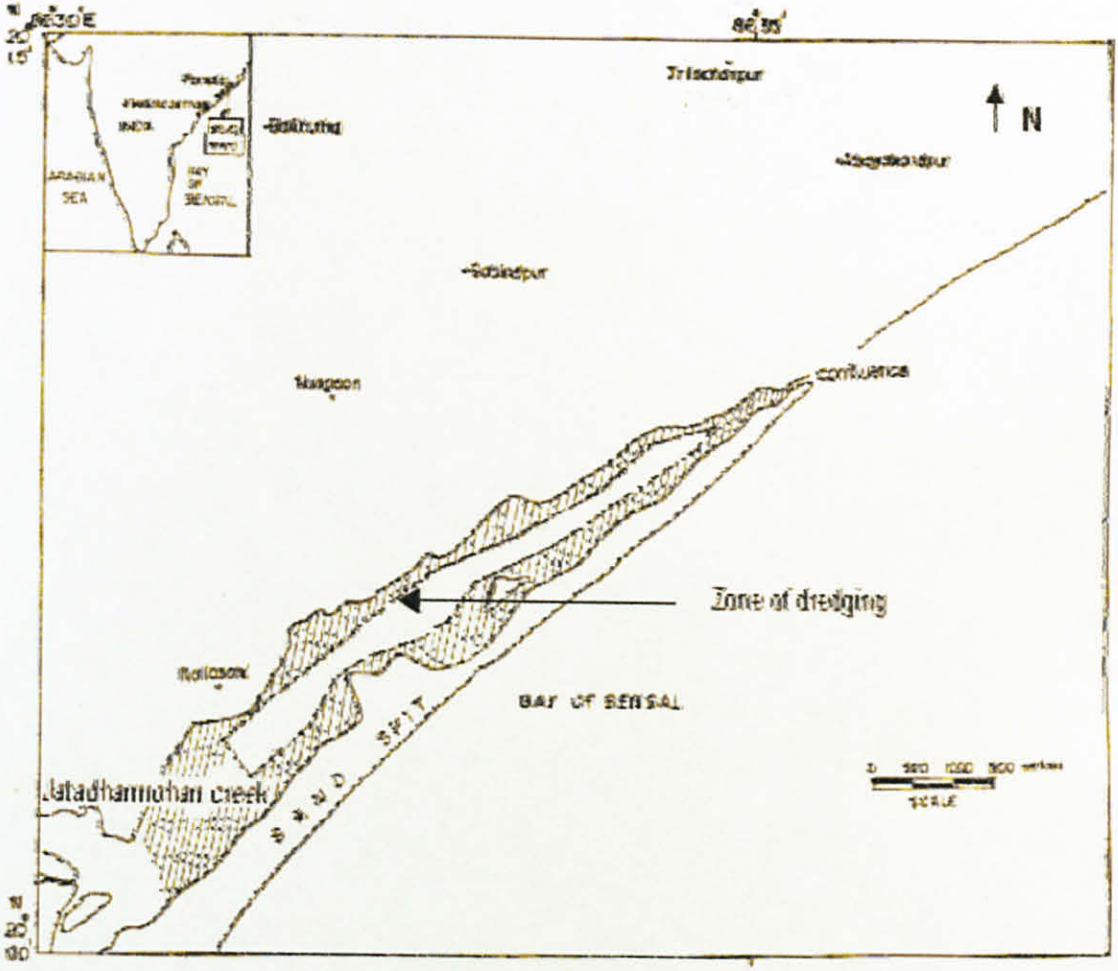

Figure 2-5 Area of study [7]

