MASTER THESIS

HYDRODYNAMIC MODELLING FOR MANGROVE REFORESTATION AT TANJUNG PIAI, WEST COAST PENINSULAR MALAYSIA

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ABSTRACT

Coastal erosion is greatly accelerated by the presence of agriculture and aquaculture activities (oil palm plantation or shrimp farming involving the construction of earth bunds) in the natural process. Earth bunds or dykes are constructed to prevent entrainment of seawater into the agriculture area behind the bunds so as to protect these valuable crops and plantings. Coastal erosion and mangrove belt depletion have exposed the earth bunds to direct wave impact. To prevent earth bund breaching and flooding of the area behind the bunds, the requirement arises to strengthen the earth bunds along the eroding coastline.

Projects are carried out to replant the mangrove on the mud flats in front of the newly constructed earth bunds for its effective wave dissipating capability and environmental values. The replanting of mangroves on the mud flats in an open coast area requires protection from waves attack during the initial stage when the mangrove seedlings are still young and weak. In view of rather calm wave conditions along the west coast of Peninsular Malaysia, a settlement field made out of soil for mangrove seedling planting and temporary breakwaters built out of bamboo poles with stone filling as a line of protection is one of the possible methods to be studied for its possibility to be applied on the study area.

This study aims to analyse the severity of coastal erosion and the hydrological aspects of Tanjung Piai; to identify the causal factors contributing to coastal erosion issue using numerical hydrodynamic modelling tool Delft3D; to identify existing or on-going restoration effort on site; and to explore restoration options that fit in the local condition. This report acts as a hypothesis analysis of erosion/sedimentation pattern at the study area.

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1 INTRODUCTION

1.1 Background information

Coastal erosion is greatly accelerated by the presence of agriculture and aquaculture activities (oil palm plantation or shrimp farming involving the construction of earth bunds) in the natural process. Earth bunds or dykes are constructed to prevent entrainment of seawater into the agriculture area behind the bunds so as to protect these valuable crops and plantings. The water from the rivers or drainage systems from the agriculture area are diverted and discharged at specific location. This has limited and disturbed the sediment supply and its distribution along the coastline which causes the coastal area to suffer erosion due to imbalance in net sediment transport. The disappearing mud flats have caused the depletion of mangrove fringes which in turn resulted in more rapid coastal erosion. Mangroves need a minimum width or area to sustain their population. In addition, the blocking of water exchange to mangrove areas by the earth bunds and the pollution from the fertilisers and nutrients used in the plantation or shrimp ponds may have resulted in an unsuitable environment for mangrove survival.

The interaction loop between coastal erosion and mangrove belt depletion will continue till a point where the whole mangrove band is gone which results in loss of valuable land area. Without the mangrove in between to dissipate the wave energy, the earth bunds are exposed to direct wave impact. The earth bunds are not designed to withstand the wave forces in which they may eventually fail in stormy weather or if the imposed wave force exceeds the design value. The failure of earth bunds and inundation of the hinterlands will result in serious economic damage.

To prevent flooding of the area behind the bunds, the requirement arises to strengthen the earth bunds along the eroding coastline. When the earth bunds are too low to protect the land behind it from sea water intrusion, new bunds or other hard structures will be built further inland. Recently, a number of projects were carried out to replant the mangrove on the mud flats in front of the newly constructed earth bunds for its effective wave dissipating capability and environmental values. The replanting of mangroves on the mud flats in an open coast area requires protection from wave attack during the initial stage when the mangrove seedlings are still young and weak. A combination of fibre-rolls for establishment of seedling and sand-filled geo-tube or breakwater made of armour units have been adopted at some locations at the west coast of Peninsular Malaysia as a first line of protection for a mangrove replanting project and the results vary.

Combating coastal erosion and its negative effects is a long-term battle which requires innovative solutions and detailed planning. This thesis seeks to investigate mangrove forest restoration method along the west coast of Peninsular Malaysia by using locally available materials as an alternative to building hard structures in front of the eroding bunds. In view of rather calm wave conditions along the west coast of Peninsular Malaysia, a settlement field made out of soil for mangrove seedling planting and temporary breakwaters built out of bamboo poles with stone filling as a line of protection is one of the possible methods to be studied for its possibility to be applied on the study area.

Tanjung Piai located at the west coast of Peninsular Malaysia has been selected as the case study area because it suffers from serious coastal erosion and mangrove depletion problem. It is seriously eroded with certain stretches of the mangrove belt reduced to 50m (Wetlands International, 2007). It has been identified as one of the critical areas of coastal erosion under the National Coastal Erosion Study. It is an interesting area to study as the coastal erosion and mangrove depletion problem are significantly escalating despite intensive restoration efforts whereas the adjacent mangrove forests along Kukup coastline (to the north west) and near to Kampung Serong Laut coastline (to the north east) are rather stable (see Figure 1). The main reasons contributing to the coastal erosion and mangrove forest depletion have yet to be investigated in depth.

Figure 1 Satellite View of Study Area, Tanjung Piai (Google Earth, 2014)

1.2 Objectives

This study focuses on effective mangrove restoration method along the south west coast of Peninsular Malaysia specifically Tanjung Piai. An important aspect studied is the key reason contributing to the coastal erosion at Tanjung Piai so that the method proposed is more appropriate. These issues stated can be translated to the following research questions:

- What are the main causes of Tanjung Piai's coastal erosion and mangrove depletion problems?
- Is a settlement field with temporary breakwater a feasible method of mangrove forest restoration along Tanjung Piai coastline?

In order to achieve the goal, the following objectives have been identified:

- To analyse the severity of coastal erosion and the hydrological aspects of Tanjung Piai to identify the causal factors contributing to coastal erosion issue.
- To identify existing or on-going restoration efforts on site and to explore restoration options that fit in the local condition.

1.3 Methodology

The research questions will be answered in stages: literature reviews, GIS analysis and numerical modelling.

To achieve the goals as discussed previously, the following plan is listed:

- Firstly, literature reviews will be conducted on mangrove forests along the west coast of Peninsular Malaysia, met-ocean condition, previous mangrove restoration efforts done, GIS and the numerical modelling program.
- Relevant information and necessary data will be collected for analysis. Kukup (with stable coastlines) and Tanjung Piai (with seriously eroding coastlines) along Johor coastlines will be studied.
- Site photographs will be utilised to quantify the accretion/erosion along both study areas in the recent years in order to evaluate the shoreline and mangrove forest changes. Both study areas will be studied and compared to look into the reasons of mangrove depletion along Tanjung Piai. This part of study will be centered on investigating the reasons why Tanjung Piai mangrove belt is seriously depleting whereas Kukup mangrove belt is stable when both coastlines are adjacent to each other.
- After the shoreline evaluation, an existing numerical model of the region will be used to provide hydrodynamics conditions of the study areas for evaluation of present conditions and different possible scenarios for coastal/mangrove protection purposes.
- At a later stage, a study will be carried out on possible coastal/mangrove protection method or mangrove restoration methods for Tanjung Piai. The method of soft defence with mangrove planting along Tanjung Piai is not working well as the coastal erosion and mangrove depletion continued through the years despite intensive mangrove planting efforts. The coastal/mangrove protection method or mangrove restoration methods shall be looked into from a different perspective, for instance protecting the Kukup area rather than the localized badly eroding areas at Tanjung Piai. The shoreline evaluation of Benut area will be useful in this part of study.

2 LITERATURE STUDY

2.1 Coastal erosion issue at Peninsular Malaysia

2.1.1 Different coastal types

Malaysia is located on the geologically stable Sunda shelf, with a land area of approximately 33000km^2 and a coastline of approximately 4800km. The settlement and accumulation of different sediment on the coast is interrelated to the materials available to the shore and the natural forces acting at the coast, which consequently determines the different coastal types. On the west coast of Peninsular Malaysia, the mild wave condition of the Malacca Straits creates the shallow mud flats lined with mangrove forests.; whereas on the east coast of Peninsular Malaysia, the harsher wave condition of South China Sea and the sediment from river discharges create the sandy bays. (Department of Irrigation and Drainage, 2009) The coastline in East Malaysia is characterised with similar forms. The different coastlines are mainly categorised into three coastal types: sandy beach, muddy coast and cliff coast. (Sharifah Abdullah, S.A., 1992)

Sandy beaches

Sandy beaches are widespread along the east coast of Peninsular Malaysia, some locations at the west coast of Peninsular Malaysia (in pocket form) and some parts of the west coast of Sabah. At the east coast of Peninsular Malaysia, coastlines are exposed to monsoon climate which normally have relatively steep and narrow sandy beaches with coarse sediments on the beach and fine sediments further offshore beyond the narrow surf zone. The sandy beaches are formed by sand transported along the shoreline by littoral drift, driven by the long-shore currents in the wave breaking zone. The sand grain sizes range from fine sand to coarse sediments. Subjecting to monsoon climate, precipitation, wave exposure and littoral transport are seasonal, leading to unstable river mouth conditions. When the sediment load from the rivers is transported to the coastal area, its transport mode will change from current-dominated to wave action-dominated. The ratio between the amount of material supplied by the river to the coastal areas and the littoral transport capacity in the area determines the coastal features in the transition zone between the river and the sea. If the river sediment supply is larger than the littoral transport capacity, the material will build up delta, or vice versa.

Muddy coasts

Muddy coasts are mostly found along the west coast of Peninsular Malaysia, northeast of Sabah and the deltas of Sarawak, on areas with low exposure to waves and significant discharges of fine sediments. Muddy coasts have broad gentle seaward slope, tidal-flats which are normally vegetated with mangroves. The muddy coasts along the west coast of Peninsular Malaysia are formed due to the sheltering protection of Sumatra Island which creates a low energy area that allows the mud to settle. Mud, the finer sediment is settled and accumulated in protected foreshore areas or sheltered areas in lagoons, with calm wave conditions. Mud does not normally establish a stable coastal profile if exposed to even moderate wave action; mud is kept in suspension by the waves until it settles in deep water. However, flocculation can influence the siltation in the mixing zone between freshwater and seawater and lead to increased siltation of fine sediments.

Cliff coasts

The small remainder of the shorelines in Malaysia is bordered by cliffs, other than the sandy beaches and muddy coasts as mentioned beforehand. Normally, these cliffs form the headlands and rocky beaches. These coasts have a slow rate of morphological change and experience weathering and erosional processes by natural forces.

2.1.2 Coastal erosion and causes

Coastline changes induced by coastal erosion or accretion are natural phenomenon, interaction between natural processes and the coastal system. A coastline in its natural state goes through cycles of erosion and accretion over times. The coastline is stable as long as its mean position remains unchanged. Coastal erosion is not a problem unless it has threatened human activities, properties or infrastructures at the hinterlands. The causes of the coastal erosion can be natural or man-induced.

The coastal erosion issue was brought up as a national concern in the 1980’s when extensive stretches of agriculture land directly behind the coastline were severely affected by the erosion issue (Ghazali, N.H.M., 2006). The National Coast Erosion Study which began in 1984 and completed by 1986 was the first comprehensive study carried out to assess Malaysia shoreline. The National Coastal Erosion Study categorised the eroding shoreline into three main groups based on the nature of land use of the backshore area: level I critical, level II significant and level III acceptable. An eroding coastline is considered critical if the structures within the area are in immediate danger;

whilst it is deemed significant if the erosion is going to endanger the structures within five years without any coastal protection. An eroding shoreline is deemed acceptable if the backshore area is uninhabited. The main factors considered in determining the shoreline category were the economic value of the backshore area development and by the physical rate of erosion. The study has revealed that about 29% of the total of 4800km of Malaysia shoreline was subjected to varying degree of erosion (Department of Irrigation and Drainage Malaysia, 2013).

The concern of the economic and social consequences of coastal erosion increases as the utilisation of coastal lands increases. As the fronting mud-flats and mangrove forest recede as a result of coastal erosion, higher wave attack may breach the earth bunds along the coastal areas thus inundating the hinterlands and damaging the crops and reducing the soil fertility which in turn affect the production and income. In some areas, coastal erosion and higher wave attack have undermined the structure foundations of the residential and commercial housing which were initially sited behind the sandy beaches or tidal mud-flats which provided protection from incoming waves, leading to collapse of the structures. In some other areas, coastal erosion has damaged the coastal roads resulting in travel interruption and rerouting of traffic to alternative road. In addition, the coastal erosion has destroyed some beaches, affecting the tourism activities and other related business activities. (Ooi, C.A., 1996)

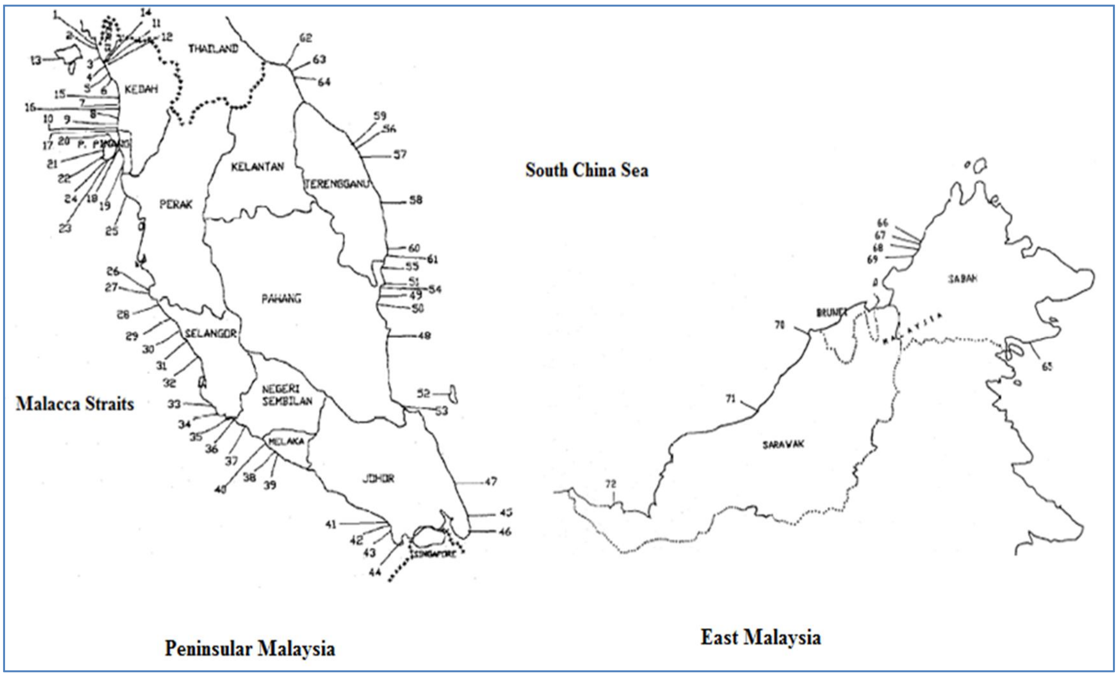


Figure 2 Critical erosion areas (Category 1) in Malaysia (Ghazali, N.H.M., 2006)

Figure 2 shows that approximately 60% of the critically eroded sites were located on the west coast of Peninsular Malaysia whereas only about 12% of the critically eroded sites were located on the less developed coastal areas of East Malaysia. In Peninsular Malaysia, the coastal erosion was more severe along the west coast as compared to the east coast although the west coast of Peninsular Malaysia is situated in a lower wave energy area. The sheltering effect of Indonesia land masses provide relatively calm sea in Malacca Straits comparing to the South China Sea that borders the east coast of Peninsular Malaysia . The west coast of Peninsular Malaysia is highly urbanised with agricultural, commercial and industrial activities. As identified in the study, the improperly planned development activities are the main cause of coastal erosion and rapidly disappearing mangrove forests. The impacts of these developments are stressing the coastal areas and forests, contributing to the above-mentioned scenario where the coastal erosion at the west coast was more severe than the east coast despite calmer wave conditions.

Most of the agriculture lands at coastal areas along the west coast of Peninsular Malaysia are under serious threat. These agricultural lands were reclaimed from inter-tidal lands with wide mangrove forests and protected by earth bunds to prevent sea water ingress. The earth bunds are constructed by Department of Irrigation and Drainage, conforming to its policy with a minimum strip of mangroves of at least 200metres maintained to serve as the buffer zone between the bunds and the sea (Department of Irrigation and Drainage Malaysia, 2013). Mangroves are used to protect the bunds and the hinterlands for the reason that mangroves to some extent are known for its ability to reduce wave energy propagating through them and thus prevent the waves from damaging the bunds. The bunds were constructed from earth and thus are susceptible to wave attack. However, ongoing coastal erosion has affected the survival of mangrove forests that fringed the coastlines, and the mangrove forest depletion has in turn threatened the safety and function of the bunds in safeguarding the hinterlands. Coastal erosion, mangrove depletion and bund erosion are closely interrelated.

It is crucial to identify the root causes of the erosion before any effective mitigation strategy can be proposed and planned. The causes as identified by Ghazali (Ghazali, N.H.M., 2006) are briefly explained as:

- Ill-planned shorefront development without due consideration of their effects on the adjacent coast resulting in adverse consequences. For example: the construction of buildings at the limited beach space interferes with the active zones of the beach resulting in beach dunes losses; or the construction of ports alters the sediment transport pattern contributing to the downdrift erosion.
- Removal of coastal vegetation such as mangroves results in the loss of natural media as wave attenuators. The erosion gets worse during storms and monsoon season as the wave is higher.
- Reclamation of mud-flats or mangrove forests to make room for aquaculture farms results in a thinning mangrove belt.
- Improper coastal protection schemes or structures have exaggerated the existing situation or shifted the upstream problem to downdrift side. For example, the construction of earth bunds cut off the sediment supply and fresh water exchange, creating unsuitable environment for mangrove growth.
- Unregulated or uncontrolled dredging or sand mining activities in near shores areas alter the hydrodynamic regime of the areas.