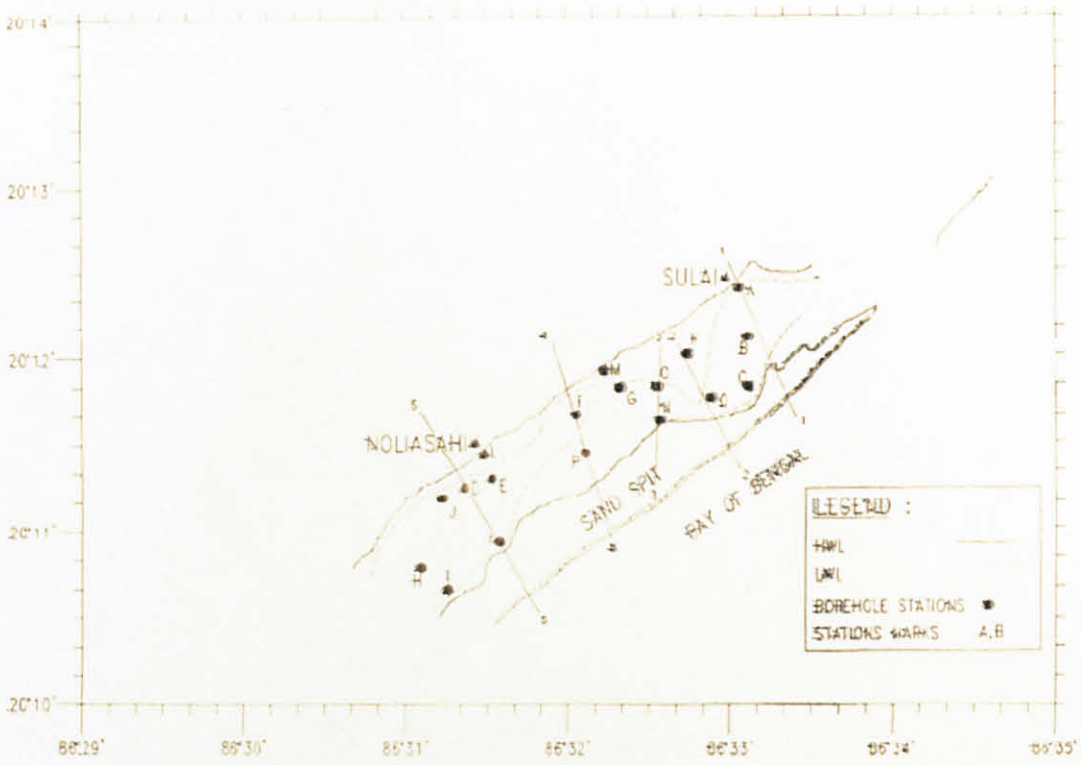

Figure 2-6 Critical section and borehole locations in the creek **[7]**

Their findings were the increase in the hydrostatic pressure due to dredging is very nominal such that the sand spit will not be affected. The dredging however should be done 700 m away from the fragile tip of the sand spit within the edges of the dredging zone. The bed slope at both sides of the creek is to be maintained so that it shall not be less than 1:6.

A study on the rhythmic development of sand spit had been carried out in Western Coast of France [8]. The study was done to investigate the relationships between variations in wave climate, longshore transport and sand spit development. Methods that had been used in this study include demonstrating the morphological changes by comparing the aerial photographs and historical maps. Numerical modeling was also conducted to get the annual values of the longshore transport. They had found that the development of the sand spit was due to the variations in longshore transport mainly caused by wave height

changes. The impact from high energetic swells or high storm surge frequency is also contributing to the increasing growth of the sand spit.

Other than that, a study on understanding the sediment dynamics along the Arcay sand spit France stated that the sedimentary dynamics of the beach has inference for the enlargement of the sand spit as a total. It has proven that the development of the sand spit is dependable on the characteristics which comprised a steep upper beach which consist of coarse sand, affecting rapidly alongshore and a flat lower beach, consisting of fine sand that moves slower. This difference is related to the increment of the wave height and wave incident during the rising tide [9].

In the coastal inlet channel stability study, it examined the concept of inlet that are not in stable condition using the Escoffier diagram. The study concerned on the adjustment of the minimum channel's entrance cross-sectional area and its effect to hydraulic and sedimentation characteristics which lead to sand spit formation [10]. It was found that the Escoffier analysis typically shows that the equilibrium area is larger than the existing one. Also, by using this analysis, the equilibrium channel area is having a tendency to have a bay that fills up with sediment completely. Up to this extent, the channel is called in a stable equilibrium condition.