2.1.3 Coastal erosion control approaches

Since 1987, the Malaysian government has implemented a short term and a long term strategy to control and solve coastal erosion issues as recommended by the National Coastal Erosion Study. The short term strategy is construction focused, to protect those existing properties located in the Level 1 critical eroded areas through structure such as the construction of sea walls or breakwater. The short term strategy is focussed on solving the local problem. The hard structures are usually built to reduce the erosion by reducing the wave energy reaching the shoreline or to stop the erosion by covering the eroded shoreline to prevent the earth material from being eroded away. On the other hand, the long term strategy is management focused, to control and to prevent coastal erosion and its negative impact by considering and integrating the consequences of possible coastal erosion in the planning of the development projects within coastal zone. The long term strategy includes the introduction of institutional changes and formulation of administrative guidelines to manage future coastal development, which has led to the establishment of the National Erosion Control Council and Coastal Engineering Technical Center to manage coastal erosion issues. (Ooi, C.A., 1996)

Coastal erosion at different coastal zones has to be resolved by different methods in considering various coastal zone hydrodynamics and material sedimentation pattern. The coastal type (either the sandy beach or muddy coast) has to be identified before any proposal is suggested and implemented. With the growing knowledge and technologies, combination of structures or methods has been applied in combating the coastal erosion issues. The most common protection options as adapted from the literature (Ghazali, N.H.M., 2005) are described below:

Do nothing

When the area has insignificant or no economic importance, it may be sensible to allow nature to take its course, letting the eroded coastal area to change without intervention.

Adaptation and retreat

Adaptation is to modify the area’s current usage; retreat is to relocate the existing population or activities. Both adaptation and retreat are meant to reduce the stress imposed on the coastal areas. For example, when the earth bund is breached and the agriculture land is inundated, new higher earth bund will be constructed further inland to keep the seawater out and the agriculture land will be moved further inland.

Armouring

Armouring (such as revetments) is the most commonly applied hard engineering approach, in which the eroded shoreline is defence at its existing current position. Revetments are mostly armoured with quarry stones as the quarry stones are economic and easily obtainable. Quarry stone revetments built directly on the slope of the existing bunds along the agricultural areas are commonly found in almost every state along the west coast of Peninsular Malaysia. Along Sungai Burung and Sungai Sekendi at Selangor coastlines, interlocking concrete blocks were used on the slope of coastal bunds and the escarpment of eroding mangrove belts. Interlocking concrete blocks are preferred when the structures are located on public or recreational location for aesthetic reasons.

Stabilisation

Stabilisation approach is meant to decrease the erosion rate by slowing down the loss of sediments and thus retaining the sediments within the site. Groynes, jetties or breakwaters are some common examples of this method. Half open concrete pile row breakwater was built at Langkawi to combat beach erosion problem and to restore the beach for recreational purposes. However, these structures were neither cost effective as compared to armouring method nor aesthetically appealing to tourism as they were exposed during low tide.

Beach nourishment

Beach nourishment is the soft engineering approach in which a huge amount of similar material to the existing beach is imported from offshore sources and placed on the eroded beach to form a protection berm. The new berm will be continuously moulded by the natural forces to an equilibrium shape. Re-nourishment is required after certain years to maintain the beach. This approach is common in rehabilitating recreational beaches. For example, timely re-nourishment works were completed at Port Dickson to maintain the beach as a tourist destination.

Combination and new technologies

The causes of the coastal erosion are complicated; innovative methods are required to solve specific site problems. Structures constructed in a specially designed arrangement or a combination of two or more structures types are used to attain the desired effect. For instance, a series of partially submerged woven geotextiles breakwaters were constructed in front of the mangrove-fringed Tanjung Piai shoreline. The geotextile breakwaters (geotextile bags filled with sand) were constructed to create a calmer wave environment in their lee to encourage the mangroves growth. Aside from acting as breakwaters, sand-filled geotextile bags can be used to replace rocks to be stacked up to form as revetment.

Eco-engineering

Eco-engineering or bio-engineering refers to green concept methods that combined the knowledge of ecosystems with engineering technology, such as mangrove re-planting. Mangrove trees are known to be wave attenuator; efforts to replant mangroves on eroding coastal zones have been carried out to halt the erosion. A low revetment of interlocking concrete blocks was constructed in 1987 to protect the escarpment on Sungai Burung shoreline at Selangor and the mangrove seedlings planted in the depleting mangrove belt behind it. The hard structure was used to provide a calmer condition for the mangrove saplings to establish themselves, in order to restore the coastal forest to act as the natural coastal protection. At Jeram, Tanjung Karang and Sungai Besar in Selangor, bamboo poles were stuck into the mudflat to reduce the wave action to enable the mangrove saplings to grow.

Bio-technical Concepts

Bio-technical concepts combine structural with eco-engineering where artificial plants are made and installed to stabilise the shoreline (e.g. artificial reefs and artificial sea grass). These artificial plants were made of polypropylene, synthetic or natural rubber. They were configured in patches and anchored to the bed, to create friction barrier to dissipate wave energy and to induce sediments in the water column to settle.

2.2 Mangrove vegetation

2.2.1 Biophysical controls on mangroves

The mangrove forests are distributed from mean sea level to the highest spring tide in the inter-tidal region between the sea and the land, a harsh environment with high salinity, high temperature, extreme tides, high sedimentation and muddy anaerobic conditions (Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J. & Duke, N., 2011). Referring to paper by Friess et al, mangroves survive in these areas when the biophysical conditions (biological factors and physical factors) are below key threshold.

Mangrove propagules (ready-to-go seedling) supply and dispersion are the biological factors affecting the mangrove establishment in an area. Mangroves colonise on a new mudflat by the introduction of mangrove propagules which are dispersed by water. Shortage of propagules supply from nearby mangrove forests is a key bottleneck to the new mangrove forest formation.

Ocean hydrodynamics, tidal flooding and et cetera, are the physical factors affecting mangrove establishment and stability in an area. These physical factors act as the thresholds; a limit beyond which a state changes. Mangroves grow well in the new location only if the hydrodynamics, substrate and tidal inundation conditions are suitable. The frequency and duration of the tidal flooding affect the survival of the seedlings, as different mangrove species have varying tolerances of these physical processes. The seedlings require low-energy environments sheltered from strong waves and currents to enable them to root and grow amply. The calm hydrodynamic conditions also encourage the deposition of suspended muddy sediments which hold the nutrients to sustain the plants growth. Other physical stressors such as the different of fresh water and salinity level, atmospheric carbon dioxide level, temperature, light intensity, sapling predation, nutrient concentration, et cetera, may affect the mangrove growth as well. (Friess, D.A. & Oliver, G.J.H., 2013)

2.2.2 Mangrove biological adaptations

To survive in harsh environment in intertidal zone, mangroves exhibit some particular adaptations to inundation, hydrodynamic forcing and salinity, such as vivipary reproduction, rapid rooting and aerial root structures. These features as explained in the paper by Friess et al are briefly explained herewith. (Friess, D.A. & Oliver, G.J.H., 2013)

Mangroves exhibit the unique vivipary reproduction. The plant embryo continues to grow through the seed coat and remains attached to the parent tree until maturity when it will then detach to be dispersed out by waves and currents. The seedlings skip the germination process; they are ready to grow once they land on suitable area. Besides, the propagules can produce their own food via photosynthesis; they can survive dehydration and remain dormant before arriving at a favourable environment. When the conditions are suitable, mangrove seedlings are able to root sufficiently in a short period of time to prevent them to be dislodged by the later waves and currents.

Mangroves have unique above-ground root system, pneumatophores, as to adapt to the anoxic and anaerobic mud flat areas which are often waterlogged and low in oxygen. There are four types of pneumatophores root: stilt or prop type, snorkel or peg type, knee type and ribbon or plank type which may combine with buttress roots at the tree base. The pneumatophores surfaces are covered in lenticels pores which allow oxygen exchange through the pores. The drawn in oxygen will be stored in the aerenchyma, some large intercellular spaces adapted for internal air circulation. Besides, the prop roots also provide the tree anchorage in the shallow tidal flats and increase the tree stability.

In addition to vivipary reproduction and pneumatophores features, mangroves are able to adapt to high salinity environments by the blocking mechanism (the accumulation of the other ions to keep the salts out at the roots); or by having salt excretion glands in the leaves that remove built up salts.

2.2.3 Mangrove species and zonation in Malaysia

Located in the tropics, South East Asia has the richest mangrove species diversity. The mangrove forests in Malaysia have more than 60 species of flora which are roughly categorised into these four main genuses: Avicennia, Sonneratia, Rhizophora and Bruguiera. The four genuses are distinguishable from the pneumatophore roots: Avicennia's type is pencil-like; Sonneratia's type is triangular cone-shaped; Rhizophora has the stilt roots; while Bruguiera has the protruding knee-like pneumatophore roots. (Giesen, W., Wulffraat, S., Zieren, M. & Scholten, L., 2006) The different genuses and flora species are scattered at the distinct regions of the forest.

The combination of physical threshold and mangroves biological adaptation can result in a fairly clear mangrove zonation pattern; the mangrove species distribution changes corresponding to the mangrove species specific tolerance to physical processes and the tree's distance away from the sea. Pioneer mangroves, genuses Avicennia and Sonneratia have high tolerance of biophysical stress which enables them to grow at the lowest elevation (areas where the intertidal stress is the highest). On the other hand, genuses Rhizophora and Brugueira have a lower tolerance of biophysical stress. They normally grow in a less stressful higher elevation where the areas are less commonly subjected to waves and tidal flooding. (Friess, D.A. & Oliver, G.J.H., 2013) Though, overlapping of some mangrove species at two or more zones may occur.

The mangroves forest in Malaysia can be divided into five zones as (Giesen, W., Wulffraat, S., Zieren, M. & Scholten, L., 2006):

Zone 1; on the highly exposed the most seaward side which is inundated during all high tides. This zone is not always present due to the harsh environment for plant growth. Rhizophora mucronata is the only species that lives in this zone; and it requires its crown to remain above water to survive.

Zone 2; on the less dynamic, exposed seaward side which is inundated by all high tides. Avicennia - Sonneratia forest subtype inhabits this zone where there is soft and deep mud. Avicennia Alba and Sonneratia Alba are common on this pioneer shore. In some areas, Rhizophora mucronata is found too.

Zone 3; on the central part which is inundated by normal high tides. Further inland in the brackish zone where there are firmer soils, the common types of forest are the Rhizophora-Bruguiera subtype and the mixed forest zone. This zone can be sub-divided into seaward facing outer zone dominated by Rhizophora subtype and landward facing inner zone dominated by Bruguiera subtype, with a lower layer of Ceriops. Species commonly found in this zone include Acanthus ilicifolius, Bruguiera cylindrica, Bruguiera gymnorrhiza, Bruguiera parviflora, Bruguiera sexangula, Ceriops decandra, Lumnitzera littorea, Rhizophora mucronata, Sonneratia alba, Xylocarpus granatum and Xylocarpus moluccensis.

Zone 4; on the landward freshwater influenced zone which is inundated by spring tides. This rear mangrove zone is inundated by the highest tides only. Species commonly found in this zone include Bruguiera sexangula, Pluchea indica, Xylocarpus granatum and Xylocarpus moluccensis.

Zone 5; on the areas with brackish to almost fresh streams and/or on occasion inundated by unusually high tides. This rarely inundated zone is dominated by Nypa palms. Species commonly found in this zone include Bruguiera gymnorrhiza, Nypa fruticans, Oncosperma tigillarium, Sonneratia caseolaris, Xylocarpus granatum and Xylocarpys moluccensis. Besides, creepers and shrubs may be seen along streams or on open patches in the well-developed mangrove forest.

2.2.4 Mangrove distribution in Malaysia

Mangroves are found on most of Malaysia's coasts. Referring to the statistics published by Forestry Department Peninsular Malaysia, Sabah Forestry Department and Forests Department Sarawak for year 2012, Sabah recorded the largest areas of mangrove forests with 333 thousand hectares; followed by Sarawak with the areas of 112.2 thousand hectares and Peninsular Malaysia with the areas of 98.8 thousand hectares respectively, refer to Figure 3 (Department of Statistics Malaysia, 2013).

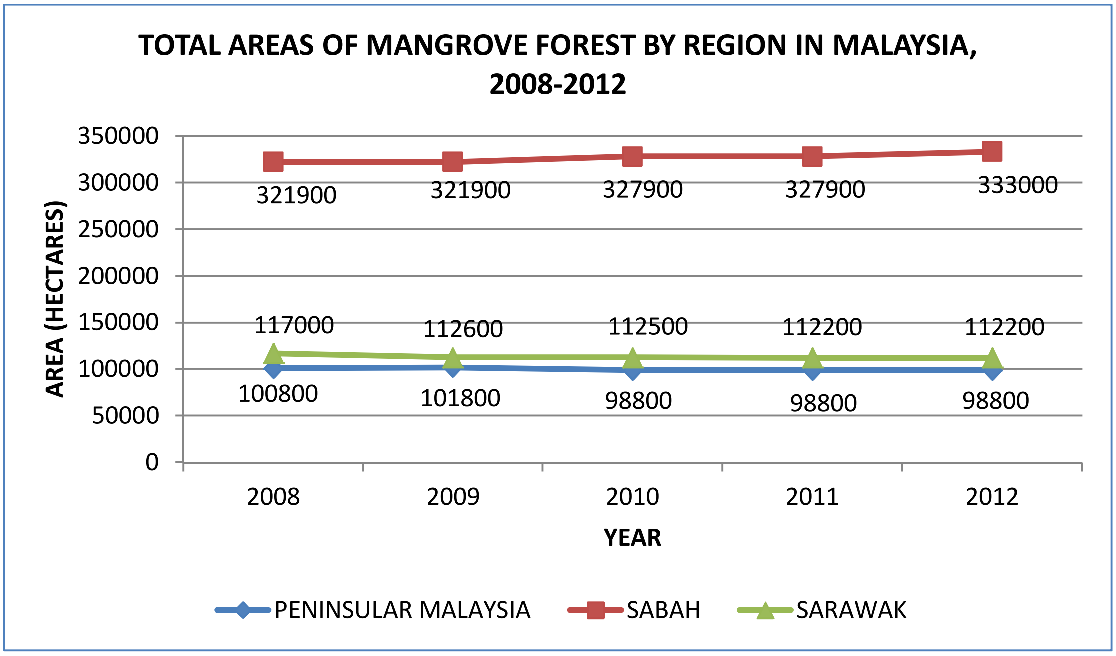


Figure 3 Total areas of mangrove forest by region in Malaysia, 2008-2012 (Adapted from Department of Statistics Malaysia)

In East Malaysia, mangroves are found mainly at the northeast of Sabah coastal embayment facing Sulu and Sulawesi Seas; and the deltas of Sarawak, Rajang and Trusan-Lawas Rivers. In Peninsular Malaysia, mangroves are found mostly on the more sheltered west coast of Peninsular Malaysia facing Malacca Straits in the states of Perak, Johor and Selangor. Perak was 42.1% of the total mangrove forest area in Peninsular Malaysia, followed by Johor with 27.5% and Selangor with 19.2% (refer to Figure 4, Department of Statistics Malaysia, 2013). In Perak, mangrove forests are mostly found in Matang mangrove forests which stretch from Kuala Gula in the north to Panchor in the south. In Johor, districts of Pontian, Kota Tinggi and Johor Bahru share the biggest portion of all the state's mangrove forests, while Batu Pahat, Muar and Mersing have a minor portion. In Selangor, mangrove forests are mostly found in Klang islands, Banjar Utara and Banjar Selatan (Jusoff, K. & Taha, D.B.H., 2008). Along the east coast of Peninsular Malaysia facing South China Sea, mangroves are limited to sheltered estuaries, like the Kemaman river at Terengganu and Bebar at Pahang. This situation is recognised from the percentage distribution of mangrove forest area as shown in the pie chart of Figure 4 where Terengganu constitutes only 1.3% of the total mangrove forest area in Peninsular Malaysia.

Some of the major mangrove forest reserves in Malaysia are shown in Figure 5. The mangrove forests in Malaysia are generally river-dominated mangroves which are built on deltaic sediments brought down from river basins, such as the Merbok, Matang, Klang and Rajang deltas to the west of Peninsular Malaysia; and estuaries of Sungai Pulai and Sungai Johor to the south of Peninsular Malaysia. Besides deltaic areas, mangrove forests also inhabit some near-shore islands such as Pulau Kelang at Selangor, Pulau Kukup at Johor, Pulau Pangkor at Perak and Pulau Tioman at Kedah. The mangrove forests at north-eastern side of Pulau Langkawi are of carbonate setting type where the mangroves grow on sandy peat substrates between limestone karsts. (Chong, V.C., 2006; Jusoff, K. & Taha, D.B.H., 2008)

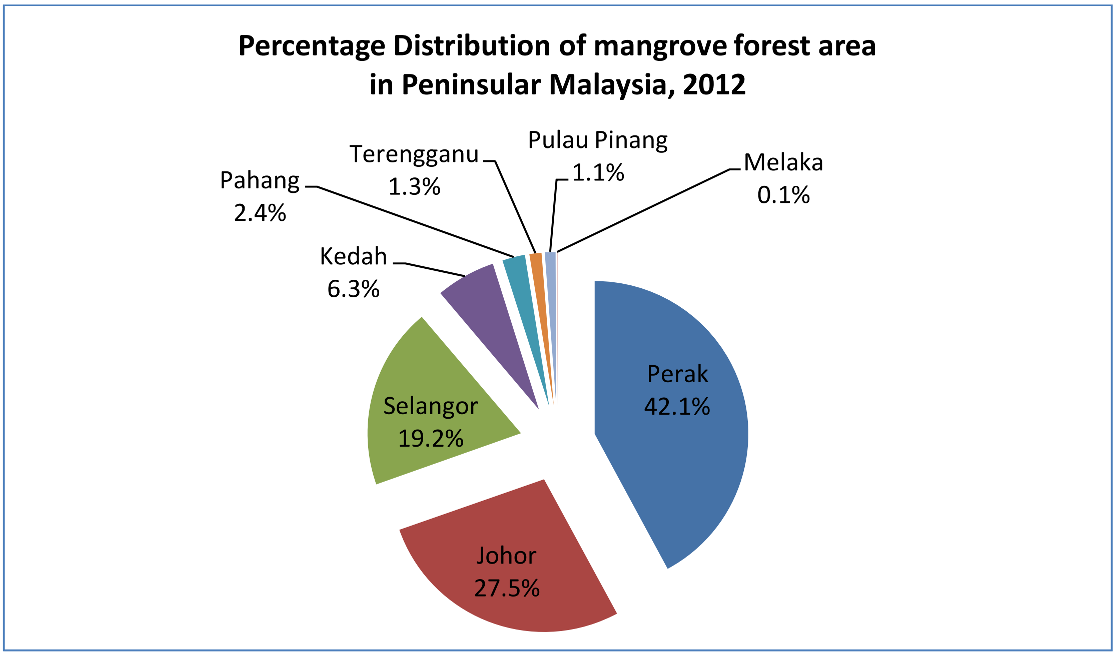


Figure 4 Percentage Distribution of mangrove forest area in Peninsular Malaysia, 2012 (Adapted from Department of Statistics Malaysia)

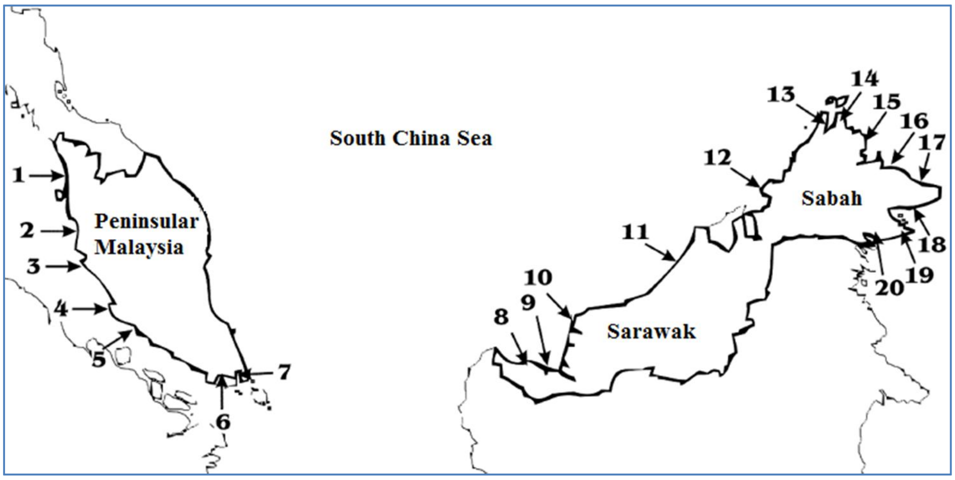


Figure 5 Map of Malaysia showing some of the major mangrove forest reserves, 1 = Merbok; 2 = Matang; 3 = Rungkup and Bernam; 4 = Klang; 5 = Sepang and Lukut; 6 = Pulai; 7 = Sungai Johor; 8 = Sungai Sarawak; 9 = Kampung Tian; 10 = Rajang; 11 = Kuala Sibuti; 12 = Menumbok; 13 = Kudat and Marudu Bay; 14 = Bengkoka; 15 = Sungai Sugut & Sungai Paitan; 16 = Trusan Kinabatangan; 17 = Kuala Segama and Kuala Maruap; 18 = Lahat Datu; 19 = Segarong and Semporna; 20 = Umas-Umas, Tawau and Batumapun (Chong, V.C., 2006)

2.3 Met-ocean conditions at Peninsular Malaysia

2.3.1 Tidal levels

Water level variation along Malaysia coastlines is influenced by astronomical tides. The tidal information of some major ports along the coast at Peninsular Malaysia is shown in Figure 6 (Department of Irrigation and Drainage, 2009). In Peninsular Malaysia, tidal regimes can be sub-divided into three regions: east coast with mainly diurnal tides, west coast with mainly semi-diurnal tides and south coast with mixed tides, mainly semidiurnal.

The east coast of Peninsular Malaysia is bordered by South China Sea which is dominated by diurnal with secondary semi-diurnal tides; while the west coast of Peninsular Malaysia is bordered by Malacca Strait (connected to Indian Ocean via Andaman Sea) which is dominated by semi-diurnal tides. Being at the point between the Malacca Strait and the South China Sea, the tidal flow in the southern part of Peninsular Malaysia (Singapore Strait) is very complex. The tidal flow in the region is driven mainly by the tidal constituent combination of M2, S2, K1, O1, N2 and K2 tides, of which the M2 tide is the most dominant component. The M2 tides generated from the South China Sea and the Indian Ocean meet and interact around the western part of the Singapore Strait, creating the complicated tidal dynamics. The tidal range varies from roughly 2.7m in the west of Singapore Strait to roughly 1.4m in the east of Singapore Strait during spring tide. (Tay, S.H.X, 2010; Chan, E.S., Tkalich, P., Gin, K.H.Y. & Obbard, J.P., 2006)

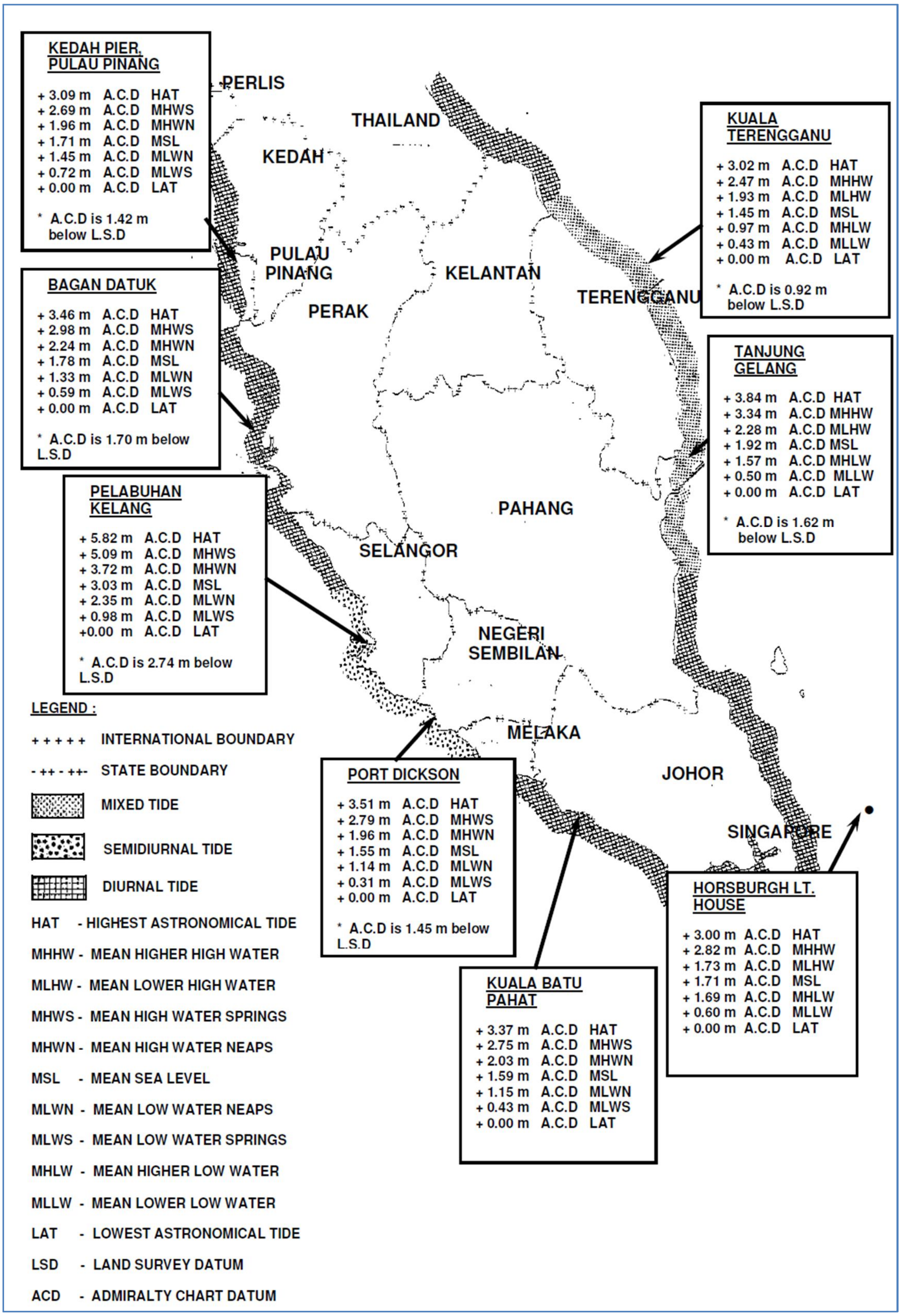


Figure 6 Tides information of major ports at coast of Peninsular Malaysia (Department of Irrigation and Drainage, 2009)

2.3.2 Waves

West coast of Peninsular Malaysia is a low wave energy coast, which exposed to mild wave condition. The Sumatra Island shelters the west coast of Peninsular Malaysia from the Indian Ocean, which has limits the winds fetch length and wave heights. Normally, the wave heights vary between 0.5m to 1.0m and the wave periods range less than 3 seconds with some having a maximum of 6 to 9 seconds. The northern part of the west coast has the longer period waves propagating in from the Andaman Sea; while the southern part of the west coast of Peninsular Malaysia is predominated by southwest monsoon waves. During the southwest monsoon, a metre high open water waves may be generated by the Sumatran squalls and by swell from the South China Sea. The east coast of Peninsular Malaysia is exposed to more severe wave condition as compared to the west coast, especially during the northeast monsoon. (Sharifah Abdullah, S.A., 1992; Tay, S.H.X, 2010)

2.3.3 Wind

Malaysia has an equatorial monsoon climate; the wind regime determines the seasonal rhythm in Malaysia. The monsoon winds are generated by a combination of the trade winds (generated by the pressure differences at various latitude of earth) and the sun seasonal shift. The resulting pressure gradient between the Pacific Ocean and Indian Ocean drives a net flow crossing the equator twice each year according to the sun position, forming the North-South component of the wind direction. (Van Maren, D.S. & Gerritsen, H., 2011)

The wind flow patterns can be distinguished into two main monsoon seasons, the southwest monsoon season (June – September) and the northeast monsoon season (December – March) which are separated by two relatively short inter-monsoon periods, the pre-southwest monsoon (late March – May) and the pre-northeast monsoon (October – November), refer to Figure 7. During the southwest monsoon, south-westerly winds of 15 knots or below prevail. During the northeast monsoon season, easterly or north-easterly winds of 10 to 20 knots prevail; however stronger winds ranged within 30 knots or more may prevail over the east coast of Peninsular Malaysia during the period of strong surges of cold air from the north. During the two short inter-monsoon seasons, the winds are usually light and variable. (Malaysia Meteorological Department, 2013)

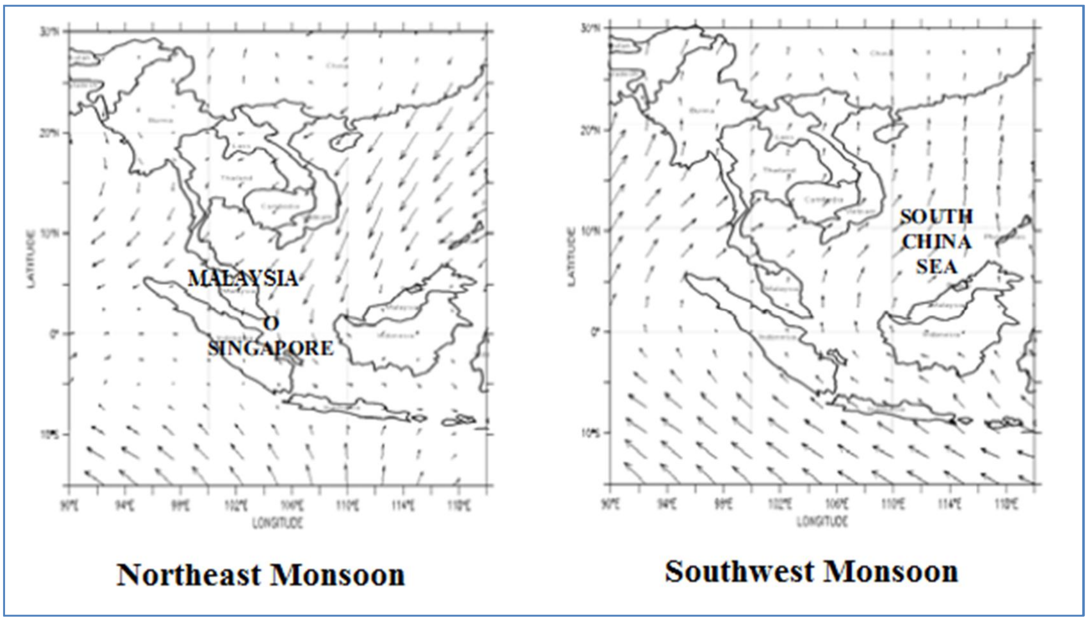


Figure 7 Northeast and Southwest Monsoon, adapted from (Tkalich, P., Vethamony, P., Babu, M.T. & Pokratath, R, 2009)

2.3.4 Sea level anomalies

Sea level anomalies (SLA) are non-tidal water level variation from the mean sea level caused by oceanographic and meteorological parameters (such as winds and atmospheric pressure gradient). Referring to papers by Tkalich et al, SLA in Malaysia and Singapore region is strongly interrelated with the seasonal monsoon winds; SLA within Malacca and Singapore Straits is built up by the monsoon driven wind forces, accounting for roughly 30cm seasonal mean sea level fluctuation in the Singapore Strait with a maximum exceeded 80cm (the highest) ever recorded in December 1999. Extreme events could happen along the east coast of Peninsular Malaysia and southern region near to Singapore Strait during northeast monsoon when SLA associated with strong persistent north-easterlies winds over the South China Sea coincided with the winter spring tide. (Tay, S.H.X, 2010; Tkalich, P., Vethamony, P., Babu, M.T. & Pokratath, R, 2009)

2.4 Settlement field for mangrove seedling planting

2.4.1 Settlement field

Preserving an existing mangrove forest is easier than creating a new forest as the young mangrove seedling planted along the mud flat is weak against natural forces and it only grows to maturity in sheltered areas. Protection measures are required to safe guard the young seedlings before they grow strong enough. Temporary breakwaters can be built around the mud flat area to form a settlement field for mangrove seedlings planting. Settlement field example as used in Dutch intertidal area is shown in Figure 8. The 400m square main compartment was fenced up by using the woodwork dam. Inside, soil dams and ditches with drainage were built to divide the main compartment into smaller 100m square subfield to enhance sedimentation.

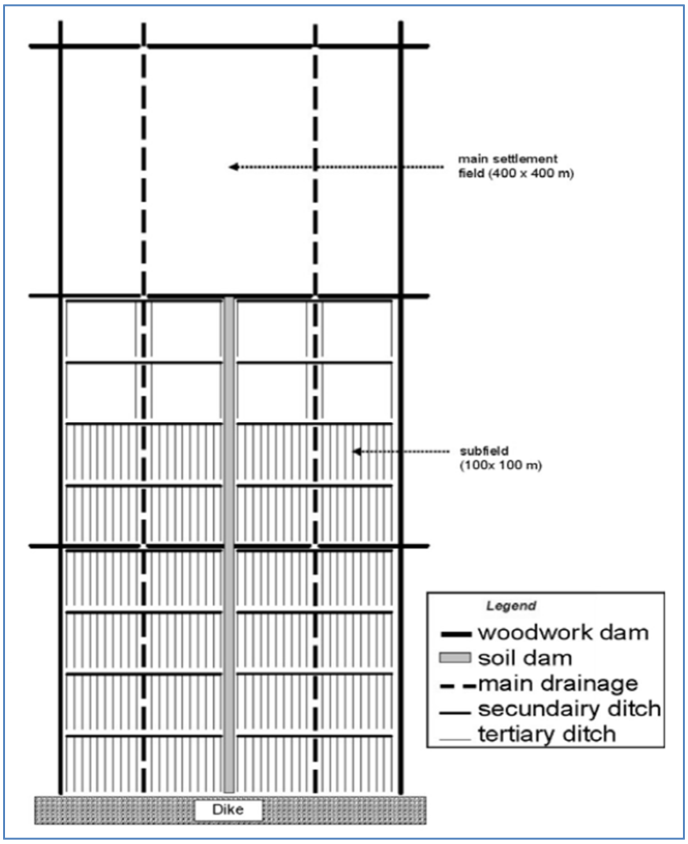


Figure 8 Example of a settlement-field (source: Verhagen et al)

The temporary breakwaters can be built of locally available materials such as bamboo, jute and stones. The bamboo poles could be piled in row to form a small dam to be filled with stones or jute bags with sand fill, see Figure 9. The temporary breakwaters can prevent the currents and storm waves from damaging the young seedlings in the settlement field. In addition, the temporary breakwaters may increase the sedimentation in the lee side (inside the settlement field area) as the flow velocity is reduced and the outflow is slow and regular. (Verhagen, H.J. & Loi, T.T., 2012)