In Malaysia (at the east coast of Peninsular Malaysia in particular), it is found that the tidal currents are relatively weak along the coastline, and the coast is completely dominated by the waves. There are also fairly strong tidal currents in the river channel with the channel being in a dynamic stable condition in terms of cross-sectional area but with shifting sand bars throughout the channel. Besides that, the cross-sectional area of the existing channel is in a dynamic equilibrium with the tidal currents and sediment discharge, but the channel prone to shifting sand bars which complicate the navigation.

One of the critical sand spits was found at Sungai Bebar, Nenasi Pahang where the river discharges into the South China Sea approximately 80 km to the south of Kuantan. At the coast, the river flows behind the sand spit, with sand bars forming across the entrance as shown in Figure 2-7. The coastline at this particular location consists of an open sandy beach which is fully exposed to South China Sea.

Figure 2-7 Sand spit at Sungai Bebar, Nenasi, Pahang

In an attempt to solve this problem, a navigation channel was dredged through the spit approximately 2 km south of the fishing jetties in 2005, and the river behind the spit was deepened between the channel and the jetties. However, the dredging works were all in vain as it was rapidly backfilled by littoral sand transport, and it is being blocked with the river continuing to discharge at the southern end of spit [11]. Various ways were conducted to study this problem including, wave modeling, 2-D Hydrodynamic (HD) Modelling, Sediment Budget and 2D Sediment Transport Modelling. At Nenasi, there is a relatively strong, net southward, littoral transport of sediment along the coast which is driven by the waves [11]. The HD model is used to calibrate against the tidal predictions at the tidal stations along the coastline of South Pahang. Model parameters are adjusted relatively within the reasonable limits so that the model predictions match the tidal

predictions. From the sediment budget, the sand spit is said to grow in a southerly direction due to the deposition of sediment at the end of the spit during southerly sediment transport (driven by the NE monsoon waves and wave driven currents).

There are several options for the river mouth improvement had been proposed to overcome the sand spit problem. There are listed as follow:

Table 2-1 Options for River Mouth Improvement [11]

Option	**Description**
Dredging	A gross sediment transport along the spit is approximately 300,000 m^3 per year. Volume of the dredged channel seaward of the sand spit is approximately 150,000 m^3
Long Training Walls	This scheme would include the dredging of the channel and construction of the training walls. It would block the majority of the longshore movement.
Short Training Walls	This scheme includes the dredging of the channel and construction of the training walls. It would block any direct transport of littoral material into the dredged channel.
Short Training Walls and Sand Bypass	This scheme includes the dredging of the channel and construction of the training walls. It is able to trap the sand build up over a two year period and prevent it from entering the channel.
Long Symmetrical Breakwaters	This scheme would include dredging of the channel and construction of the breakwater. It would block virtually all littoral transport.

Historical images of Kuala Sg. Besut as shown in Figure 2-8 indicated that sand spit has formed at the river mouth even earlier than 1955. High sedimentation rate is experienced at Sg. Besut and therefore lead to the shallower river. This has also caused flooding. The fishermen used to having the same navigation problem as experienced in Sg. Bebar. This has continued dynamically until a pair of breakwaters was built in the late 1990's. It was also reported that in recent years, sedimentation has become more evident especially in the river mouth. Among the mitigation measures that have been taken are the maintenance dredging works. The government is currently planning to improve by constructing new and longer breakwaters.