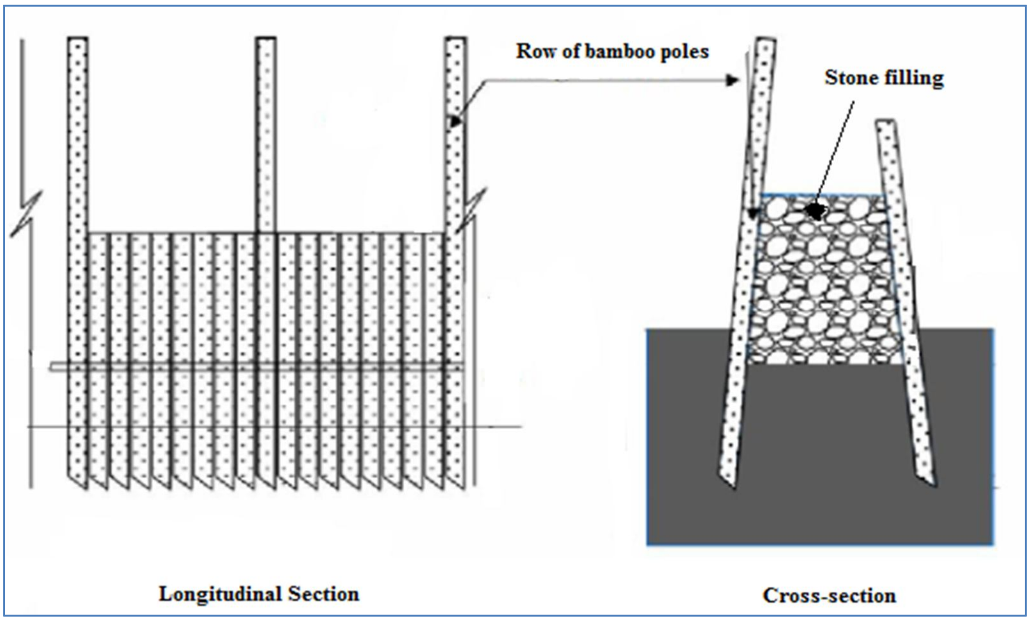


Figure 9 Small dikes (made of bamboo poles with stones filling) to stimulate siltation in mangrove plantings (source: Verhagen et al)

Replanting of some mangrove seedlings and maintenance of the temporary breakwaters and soil dams may be required after storm events as the materials used are light structures which may be damaged by storms. However, the repair of these structures are cheaper than making the breakwaters storm-proof as the materials are easily available locally and the repair works are rather straight forward without the need for complicated machinery. Once the mangroves are mature enough to stand against the storms and currents, maintenance of these temporary structures are no longer required. The removal of these temporarily structures are not required as they are made of natural material. (Verhagen, H.J. & Loi, T.T., 2012)

2.4.2 Numerical modelling of Settlement field

2.4.2.1 Delft3D program

The numerical modelling program Delft3D was used in this research. Delft3D is capable of simulating 2D or 3D flows, waves, sediment transport and morphology development, water quality and ecology for coastal, river and estuarine areas. The underlying equations in Delft3D are the non-linear shallow water equations derived from the three-dimensional Navier-Stokes equations for incompressible free surface flow which are solved in Delft3D-Flow module. Delft3D-Flow module was utilised in studying the dynamic coastlines while investigating the coastal zone problems at the study area. The Delft3D-Flow module focuses on the hydrodynamic simulations and calculates the non-steady flow and transport phenomena resulting from the tidal and meteorological forcing on the curvilinear boundary fitted grid. (Deltares, 2011)

2.4.2.2 Schematisation of settlement field

Porous plate, the hydraulic structure features in Delft3D was used to represent the settlement field temporary breakwaters in the hydrodynamic model. Porous plate is a partly transparent structure which allows mass and momentum exchanges across. The porous plate is extended into the flow along one of the grid directions, covering some or all layers in the vertical direction. The porous plate is thin relative to the grid size.

Porous plates as the obstacles in the flow cause energy loss and may change the flow direction. The energy loss is taken into account by adding additional quadratic friction term to the momentum equations used in the numerical modelling. The additional quadratic friction term in the momentum equation is as follow:

$$M_{\varepsilon=-c_{loss}-u\frac{U_{m,n|\overline{U_{m,n}}|}}{\Delta x}}$$

Where c_{loss} is the energy loss coefficient or friction coefficient; u is the flow velocity; $|\bar{u}|$ is the magnitude of the depth-averaged horizontal velocity vector; and Δx is the grid cell width.

The porous plate porosity is controlled by the friction coefficient. The friction coefficient is to be specified at the input; and the friction coefficient value has to be positive. As the porous plate module has not been built into the interface of Delft3D; the keyword ‘Filppl’ has to be specified at the additional parameters section. The accompanying values have to be specified in the porous plate input file in the model folder. The input file includes the description of the direction of the porous plate normal to the flow (U- or V-porous plate); porous plates begin and end indices; the number of layers over of the plate extension; and the friction coefficient of the quadratic friction term. Keyword ‘Upwppl’ can be specified at the additional parameters section to damp the oscillations caused by large gradients, in which upwind approximation is used in the advective terms of the momentum equations at the location of the structure.

3 STUDY AREA - TANJUNG PIAI

3.1 Tanjung Piai land development

Tanjung Piai is located in Mukim Serkat, Pontian, Johor, Malaysia; at latitude 01º16.06' North and longitude 103º30.46' East. Tanjung Piai is the Johor State Park located at the southernmost point of the Asian Continent. It consists of coastal mangroves and intertidal mudflats which connects Pulau Kukup wetlands at the north west to Sungai Pulai mangrove forest reserve at the north east, forming a stretch of protected coastal mangroves that fringed the western and south-western coastal of Johor.

During the 1970's and early 1980's, Johor state went through swift industrialisation and development transformation, where large parcels of forest land at Tanjung Piai area were converted to agricultural, farming and aquaculture projects. Nevertheless, by late 1980's, after its geographical significance as 'The Southernmost Tip of Mainland Asia' and its unique habitat and bio-diversified mangrove forest were acknowledged, the Johor State Government decided to conserve the precious mangrove forest of Tanjung Piai and manage it in a more systematic and sustainable manner to protect it from the cumulative effects of erosion.

In 1997, Tanjung Piai was designated as a Johor State Park and subsequently came under the jurisdiction and management of the Johor National Park Corporation. The mangroves of Tanjung Piai were protected under the Johor National Park Enactment 1989. In 2003, Tanjung Piai was designated as Ramsar site, the wetlands of international importance selected under Ramsar Convention (The Ramsar Convention on Wetlands, 2003). Tanjung Piai comprises some 526 hectares of coastal mangroves. This State Park homes about 20 mangrove plant species and 9 mangrove-associated species. Rhizophora apiculata and Bruguiera cylindrica dominate the coastal forest in this State Park. Tanjung Piai is also rich in fauna,; it homes more than 41 species of birds, 7 species of mammals, 7 species of reptiles, 1 amphibian species and a host of invertebrates. (Wetlands International, 2007)

3.2 Assessment of existing coastal changes

Erosion has been observed at Tanjung Piai and classified as Category 1 or critical according to the classification system by the Department of Irrigation and Drainage due to its heritage value. Azlan and Othman (2009) had overlaid three satellite images datasets of year 1995, 2000 and 2005 to assess the coastline changes. The changes between 1995 and 2005 were classified and summarised as shown in Table 1 and Figure 10.

Colour	**Class name**	
	Year 1995	**Year 2005**
Blue	Mangrove	Water
Green	Mangrove	Mangrove
Magenta	Water	Mangrove
Yellow	Mangrove	Sand
Red	Non-mangrove vegetation	Mangrove
Orange	Mangrove	Non-mangrove vegetation
Purple	Mangrove	Non-mangrove vegetation

Table 1 Legend, classification of changes between 1995 and 2005 for Tanjung Piai areas

In 10 years, loss of mangrove was substantial (see Figure 10), especially for the areas located between Parit Che Uda to Sungai Perepat Pasir. The coastal forest has decreased about 45% from the existing 180.09 hectares in 1995 to 99.81 hectares in 2005. Additionally, several vegetation changes were detected where non-mangrove vegetation has been replaced by mangrove (area marked in red) or vice versa (area marked in orange).

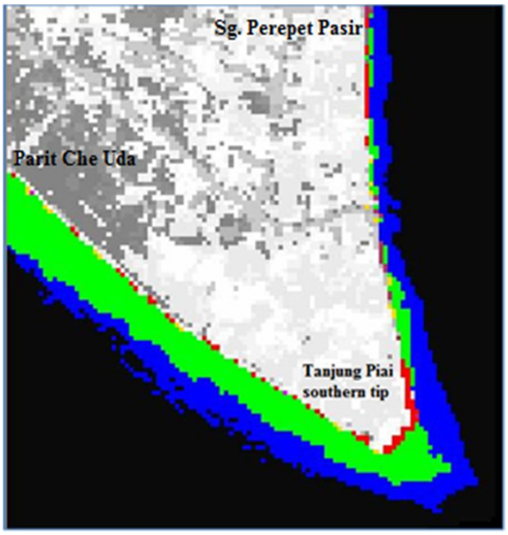


Figure 10 Maps overlay of year 1995 with 2005 of Tanjung Piai (left) and Kukup island (right) (source: Azlan, N.I & Othman, R.)

However, northwest from Tanjung Piai, accretion was observed as shown by the light purple areas in Figure 11. The accretion process deposited mudflats along the coastal area. The accretion was located along the coastal area, the area where non-mangrove vegetation has changed to mangrove (area marked in red). The coastal forest has increased about 12% from the existing 164.97 hectares in 1995 to 185.31hectares in 2005.

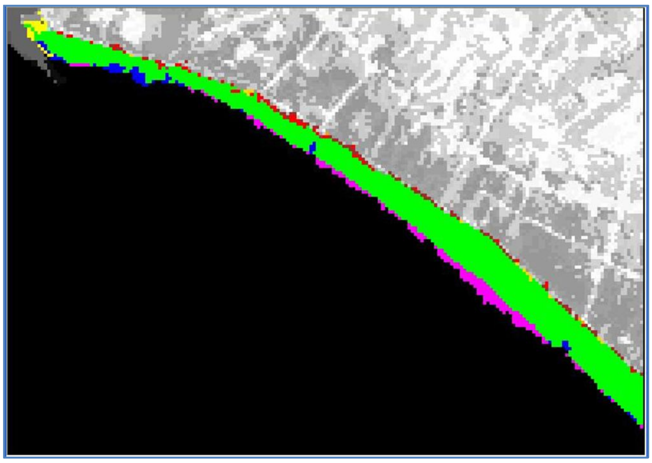


Figure 11 Maps overlay of year 1995 with 2005 of Tanjung Piai coastal area, northwest side (source: Azlan, N.I & Othman, R.)

Further north around Kukup Island, mangrove forest depletion was observed around the shoreline area from the south eastern part to the whole of the western part of the island (refer to Figure 12). The coastal forest has decreased about 13% from the existing 545.22 hectares in 1995 to 476.28 hectares in 2005. Nevertheless, accretion of about 1.98 hectares was observed along the north eastern part of the island, where the water has been replaced by mangrove.

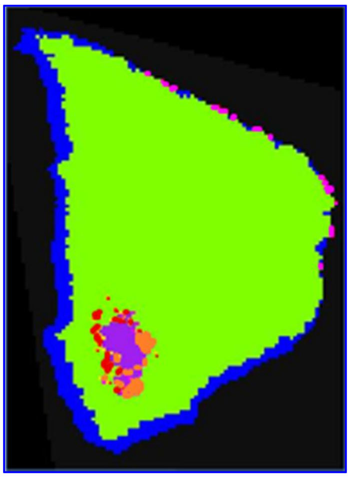


Figure 12 Maps overlay of year 1995 with 2005 of Kukup (source: Azlan, N.I & Othman, R.)

Within the ten years period the mangrove forest along the shoreline from the tip of Tanjung Piai to Sungai Perepat Pasir has been depleted due to the extreme erosion and damage caused by the tidal surges, swift currents and storms (refer to Figure 13). On the other hand, the mangrove forest along the shoreline from Parit Che Uda to Kukup has increased in acreage due to the accretion process of the sediments eroded from the tip of Tanjung Piai to Sungai Perepat Pasir.

Figure 13 Photos showing the areas with heavy erosion where the trees have collapsed

3.3 Mangrove restoration

The conservation of the coastal forest of Tanjung Piai is considered necessary for its invaluable unique habitat and bio-diversified mangrove forest; and for the purpose of shoreline protection to safeguard the agricultural farmlands at the hinterlands where additional provision of earth bunds was built along Tanjung Piai coastlines (behind the coastal forest) to protect the farmlands from seawater intrusion. Due to the continuous coastal erosion and mangrove depletion, likelihood of earth bund failure and subsequent inundation of the hinterland has raised the urgency for protection.

The protection method has to consider the impact of the construction on the environment, aesthetic and tourism functions of the park. The chosen method, thirty sand-filled geotextile tube breakwaters were constructed at Tanjung Piai between 2003 and 2005 to reduce the wave energy in order to mitigate the erosion problem, refer to Figure 14. Geotextile tubes were made from high-strength geosynthetic fabrics which could retain the in-filled material in while permitting the water flow through the pores. Sand was pumped in through the filling port of the close-ended tubular geotextile tube. The sand-filled geotextile tubes were constructed to 1.5m in height and 50m in length; spaced at 5m apart and arranged parallel to shore at a distance of about 20 meters from the escarpment. The geotextiles tubes were completely submerged during high tides and partially exposed during low tides. (Tan, K.S., Ghazali, N.H.M., Ong, H.L. & Arbain, M.Z., 2007)

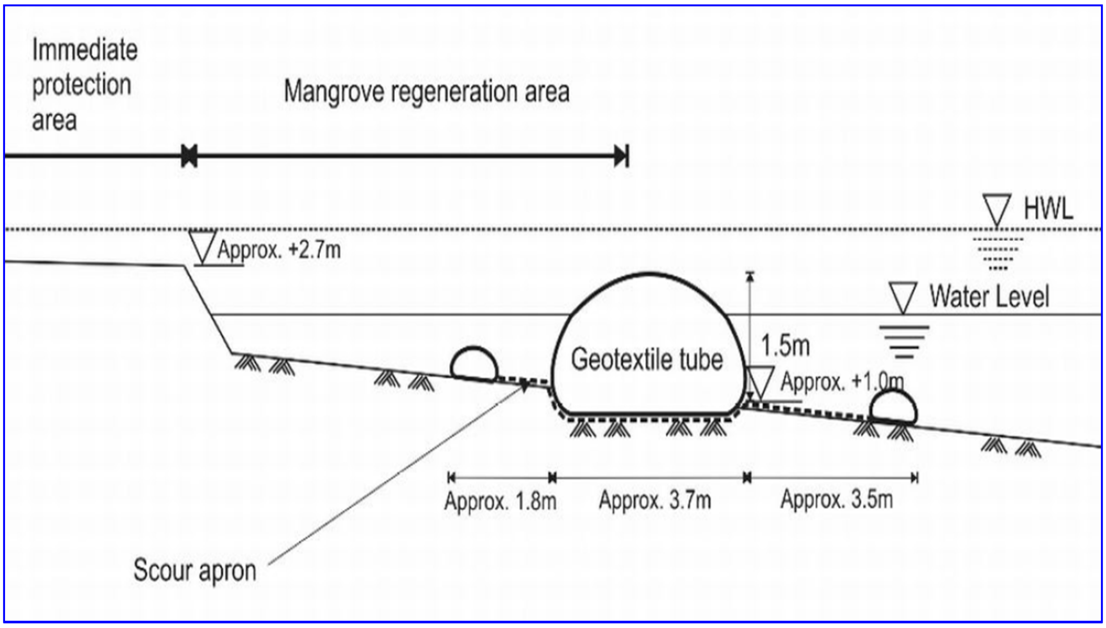


Figure 14 Schematic diagram of Tanjung Piai geotextile tube breakwaters (source: Tan, K.S. et al)

Observations showed positive result with sediment built-up at the lee of the breakwaters where a lower energy zone was created by the breakwaters (refer to Figure 15). The capability of the geotextiles tubes (acting as breakwaters to reduce the wave energy) was proven. However, the performance of the geotextile tubes on muddy coasts may suffer from settlement which may affect the geotextiles tubes erosion protection ability and subsequently lead to the high maintenance cost in long term. The settlement issue can be minimised by applying concrete apron or pile foundation underneath the tubes which may then top up the construction cost. The question rose as if there is any other even simpler and more economical method to replace the geotextile tubes.

Figure 15 Geotextile tube breakwaters at Tanjung Piai with substrate build-up behind it (source: Tan, K.S. et al)

In the long term, mangroves restoration is a more economical and more environmental friendly method in defending against coastal erosion. The settlement field with temporary breakwaters made of bamboo poles with stone filling is proposed as an alternative to geotextile tube breakwaters as its construction is simpler. These temporary breakwaters are made of locally easily available materials. The water level encapsulated and sediment accreted within the settlement field are crucial in determining young seedlings survivability; these factors are interrelated to the porosity of the temporary breakwaters, the degree of flow and sediments permitted through. The design of the temporary breakwaters of the settlement field and its designated porosity should be finely prepared to produce the appropriate environment for the selected mangrove species. However, the performance of the design can only be ascertained through experiments. Thus, this research is focussed on investigating the performance of these temporary breakwaters in creating a low energy environment by assessing the velocity reduction; and the capability of these temporary breakwaters in capturing the suspended sediments by assessing the bed level changes within the settlement field. The analysis of the temporary breakwaters is discussed in the following chapters.

4 POROUS PLATE ANALYSIS

4.1 Test-case using 3D channel

The settlement field fenced up by temporary breakwater (small dikes of bamboo poles with stone filling) was tested in this research. Porous plate, one of the hydraulic structure features in Delft3D was adopted to represent the temporary breakwaters in the hydrodynamic model. As there is little literature explanation on the appropriate porous plate friction coefficient/energy loss coefficient to be applied to the model and there is no laboratory experiments or data to validate the coefficient, this test-case using simplified 3D channel was set to check if the porous plate reduces the flow velocity inside the settlement field to enhance seedlings growth; to investigate the appropriate friction coefficient to be specified as input for the porous plate; to assess the influence of the friction coefficient; and to understand its working and performance before it was applied in the finalised model, the nested model from Singapore Regional Model (SRM). Finding the reliable friction coefficient to be inserted as input is crucial. Understanding gained from the test-cases will be then applied in the finalised model runs.

In the simplified 3D channel model, a channel of 8 kilometers long and 4 kilometers wide by 10 meters deep was modelled, refer to Figure 16. The grid cells were set as 200x200 meters, similar to the finalised refined grid cells at the study area. The porous plates were placed around the grid cells to form the small boxes which made up a total area of 2 kilometers by 1.2 kilometers at the middle of the channel to represent the settlement field. The porous plates were extended from the water surface to the bottom of the channel to represent the temporary breakwater used for the settlement field. The friction coefficient of the porous plate was varied in the different runs. Combination of upstream discharge with downstream water level was prescribed to model the river flow.

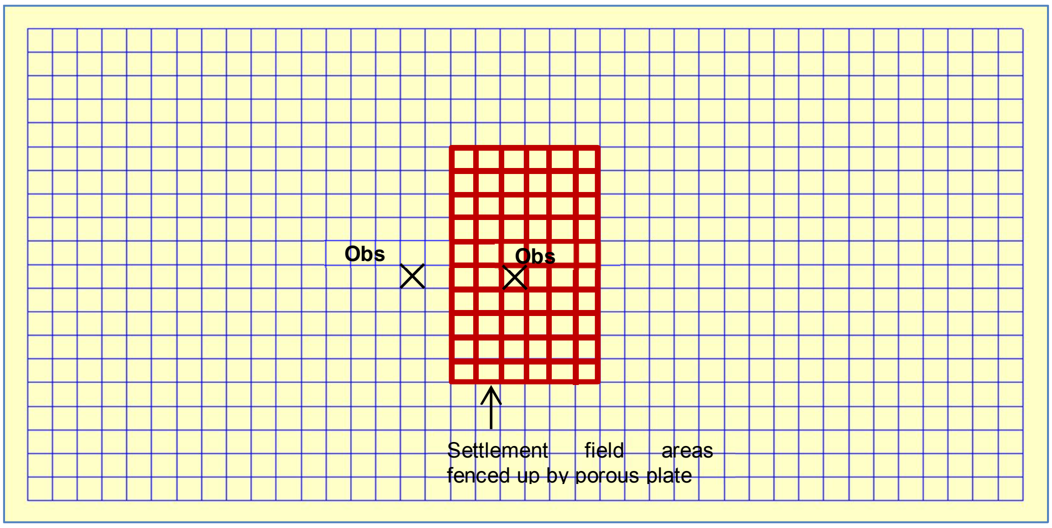


Figure 16 Schematisation of 3D channel of 4km (width) X 8km (length) X 10m (depth) (porous plates locations were indicated with red lines)

4.2 Model parameters

In the Delft3D manual, values of porous plate friction coefficient from 800 to 1000 were suggested; while Hoogduin (2009) who has adopted the porous plate to account for extra energy losses in the model suggested a value of 2.3. There is little specification listed for the porous plate friction coefficient in the Delft3D manual, as long as the coefficient is a positive value. In view of these two very different values from two separate cases, a limit of 1 to 1000 was set as the capping limit to be tested out in this simplified 3D channel. The lower the value of the friction coefficient of the porous plate, the higher the porosity it has. Aside from porous plate friction coefficient, sediment size and discharge velocity were varied and tested in the test-case in order to check the influences of the parameters to each other and to serve as the sensitivity analysis.

The model parameters were summarised in Table 2. A virtual sediment layer thickness of 5m was prescribed on the bottom. From this layer, sediment would be picked up when the flow reaches the critical flow velocity. Default values were applied to the sediment data and morphological data due to the lack of morphological data for validation and calibration; the finalised model simulations were considered as a sediment transport hypothesis assessment. The remaining parameters were set as per SRM as those parameters were calibrated and validated in SRM; and the findings from this section were eventually used as the input in the finalised model adapted from SRM.

Parameter	Value
Size of grid cells in m-direction	200 meters
Number of grid cells in m-direction	40
Size of grid cells in n-direction	200 meters
Number of grid cells in n-direction	40
Simulation time	01-01-2013 00:00:00 till 31-01-2013 00:00:00
Time step	4 minutes
Processes	Constituents = Sediment (non-cohesive)
Initial condition	Water level = 0 meter Sediment concentration = 10kg/m^3
Boundaries	West – total discharge (time series) East – water level (time series)
Gravity	9.81m/s^2
Water density	1000kg/m^3
Roughness	Manning, 0.022
Background horizontal viscosity/diffusivity	Uniform horizontal eddy viscosity/diffusivity of 1 m^2/s
Background vertical viscosity/diffusivity	Uniform vertical eddy viscosity/diffusivity of 10^{-6} m^2/s
Reference density for hindered settling	1600kg/m^3
Data for non-cohesive sediment	Specific density = 2650kg/m^3 Dry bed density = 1600kg/m^3 Median sediment diameter = 65μm or 200μm Initial sediment layer thickness at bed = 5m

Table 2 Model parameters for test-case 3D channel

4.3 Depth-averaged velocity distribution at Tanjung Piai area

The flow velocity used in the simplified 3D channel was obtained from the analysis of the velocity data obtained from the Singapore Regional Model (using the depth-averaged velocity of several observation points near to Tanjung Piai area); as to ensure the porous plate would work well in the similar condition when it was applied at the study area in the nested model. Figure 17 showed that the flow velocity at the Tanjung Piai to Kukup area could be roughly divided into two zones: the inner zone with calmer flow and the outer zone with higher flow velocity. The calm condition in the inner zone can be attributed to the sheltering effect of Kukup Island and Tanjung Piai's southern tip. These two areas shelter the inner zone from being affected by the flow from south-east and north-west during the two different monsoon seasons. The velocity at the stretch from Tanjung Piai towards Sungai Pulai (north east of Tanjung Piai) was rather calm as well with low flow velocity throughout the months.

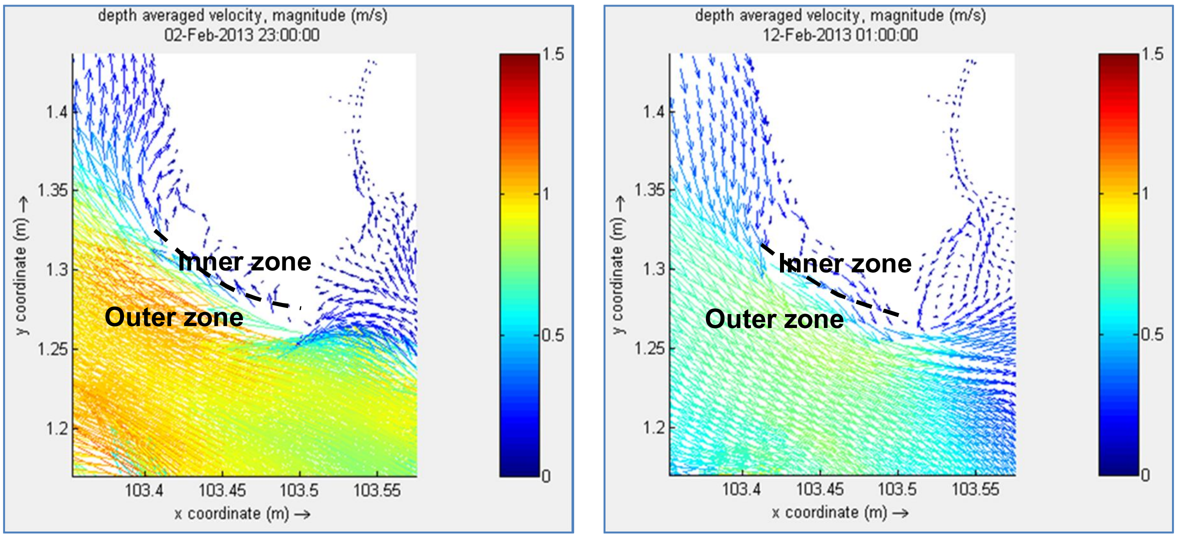


Figure 17 Depth-averaged velocity map of study area (left: flow from south-east; right: flow from north-west)

A year of depth-averaged velocity data from the different observation points near to the study area was gathered and grouped under three categories to be analysed separately: inner zone, outer zone and northeast zone. Statistics of the depth-averaged velocity of these different zones were tabulated as Table 3. The velocity distribution for the three different zones was of positively skewed bell curves (leaning to left), refer to Figure 18. Most of the velocity values fell within the lower value bins with only a few percent fell around the maximum value bins.

As the flow velocity distribution was skewed, median value was a better representation of the data. Median values of the three different categories were selected to be applied in the test-case. 0.235m/s (from inner zone) and 0.378m/s (from outer zone) were selected. In addition, the maximum values of 1m/s (from inner zone) and 1.418m/s (from outer zone) were applied in the test-case as well to cater for extreme cases and to check if the higher velocity flow exhibits similar behaviour as the medium flow velocity.

Parameter	**Depth-averaged velocity (m/s)**		
	Northwest of Tanjung Piai		**Northeast of Tanjung Piai**
	Inner zone	**Outer zone**	
Min	0	0	0
Max	1.000	1.418	0.514
1st quartile	0.141	0.194	0.090
Median	0.235	0.378	0.154
3rd quartile	0.376	0.578	0.227
Mean	0.272	0.410	0.166

Table 3 Statistic values of depth-averaged velocity around Tanjung Piai area

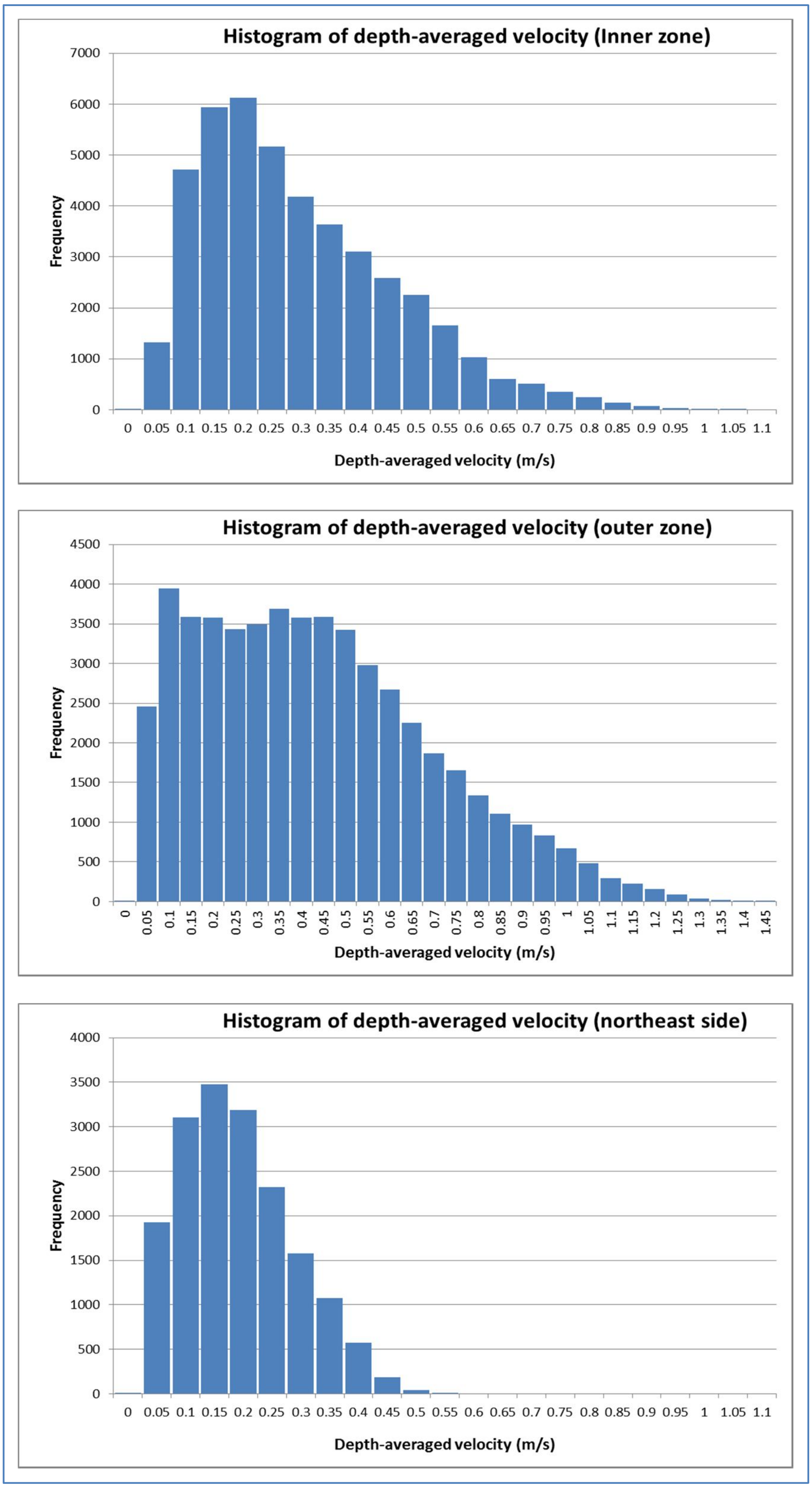


Figure 18 Histogram of depth-averaged velocity for Tanjung Piai areas (top: inner zone; center: outer zone; bottom: northeast side)

4.4 Analysis result

Depth-averaged velocity, energy dissipation and bed level changes were analysed. The depth-averaged velocity and energy dissipation of two observation points at mid channel (as shown in Figure 16) were compared to check if the porous plates would slow down the flow velocity to reduce the flow energy within the settlement field area. Then, a longitudinal cross section was picked at mid channel to check if the porous plates would trap sediment within the fenced up area to increase the sediment deposition within the area.

4.4.1 Depth-averaged velocity

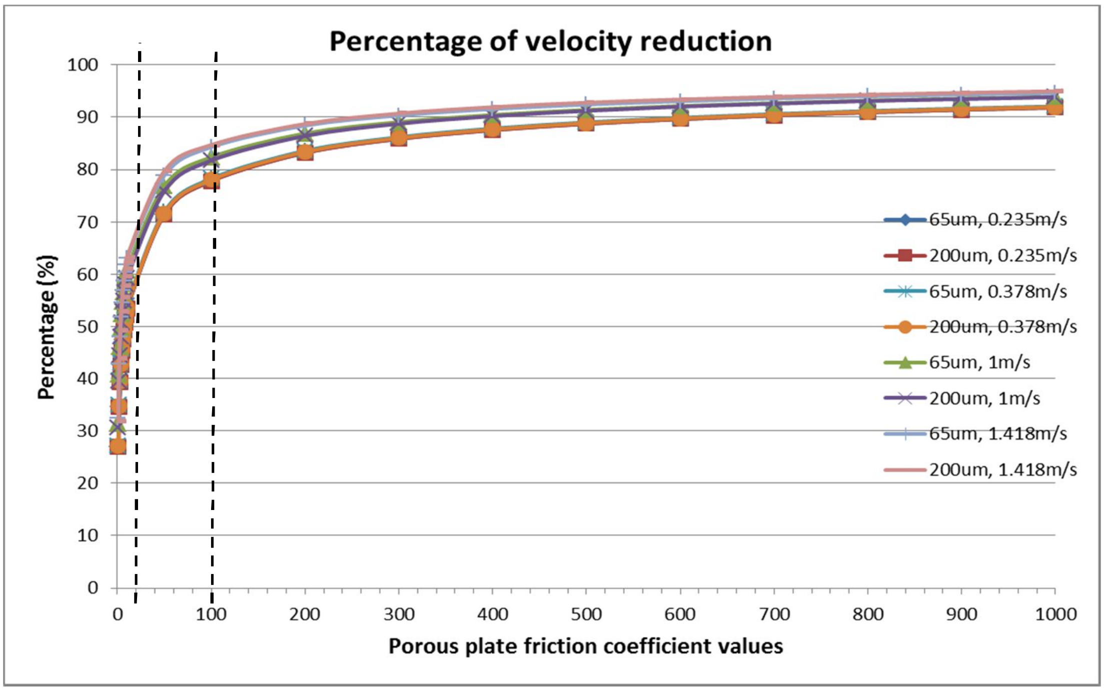


Figure 19 Comparison of velocity reduction between the observation points before and after the porous plates @ mid channel

Figure 19 shows that the porous plates slowed down the flow passing through the plates. The percentage of velocity reduction depended on the porosity of the plate; the percentage increased as the porous plate porosity reduced. With a coefficient of 100, the velocity was reduced by approximately 80% for all test cases. The increment of velocity reduction percentage was steeper for the values within 1 – 10; the increment became gradual and rather constant from the value of 100 onwards. From the graph, the friction coefficients could be clustered into roughly three groups: 1-10, 10-100 and 100-1000. A representative value could be picked from each group for the final model. A better selection of the friction coefficient could be made by checking the bed level in water level points.