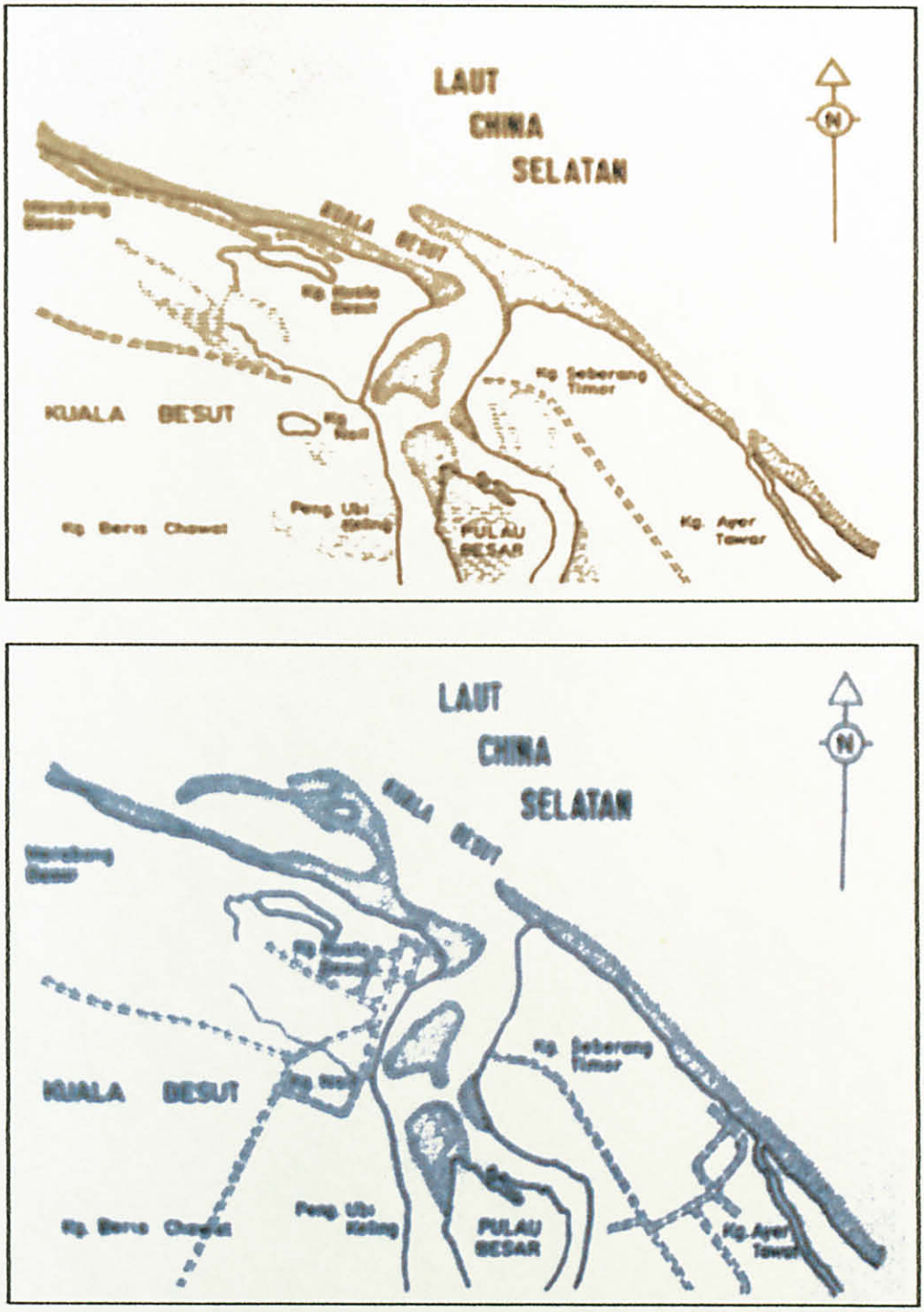

Figure 2-8 Sungai Besut River mouth changes (1955-top and 1967-bottom) [12]

Figure 2-9 Sungai Besut Rivermouth

Before the construction of the breakwaters, the river bed surveys were conducted to further substantiate the sediment source from the river. It was found the longshore transport has contributed most of the sediment or caused the river mouth to be silted up.