4.4.2 Energy dissipation

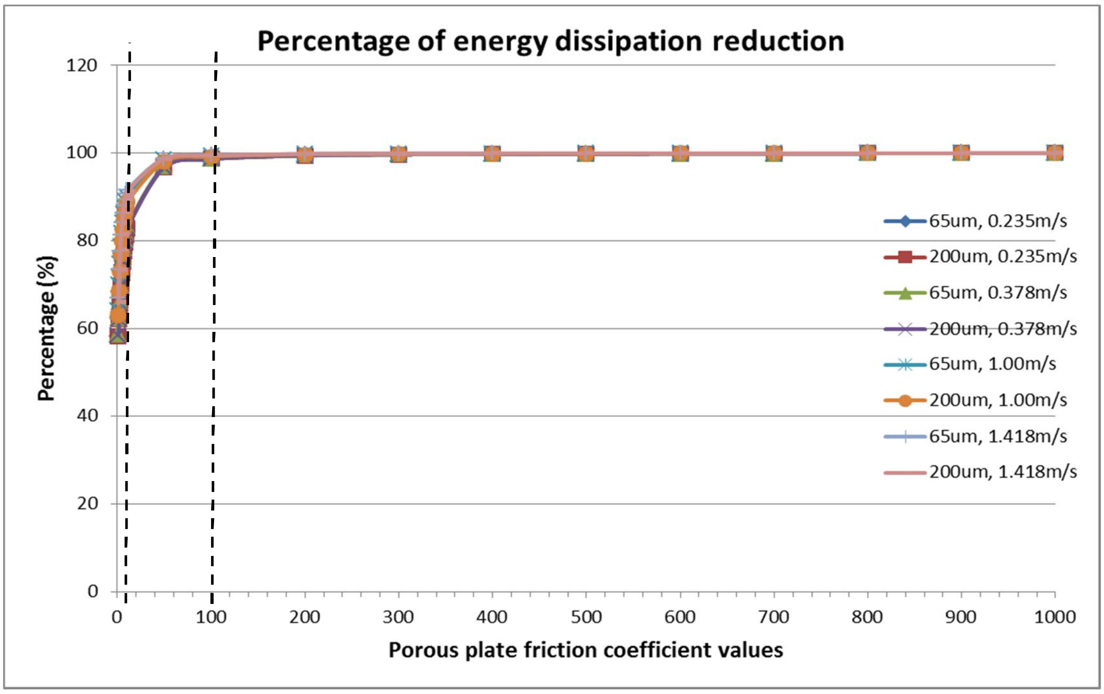


Figure 20 Comparison of energy dissipation between the observation points before and after the porous plates @ mid channel

Figure 20 showed that the porous plates did reduce the energy of the flow passing through the plates as the flow slowed down. The percentage of energy dissipation reduction depended on the porosity of the plate; the energy dissipation percentage increased as the porous plate porosity reduced. With porous plate friction coefficient of 10, the flow energy was dissipated by almost 90% for all test cases. The increment of energy dissipation reduction percentage was steeper for the values within 1 – 10; the increment became gradual and rather constant from the value of 100 onwards in which the percentage was almost 100%. From the graph, the friction coefficients could also be clustered into roughly three groups: 1-10, 10-100 and 100-1000, similar with the finding from the previous section. The flow energy dissipation and flow velocity were related. Porous plate is effective in reducing the values of the both parameters.

4.4.3 Bed level in water level points

4.4.3.1 Velocity of median value

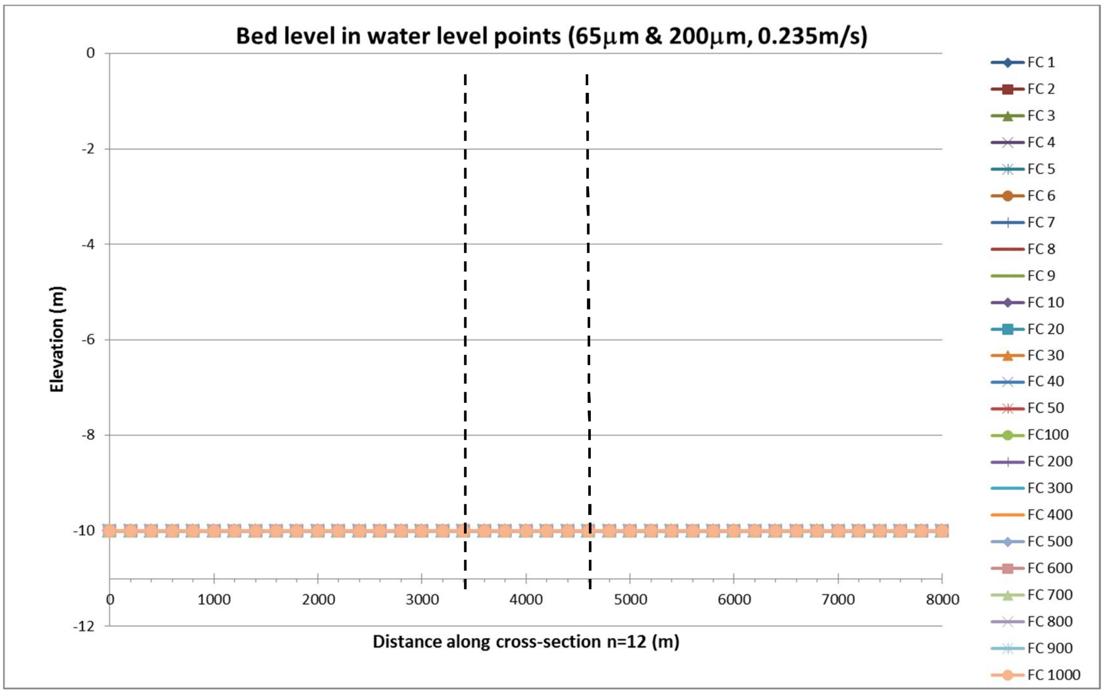


Figure 21 Bed level in water level points for various porous plate friction coefficient values for both sediment sizes with flow velocity of 0.235m/s (dashed black lines indicate the area fenced up by porous plates)

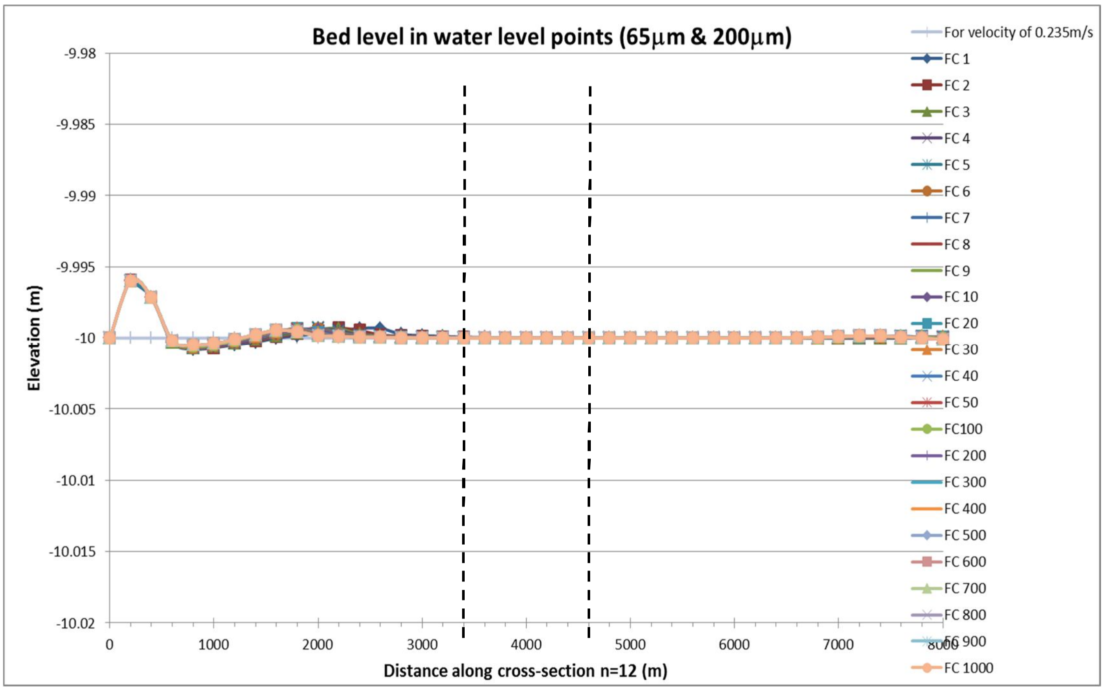


Figure 22 Bed level in water level points for various porous plate friction coefficient values for both sediment sizes with flow velocity of 0.378m/s (dashed black lines indicate the area fenced up by porous plates)

Applying the median velocity of 0.235m/s (of the inner zone) in the test case, there wasn't any bed level changes for both sediment sizes (refer to Figure 21). The flow velocity was too low to stir up the sediments; there was no local scouring in the channel. When the higher median velocity of 0.378m/s (of the outer zone) was applied in the test case, bed level changes (erosion and deposition) was observed though the magnitude was very small (refer to Figure 22). It showed that the sediment transport depended on the ambient flow velocity. Sediment would be picked up from bed and transported away when the flow reached the critical flow velocity; the particles would then drop out due to sediment settling.

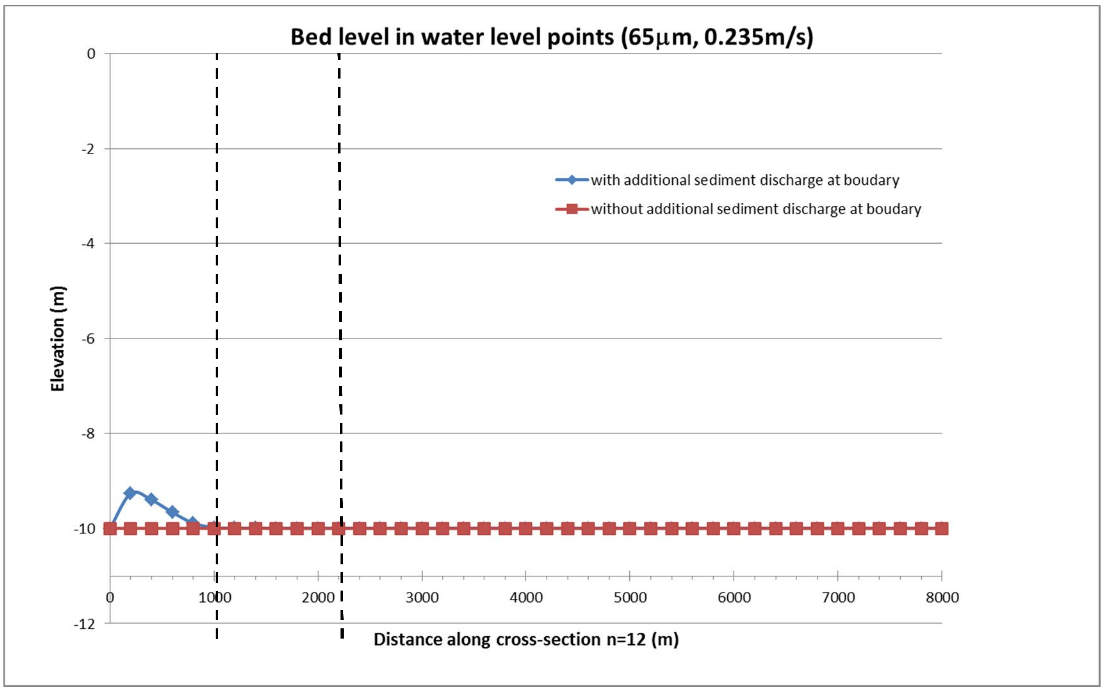


Figure 23 Bed level in water level points for porous plate friction coefficient value of 2 for sediment size of 65μm with flow velocity of 0.235m/s (dashed black lines indicate the area fenced up by porous plates)

As there was no any localised scouring or bed level changes when the flow velocity was low, some additional sediment was discharged at the boundary to confirm that the low velocity did able to transport suspended sediment and to check if the suspended sediment would settle in the channel. As seen in Figure 23 for case where there was sediment supply at the boundary, there was deposition at the porous plate area where the velocity was slowed down. It showed that the low velocity was able to transport suspended sediment and the suspended sediment would settle in the right condition. The results also showed that the porous plates were able to block the sediments.

4.4.3.2 Velocity of maximum value

Flow velocity of 1m/s

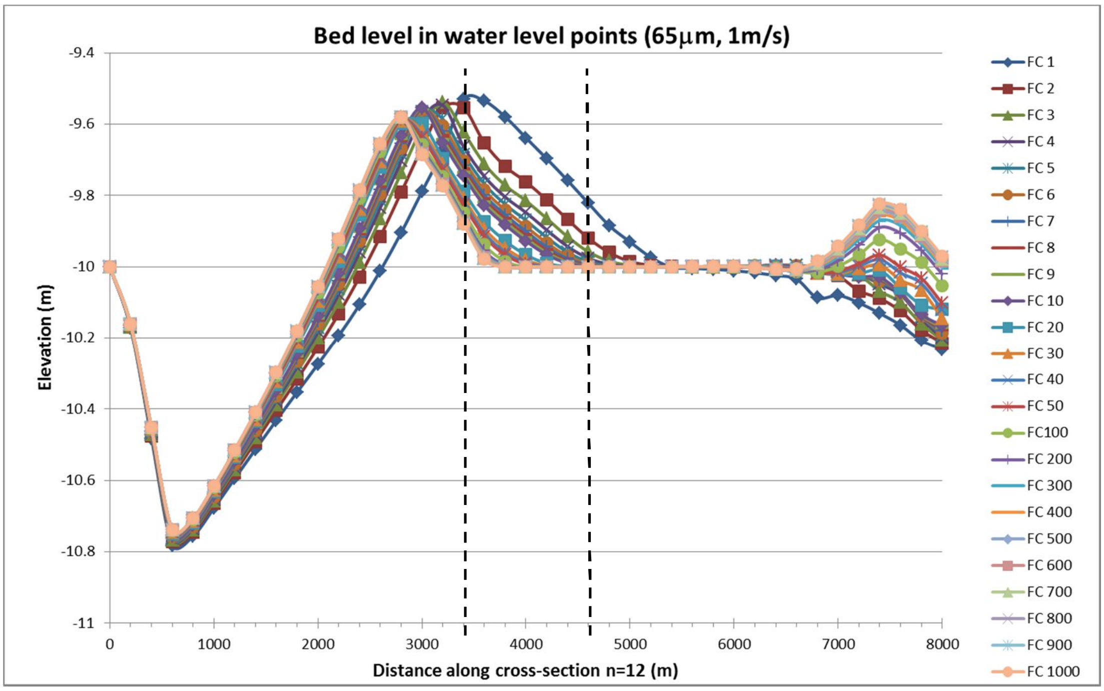


Figure 24 Bed level in water level points for various porous plate friction coefficient values for sediment of 65µm (dashed black lines indicate the area fenced up by porous plates)

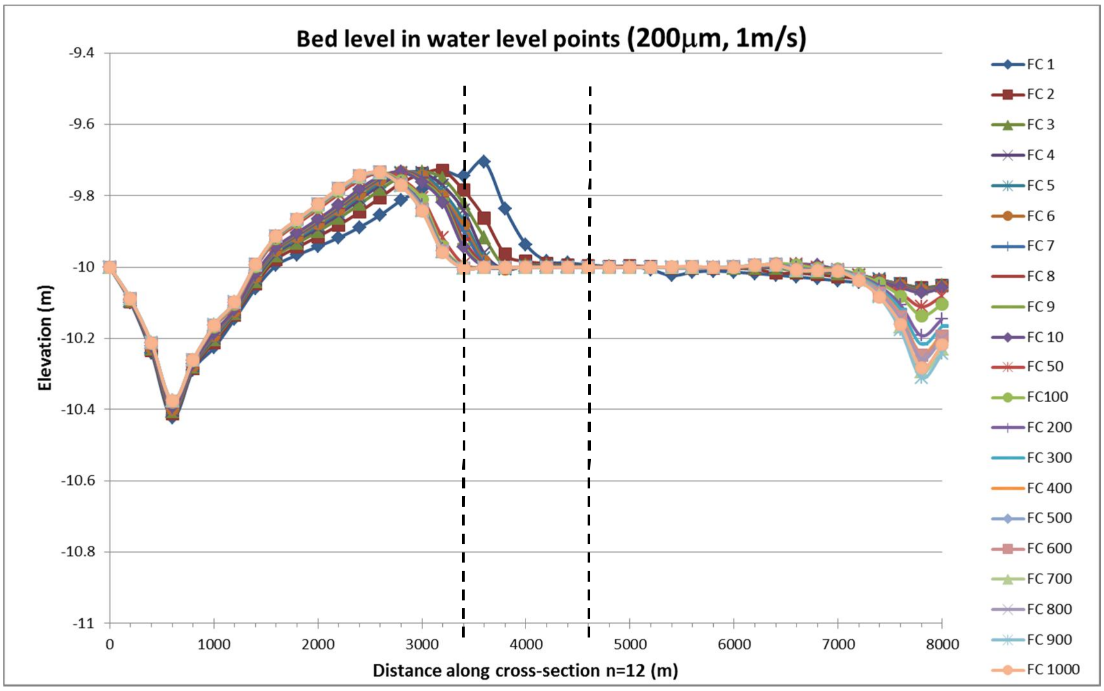


Figure 25 Bed level in water level points for various porous plate friction coefficient values for sediment of 200µm (dashed black lines indicate the area fenced up by porous plates)

Applying the maximum velocity of 1m/s (of the inner zone) in the test case, bed level changes were clearly visible (refer to Figure 24 and Figure 25). The sediment eroded on the upstream end of the channel and deposited downstream right in front of the porous plates and inside the settlement field area where the flow velocity reduced. With sediment availability, the porous plates were able to capture the suspended sediment within the fenced up area and allowed them to settle down. The accumulation of sediments inside the settlement field depended on the flow velocity within the area and the total amount of sediments passing through the plates. This is related to the sediment sizes and the porosity of the plates.

From Figure 24 for sediment sizes of 65μm, all plotted lines could be clustered into three groups of different friction coefficient: 1 (with most sediment deposition within the fenced up area), 2-10 (with medium sediment deposition within the fenced up area) and 10-1000 (with least sediment deposition within the fenced up area). A similar grouping pattern was observed in Figure 25 for sediment sizes of 200μm. However, the third group with friction coefficient of 10 onwards has blocked out all sediment. The porous plate porosity might be too small to allow the bigger size sediments through or the flow velocity might be too low to push the sediment through the plate; the exact reason of this will have to be tested in physical experiments which will not be covered in this research.

In consideration of the sediment sizes and the plate porosity, friction coefficient of 1, 2 and 10 were selected as input for the porous plate for the final model. The upper and lower limits of the second group were selected assuming the performance of other friction coefficient would fall within these two limits. This range is consistent with the findings of Hoogduin (2009) in which value of 2.3 was applied. To allow sediment of 200μm through, the porous plate friction coefficient has to be within 1-10, thus none of the value within the third group was chosen.