CHAPTER 3
METHODOLOGY

3.1 Methodology flow chart

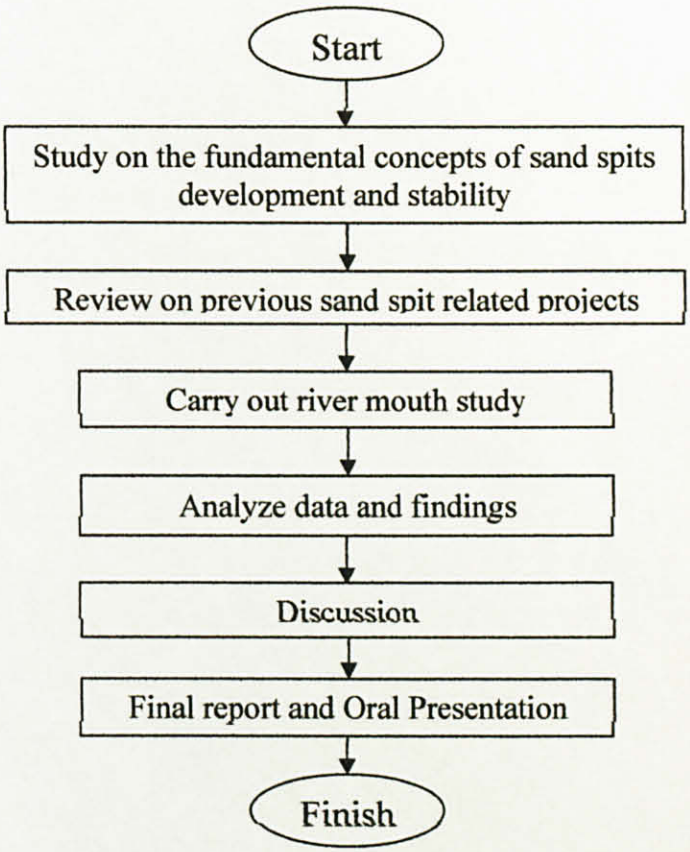

Figure 3.1 Methodology flow chart

3.1.1 Study on the fundamental concepts of sand spits development and stability

At the early stage of this project, the fundamental concepts of sand spits development and stability study was carried out in order to understand the sand spit phenomenon. This was done through research on journals, reports, and internet sources. Sand spit occurrences at several locations were studied in detail and comparisons were made to investigate the factors affecting its development and stability.

3.1.2 Review on previous sand spit related projects

Visits to headquarter of Department of Irrigation and Drainage (*DID*) at Kuala Lumpur were conducted to gain knowledge and seek information on sand spit related projects done in Malaysia. Detailed studies on these projects were then carried out to investigate further the causation of the sand spit. Information on detail project location, activities been carried out surround the area and the protections work done were also studied.

3.1.2 Carry out river mouth study

Information regarding the river mouth in Malaysia were studied and analyzed based on several factors; tidal prism and the characteristics of the river. The formation pattern or development and stability characteristics of the sand spit were then being determined based on the analyzed data. The relationship between the tidal prism and the inlet stability is to be determined by studying the Escoffier's approach.

3.2 Gantt Chart

At the end of this report, Gantt chart comprises both Final Year Project (FYP) 1 and 2 milestones will be presented to show the overall activities done for this research study as shown in Appendix A.

CHAPTER 4
RESULT AND DISCUSSION

Based from the data obtained from the river mouth study which had been conducted by the government of Malaysia and Japan International Cooperation Agency (JICA) in December 1992, selected river mouth in every states in Peninsular Malaysia had been analyzed and all of the data have been narrowed down to look into the relationship. The result is shown as in Table B-1 in Appendix B.

From the extracted information, several locations have been identified as the most critical river mouth. There are as shown in figure below:

Figure 4-1: Location Map

These locations are defined as critical due to their geographic and socioeconomic conditions which are considered as serious due to activities occurring near the river mouth.

4.1 Perlis River Mouth

The opening of the river mouth is protected by Langkawi Island and Tarutao Island and thus preventing swells from wind wave generated coming from Malacca Straits. The tidal prism is relatively large which is recognized as one of the forces in the river mouth formation. Coastal erosion is expected to happen at this area due to the failure of mangrove and the coastline has been retreated several metres away. Perlis river mouth is used as fishing and commercial port. Ferry are fully utilising the port to transport passengers and cargo to Langkawi Island. In fact, the port is the largest fishing port in the state.

4.2 Kedah River Mouth

Tidal prism for Kedah river mouth is large due to long tidal influence and also wider river width. The river mouth is formed by the low wave and large tidal prism. However, there is siltation problem due to the worsening of sediment transport from the basin. The coastline is also retreating due to mangrove failure. Kedah river mouth has been used as the commercial and fishing port. And the surround area is surrounded by the paddy field.