Flow velocity of 1.418m/s

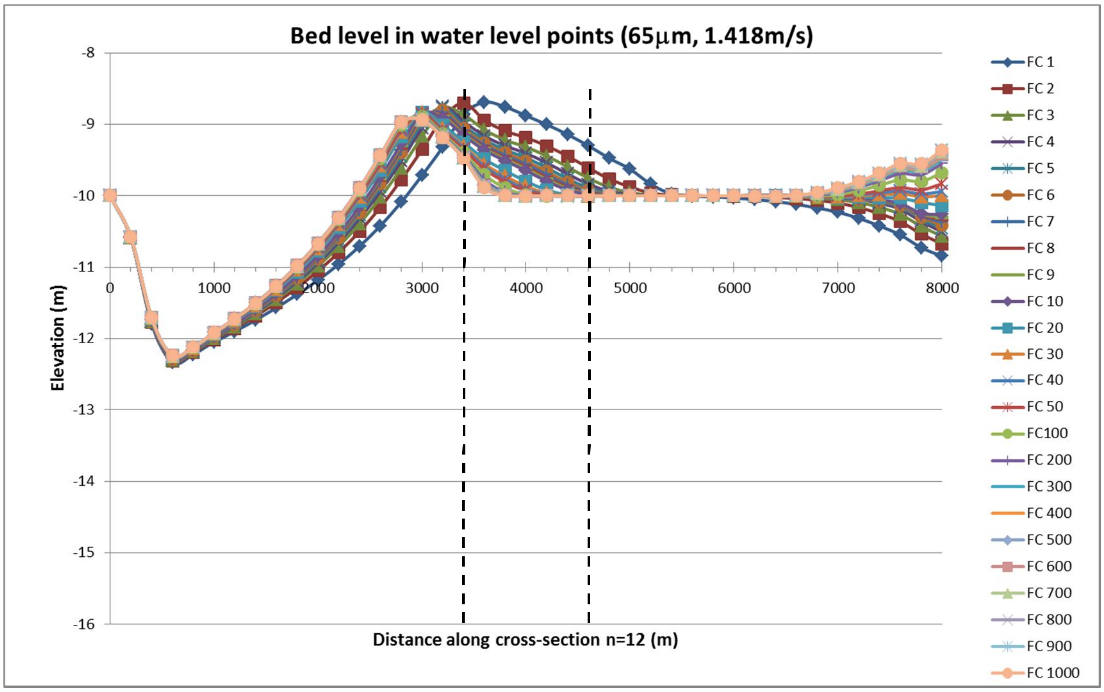


Figure 26 Bed level in water level points for various porous plate friction coefficient values for sediment of 65µm (dashed black lines indicate the area fenced up by porous plates)

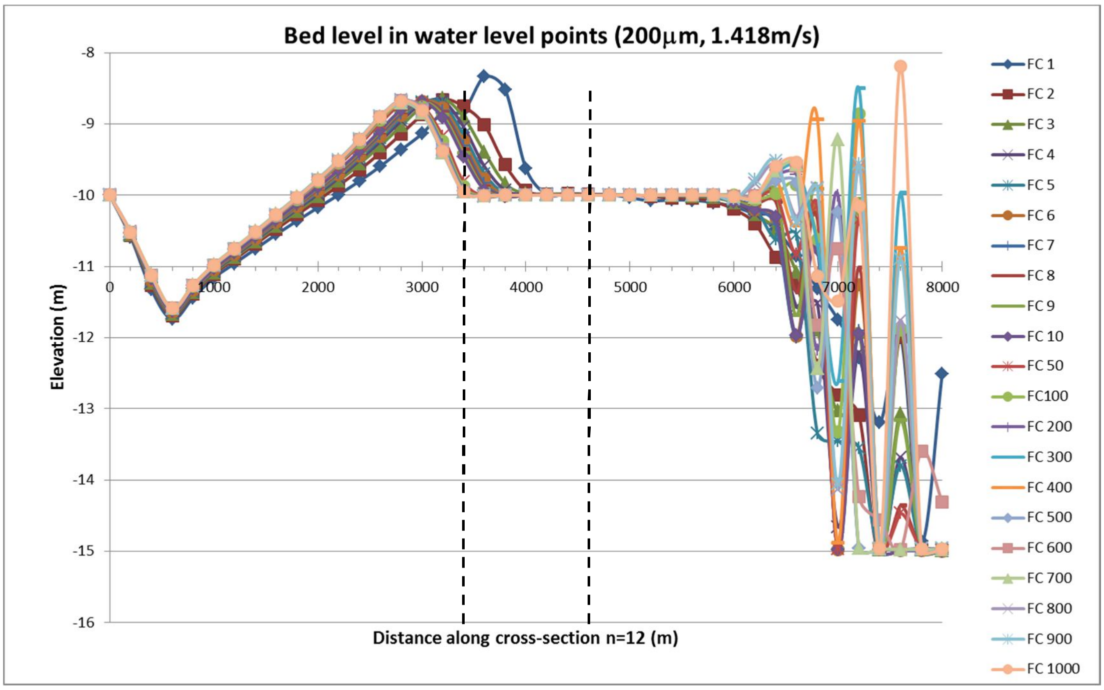


Figure 27 Bed level in water level points for various porous plate friction coefficient values for sediment of 200µm (dashed black lines indicate the area fenced up by porous plates)

Applying the maximum velocity of 1.418m/s (of the inner zone) in the test case, similar bed level changes pattern as the test cases of 1m/s was observed, just with a larger magnitude (refer to Figure 26 and Figure 27). Again, all lines plotted could be clustered into three groups of different friction coefficient as well: 1 (with most sediment deposition within the fenced up area), 2-10 (with medium sediment deposition within the fenced up area) and 10-1000 (with least sediment deposition within the fenced up area). Viewing this, the selection of friction coefficient of 1, 2 and 10 was certain.

There were irregular bed level changes observed at the end of channel for the different porous plate friction coefficient. The occurrence was caused by the model layout. The porous plate placed at the middle of the channel had greatly reduced the width of the channel which caused the contraction effect that sped up the flow velocity when the flow passed the narrow part. After the narrow passage way, the expansion of the passage way back to normal width would then slow down the flow. The contraction-expansion effect would have caused turbulence at the downstream which created the pattern as seen in Figure 27. The magnitude of irregularities increased when the plate porosity reduced. As the porous plate would be placed at the open area in the finalised model, the effect of channel contraction-expansion would not be obvious.

5 SETTLEMENT FIELD MODEL SETUP

5.1 Grids and bathymetry

5.1.1 Grids

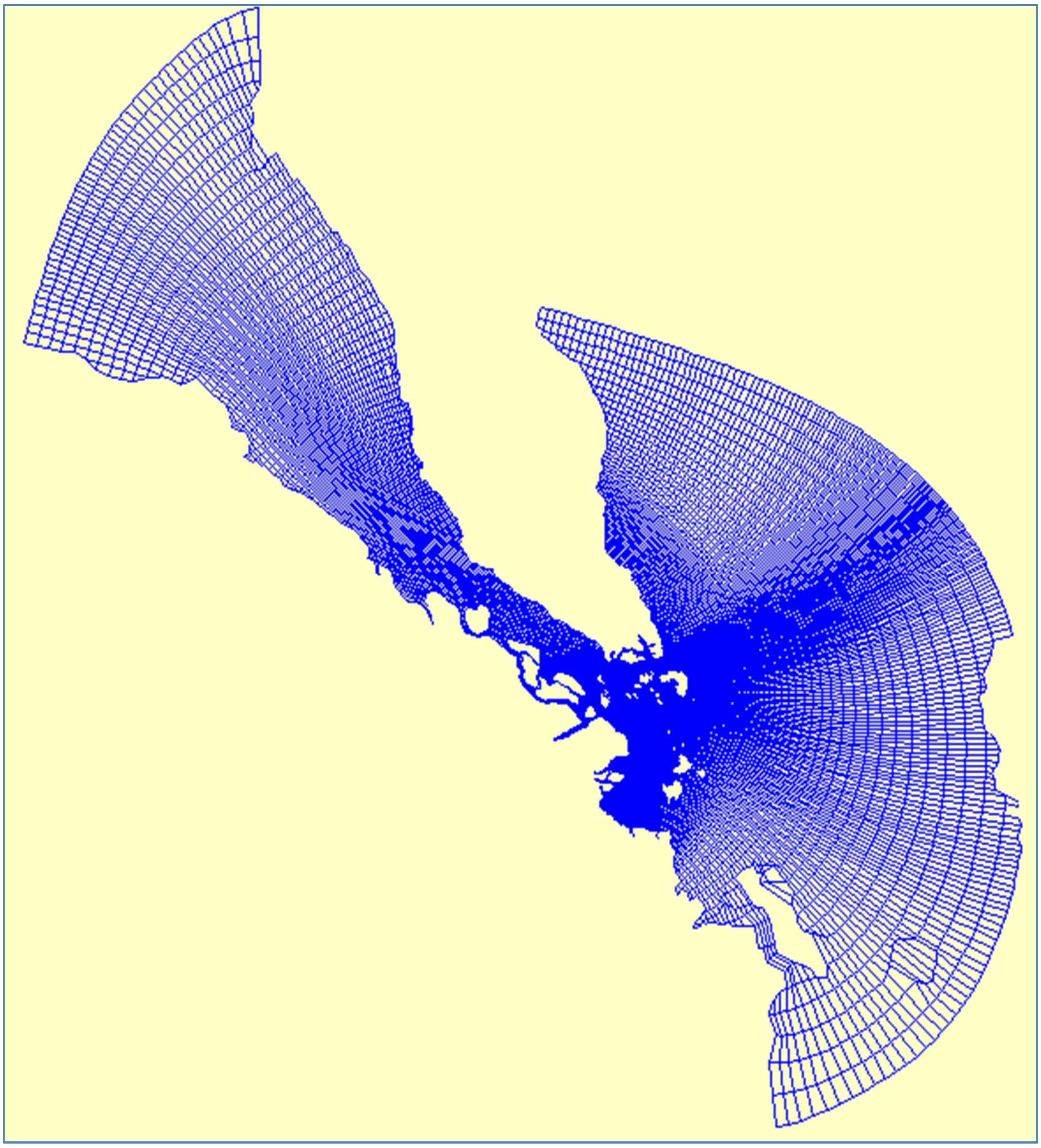


Figure 28 Singapore Regional Model

Singapore Regional Model (SRM) which was extensively validated during previous studies was used to set up the settlement field model (refer to Figure 28). SRM as designed using curvilinear grid was primarily developed to provide accurate tidal information in the Singapore Strait region. SRM covered the region from 95°E–109°E and 4°S–10°N, extending from northern Sumatra to the eastern coast of Borneo. The model was built of approximately 38,600 grid cells with varying grid cell sizes of about 20x40 km^2 at the boundaries to about 150x200 m^2 at the Singapore interior water areas. The model has open water boundaries set at the Andaman Sea, Java Sea and the South China Sea. At the open water boundaries, 8 main tidal constituents Q1, O1, P1, K1, N2, M2, S2, and K2 were prescribed, with direct tide generating forces included in the interior domain. (Kurniawan, A., Ooi, S.K., Hummel, S. & Gerritsen, H., 2011)

The settlement field would be placed at Tanjung Piai area where the grid cells in that area vary around 1.2km^2. Local grid cells refinement was required for the settlement field analysis in order to produce accurate model predictions in the study area while keeping the computational time low. Refining all grid cells in SRM would be too computationals expensive as the desired grid resolution at the study area was around 150m^2 to 200m^2 to fit in the settlement field which would require a refining scale of about 10.

Local grid cells refinement was preferred. The grid cells refining would be done gradually through domain decomposition procedure. Primarily, SRM was refined via three stages (referring to Figure 29). A smaller domain cut out from the SRM (DD01) was refined with a scale of 3x3; subsequently another even smaller domain cut out from DD01 (DD02) was refined with a scale of 3x3. By doing this, the grid cells around study area were able to be refined to approximately 120m^2. However, the total grid cells count was increased by almost 5 times which has resulted in an almost 10 days run for a single layer model. As the model would eventually be tested in three-dimensional setting with 10 layers, the simulation time required would be escalated up. Running 3 domains synchronously was not time-effective. This refined SRM would have to be amended; the refining was kept to 2 domains to save computational time.

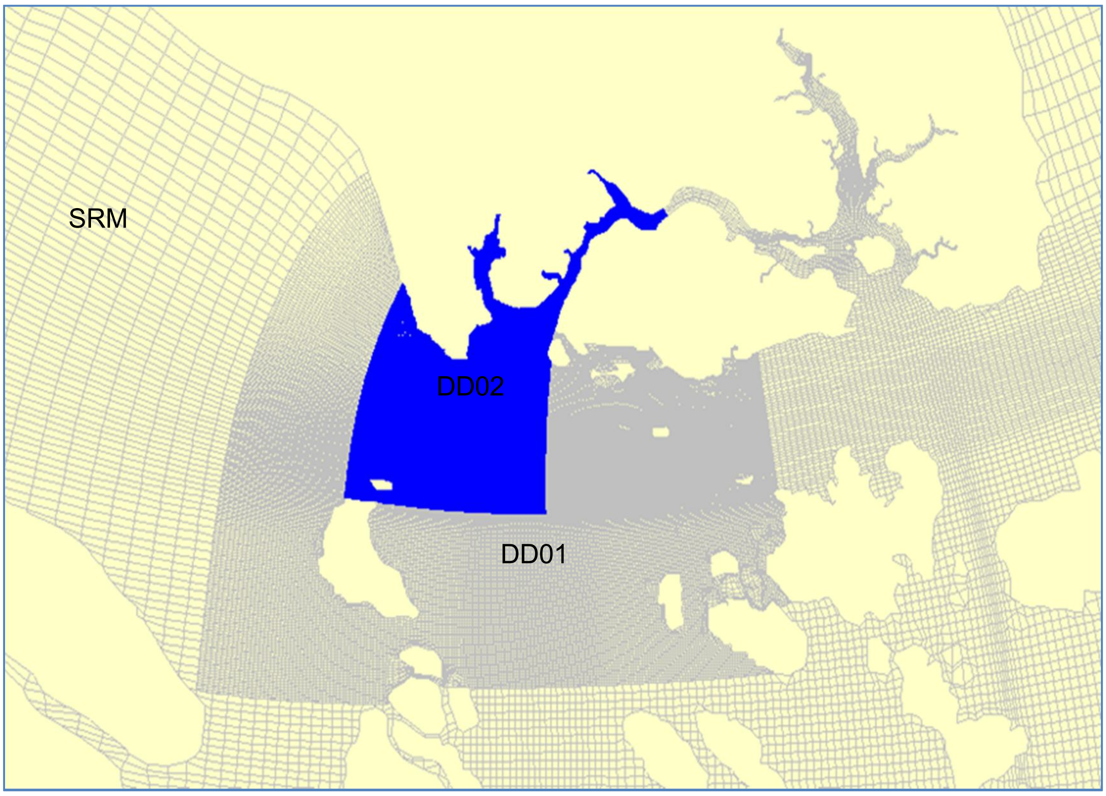


Figure 29 SRM grid cells refining

A number of iterations was required of refinement and alignment, yet it was challenging to obtain a stable model and to maintain the balance between model resolution and computational time if the sub-domain was to be run parallel to the main domain. Eventually, it was decided to refine the model via domain decomposition procedure and to run the model independently via nesting procedure. The local grid cells refining and reconstructing were done gradually in two stages, as explained in the following.

Stage 1:

In order to avoid refining the whole SRM, the region near to study area was cut out from the SRM and refined separately. The section near to study area was refined with a scale of 5x3 (m- x n – directions) while other section further away was refined with a scale of 3x3 (refer to Figure 30). After refining and fulfilling the grid properties check, the cut-out model was run parallel to the SRM via domain decomposition procedure of Delft 3D to generate the hydrodynamics information within the model for a year. The newly data obtained from the domain decomposition model was validated against the SRM (described in section 5.3) to ensure the model exhibit similar behaviour as the SRM and to confirm if the result obtained was reliable before the next stage was carried out.

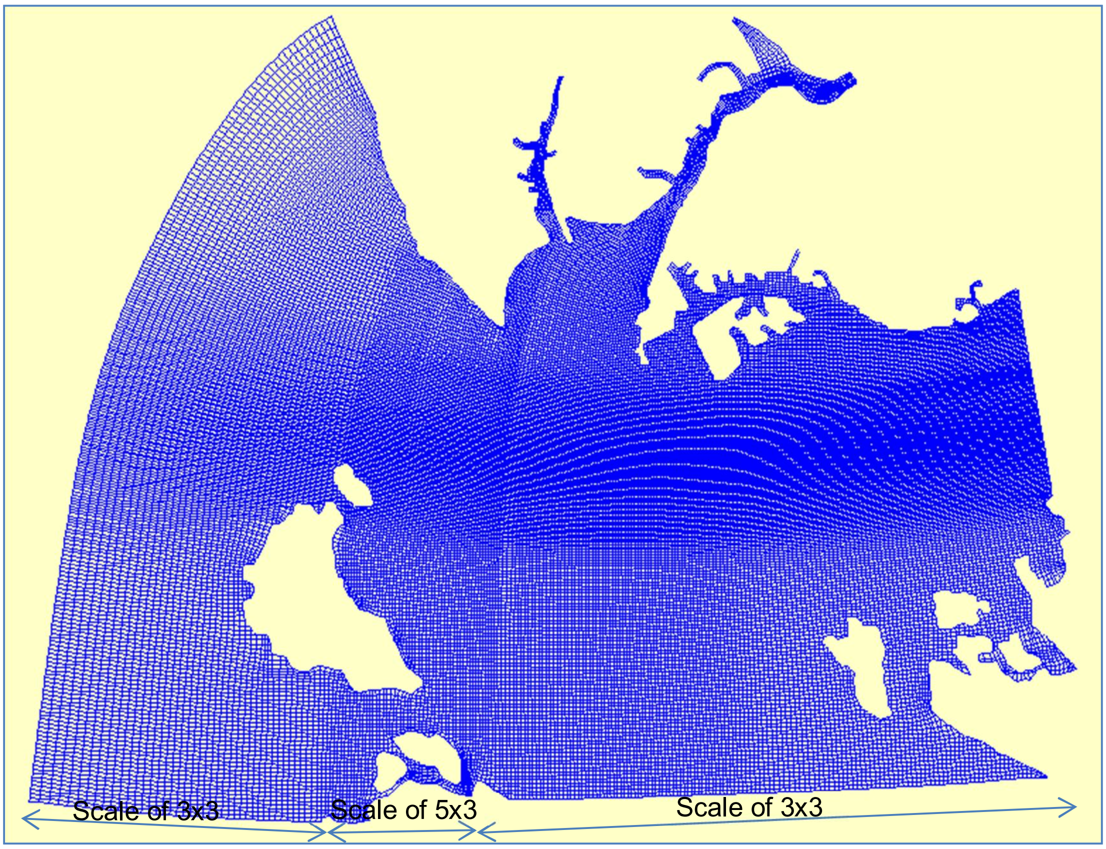


Figure 30 Domain decomposition model

Stage 2:

After the validation of the domain decomposition model, an even smaller domain was cut out from the domain decomposition model and further refined with a scale of 3x3 to be used as the finalised model for all analysis, refer to Figure 31. As this finalised model would be expanded to three-dimensional with 10 layers which may significantly extending the computational time, this finalised model was decided to be run independently from SRM to save computational time. The model was then nested to the domain decomposition model from Stage 1 in order to generate the relevant boundaries conditions (time-series) required to force the flow in this finalised model. These abstractions permitted this finalised model with smaller domain to function isolated from the surroundings it was set in and yet still provided the similar results as the bigger domain decomposition model. The results obtained from the nested model was validated against the SRM too (described in section 5.3) before it was expanded to three-dimensional model and being utilised in the settlement field analysis.