4.3 Tg. Piandang

River mouth of Tg. Piandang is formed by the small tidal prism which emerged with the siltation in the inner outlet of the river. Tg. Piandang is used as the fishing port where it's surrounding is also surrounded by the paddy field.

4.4 Beruas River Mouth

Wind wave generated from Malacca strait are attenuated by breaking and bottom friction. The formation of estuary at the river mouth is resulting from the tidal currents which filling and emptying the river and abundant river discharge. The river mouth has been fully utilised as the fishing port. The area is surrounded with fishing village and swamp area.

4.5 Kuantan River Mouth

The river mouth is protected from Tg. Tembeling at the north direction and by Pahang river at the south direction. The river mouth is formed by high and oblique wave and also with large tidal prism. There is sand spit development been identified at the river mouth from one side of the river bank. The river mouth is used as fishing port and also for commercial boats.

4.6 Kerteh River Mouth

The river mouth is exposed to South China Sea and is formed by the high and oblique wave with small tidal prism. There is also sand spit problem been recognized at the river mouth entrance and the outlet is closed by the sand bars. Socioeconomic activity at Kerteh is fisheries. The industrial plant owned by PETRONAS is located 10 km away from the river mouth.

4.7 Marang River Mouth

The formation of the river is due to the high wave condition combined with large tidal prism. There is also formation of sand spit at the river mouth area and the sand bars are sometimes found in the inner channel. The river is mainly used for fishing and commercial port and it is surrounded by swampy forest.

4.8 Terengganu River Mouth

The river is exposed to South China Sea and thus is expected to experience swell. The river formation is due to large tidal prism and high wave. There is also sand spit problem encountered at the area of the river entrance. The river is used for commercial and fishing port where the surrounding area is developed as the capital of Terengganu.

Table 4-1 shows the features of the river mouth in tabulated form.

Table 4-1 Feature of the critical river mouth

RIVER MOUTH	FEATURES		
	Tidal Prism	Wave	Soil
Perlis	Large	Low	Soft clay, stiff clay and limestone
Kedah	Large	Moderate	Marine clay
Tg. Piandang	Small	Low	Clayey sand and silty clay
Beruas	High and Oblique	Low	Clayey sand and silty clay
Kuantan	High and Oblique	High and Oblique	Fine sand and medium stiff clay
Marang	Large	Large	Fine sand and silt
Kerteh	Small	Small	Coarse and fine sediment
Terengganu	Large	Large	Alluvium gravel, sand, silt and clay

Comparison between Arcay spit, France and the one at Sungai Bebar, Malaysia was made since both of these sand spits are considered as the most critical occurrence. From the comparison, we can see that the cause of the sand spit formation is due to the longshore sediment transport which was driven by the dominant wave. The table of comparison is shown in Table 4-2. There is also another comparison shown in Table 4-3 on other sand spits at different locations.

Sand spit formation is influenced by:

i. Tidal current
ii. River discharge
iii. Sea wave

Cross-sectional area located at the end of an inlet's main channel is important to ensure its stability. The inlet has to maintain the critical cross-section. The sediment will fill up the channel until it reaches the critical cross-section where it becomes stable. However, scouring will happen from the inlet if the actual cross-section is smaller than the critical cross-section. The scouring will continue until the critical size of the channel achieved. In the tidal prism context, the larger the tidal prism the more sediment will be deposited in an estuary or channel inlet. This is due to its power to erode and remove sand from the adjacent shore. Thus, we can relate that, the larger the tidal prism, the channel is more stable.

Table 4-2 Comparison of critical sand spits

Characteristics	Sand Spit	
	Arcay Spit, France	Sg. Bebar, Malaysia
Wave Climate	Oceanic climate (rainfall and cool summer)	Influenced by North East Monsoon
Length of sand spit	9 km	5 km
Main cause of formation	Longshore transport (dominated by North West wave direction)	Longshore transport (dominated by North East wave direction)
Development	Oblique	High and Oblique
Sediment transport rate (m^3/year)	40 000 - 100 000	250 000

Table 4-3 Sand spits at different locations

Characteristics	Yoneshiro River, Japan	New Brighton Spit, Canterburry
Wave Climate	Winter and summer	Mild Temperature, moderately high rainfall
Length of sand spit	500 m	18 km
Main cause of formation	Longshore sediment transport influenced by winter wind coming from Japan Sea	Longshore drift of sediment from Waimakiriri River
Development	not mentioned	Growing Southward
Catchments area	3750 km^2	3560 km^2

CHAPTER 5
ECONOMIC BENEFITS

Better understanding on the processes that influence the formation and growth of sand spit is required in finding the appropriate mitigation measures at the critical river mouths. This study has presented some of the possible causes and several comparisons have also been described to show similar and peculiar aspects of chosen sand spits examples.

The acquired knowledge can be utilized to develop future sand spit or river mouth improvement options. Early and optimum prevention work will avoid the sand spit from growing much further and worsen the impact to the affected area. Sustainable stabilization approach will not only reduce or avoid serious flooding especially during heavy monsoon season due to the impeded flow but it can provide promising measures to alleviate costly travelling time to the sea for the navigating vessels. Eventually it can also help to maintain acceptable water quality in the created lagoon behind the sand spit and ensure physical interferences, if any, will only cause minimal impact to the adjacent coastline. Although there are still room for further research to improve the understanding of the persistent phenomena, findings from the present study is hoped to provide a basis for initial and conceptual alternatives in addressing such sand spit development and stability problem.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

Longshore sediment transport is the most important process responsible for sand spit formation and development. It has been the cause for the entire sand spits occurrence around the world. The factors affecting its orientation are the wind and wave direction. The development of sand spit will follow the dominant wave which driven along the sediment.

Apart from that, the sea wave condition and the river discharge also influencing the formation of the sand spit. This is due to the tendency of the of the sand spit formation developed by wind wave as river discharge cannot maintain the original orientation of its river mouth prior to flooding.

Larger tidal prism has the potential to provide sufficient flushing that can ensure a tidal inlet to remain open. The stability of an inlet is the result of a dynamic equilibrium condition when the longshore sediment transport contribution is reasonably balanced by the upstream flow discharge through the inlet.

Future works should be done to study other relationships concerning the sand spit formation and other environment effects. Numerical modelling should also be conducted to estimate the sediment budget at the sand spit area so that the growth pattern of the sand spit can be determined.

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APPENDICES

APPENDIX A
FYP1 AND FYP2 GANTT CHART

Table A-1 Gantt Chart of FYP1 progress

No	Week/Detail	1	2	3	4	5	6	7	8	M	9	10	11	12	13
1	Project topic selection									I					
2	Research and discussion with supervisor									D					
3	Technical writing seminar									S					
4	IRC seminar									E					
5	Technical writing & Laboratory seminar									M					
6	Submission of progress report 1									B					
7	HSE talk									R					
8	Gathering of data (survey & interviews)									E					
9	Data collection									A					
10	Analyzing data									K					

Table A-2 Gantt Chart of FYP2 progress

No	Week/Detail	1	2	3	4	5	6	7	8	M	9	10	11	12	13	14
1	Analayze data and results									I						
2	Find a suitable site project									D						
3	Gather the significant data at the location									S						
4	Detail site assesments									E						
5	Hydrodynamic modelling									M						
6	Sediment Transport modelling									B						
7	Analyze model's results									R						
8	Final report									E						

APPENDIX B

CHARACTERISTICS OF SELECTED RIVER MOUTH

Table B-1 Characteristics of Selected River Mouth

SERIAL	NAME	CATEGORY			Wave	Tidal Prism	Catchments Area (cubic meter)	Length (m)	Width (m)	Surface Soil Loss Rate (1000 ton/yr)
		1	2	3						
1	Perlis	√			Low	Large	600	45	60	210
2	Kedah	√			Low	Large	3060	110	200	1270
3	Tg. Piandang	√			Low	Small	9	10	25	3
4	Beruas	√			High and Oblique	Large	240	45	50	70
5	Kuantan	√			High and Oblique	Large	1710	80	130	337
6	Kerteh			√	High and Oblique	Small	240	40	30	33
7	Marang	√			High and Oblique	Large	460	50	80	194
8	Terengganu	√			High and Oblique	Large	4650	180	200	2041