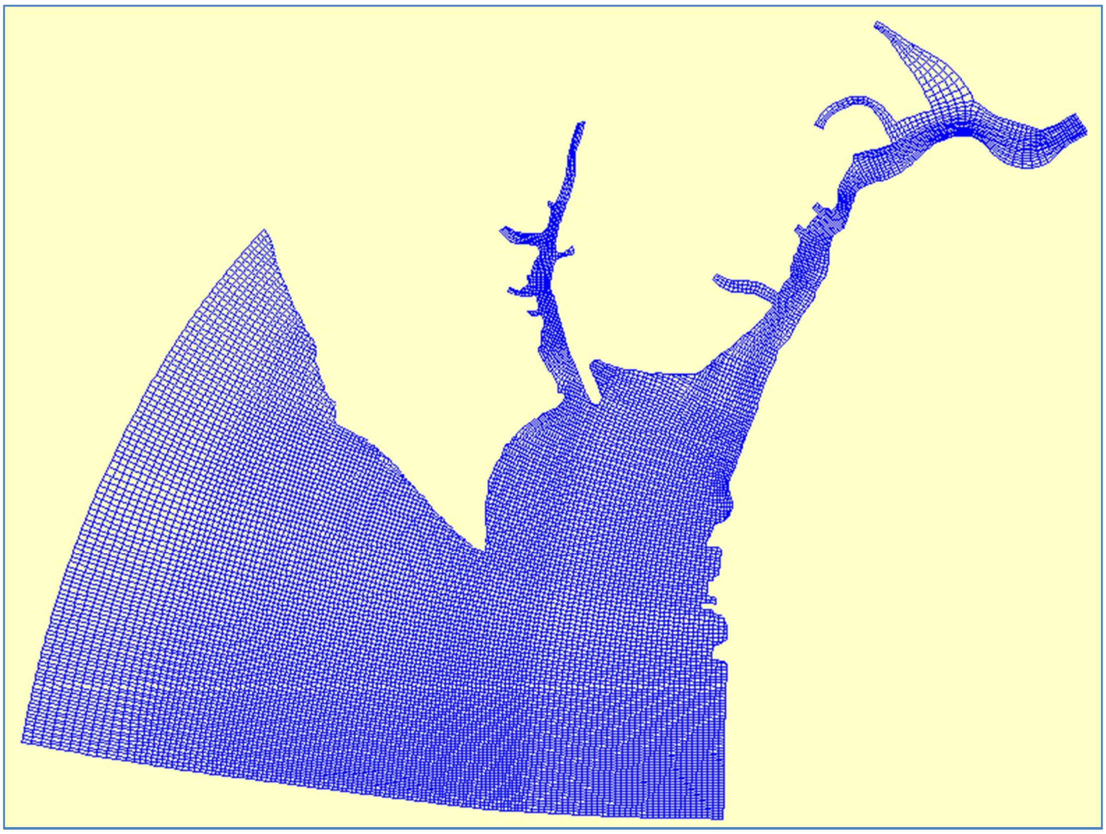


Figure 31 Nested model (finalised model used for all simulations)

During the iterative process of model grid refining before the finalised model as shown in Figure 31 was confirmed, artificial flow jet (high velocity flow) was observed near to the study area. The artificial flow jet created instabilities in the computational model which resulted in abrupt termination of simulation.

To solve the issue, the grid cells were readjusted and the different sub-domains were tried and tested. Some of the layouts tested were showed in Figure 32, though those layouts were eventually left out due to inaccuracy and instability. In addition, the grid cells around the study area (especially at the area as circled up in Figure 33) were realigned to ensure a smooth transition of the grid cells in order to have a stable model. The finalised nested model was confirmed after numerous trial and errors.

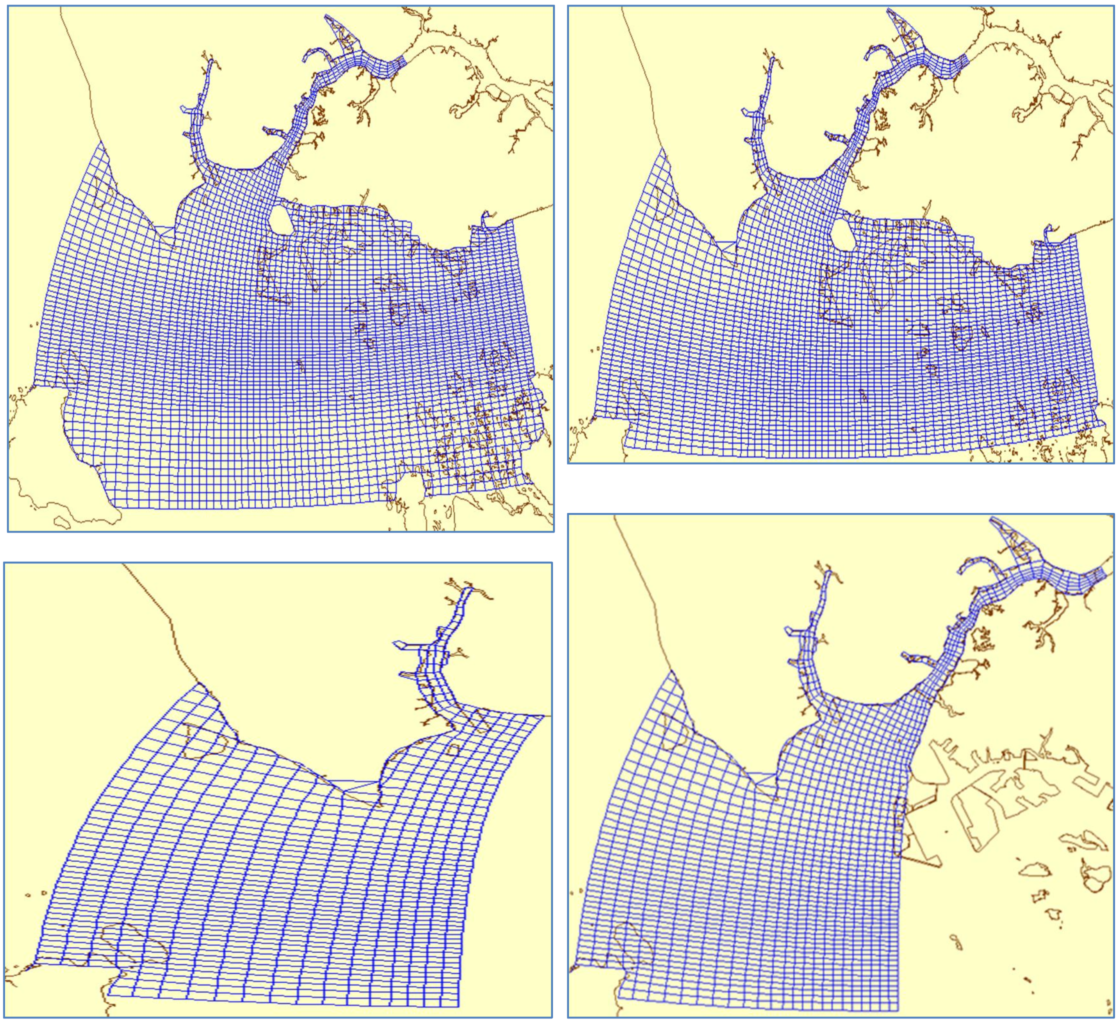


Figure 32 Different sub-domains tested

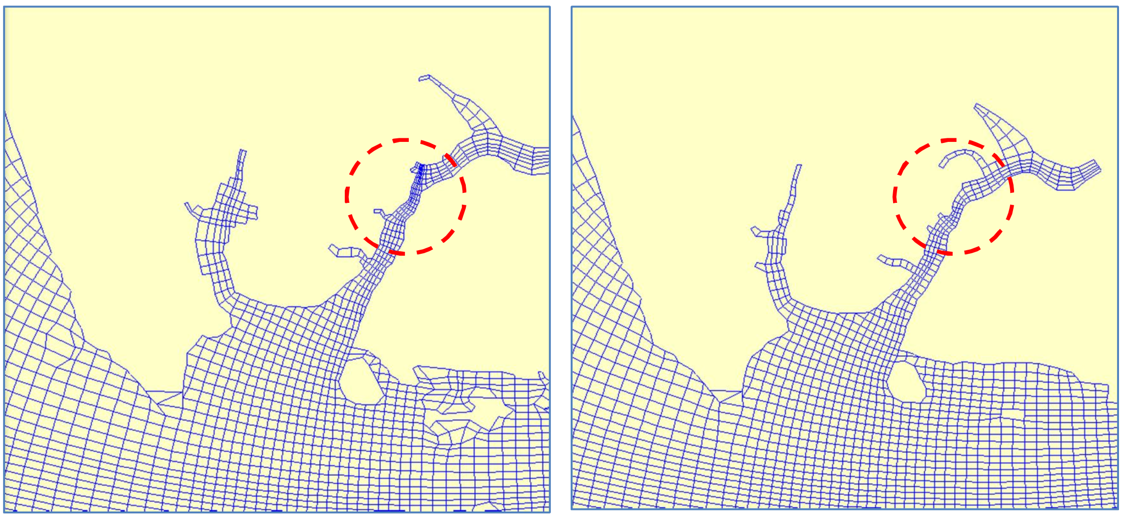


Figure 33 Grid realignment at Johor Straits

During model grid construction and refining process, several important properties such as orthogonality, smoothness, spatial resolution, and coverage were checked to ensure the stability and accuracy of model simulations. Orthogonality is the measure of cosine angle formed between adjacent cell walls, degree to which the flow direction remained unchanged between cells. The grid lines direction should change gradually with near-perpendicular corners. The orthogonality value should be kept well below 0.02. Smoothness is the measure of cell dimension changes from one cell to the next cell in m-direction and n-direction. The grid cells areas from cell to cell should not change abruptly. The smoothness value in m- and n- direction should be closed to 1 with a maximum value of 1.2. Spatial resolution refers to the total number of grid cells. Higher spatial resolution normally gives better model accuracy, but it also increases the simulation computational time required. Higher resolution can be set for the area of interest while other areas further away can have relatively coarser resolution; the balance is weighted by the model accuracy and computational time. The property of coverage simply means that the grid should fully cover the area of interest with adequate surrounding areas to accurately model the boundary conditions and flows.

Orthogonality, m- and n-smoothness of the finalised nested model were displayed in Figure 34 to Figure 36. The figures showed the nested model fulfilled the parameter constraints. The orthogonality was well below 0.02 while the smoothness in both directions was well below 1.2 across the study area. Though, some imperfect orthogonality and smoothness were noticed along the coastlines due to snapping of grid lines to the land boundaries. The slight decrease of orthogonality and smoothness at the grid boundaries has no substantial effect on the accuracy of the model; the model validation check of water level and velocity correlations for the observation points around the study area were well above 70% (refer to section 5.3).

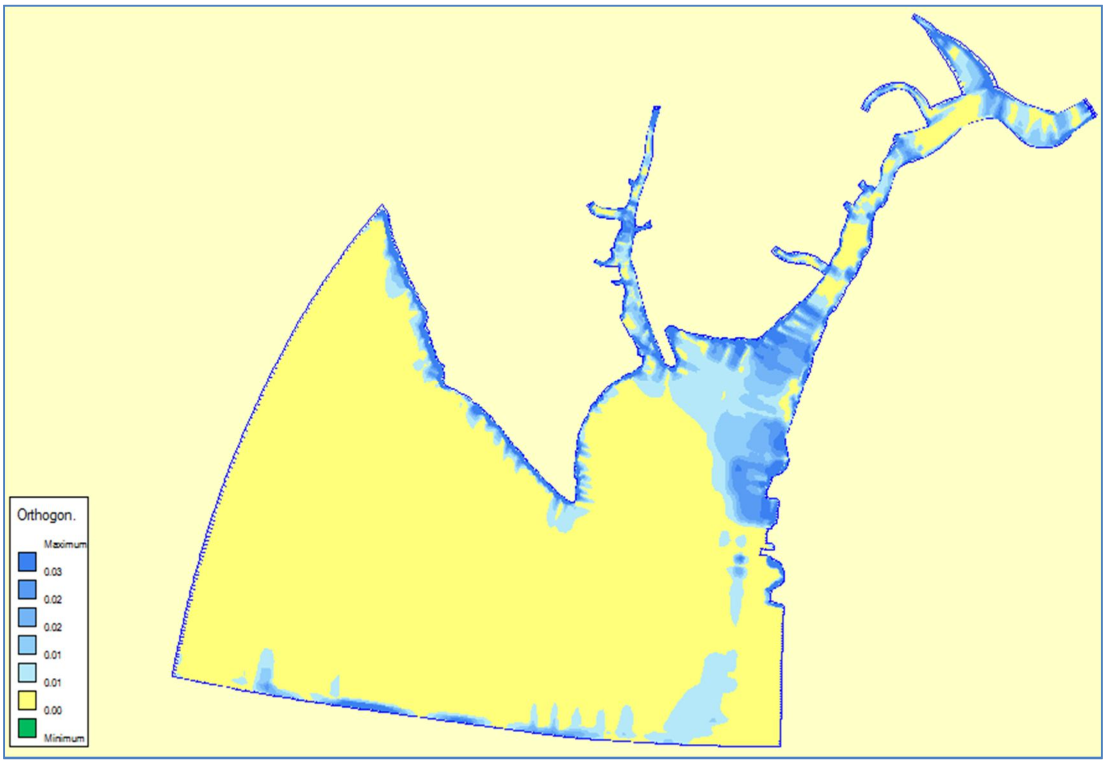


Figure 34 Orthogonality of the finalised nested model

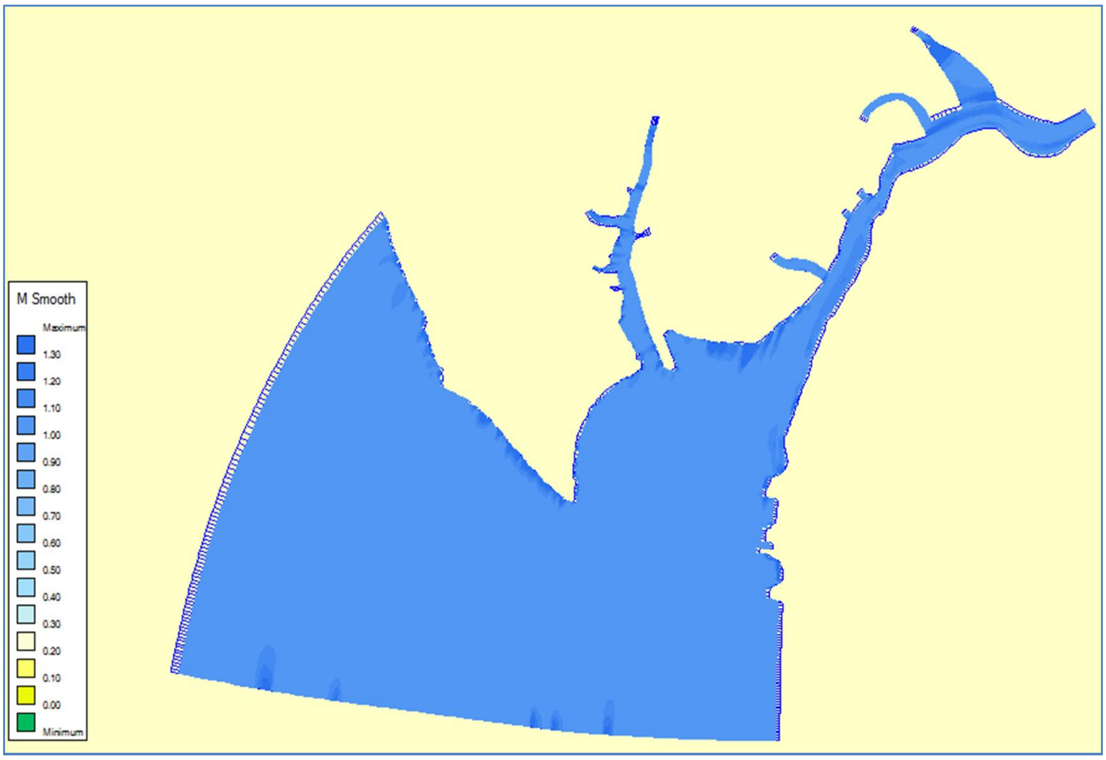


Figure 35 M-smoothness of the finalised nested model

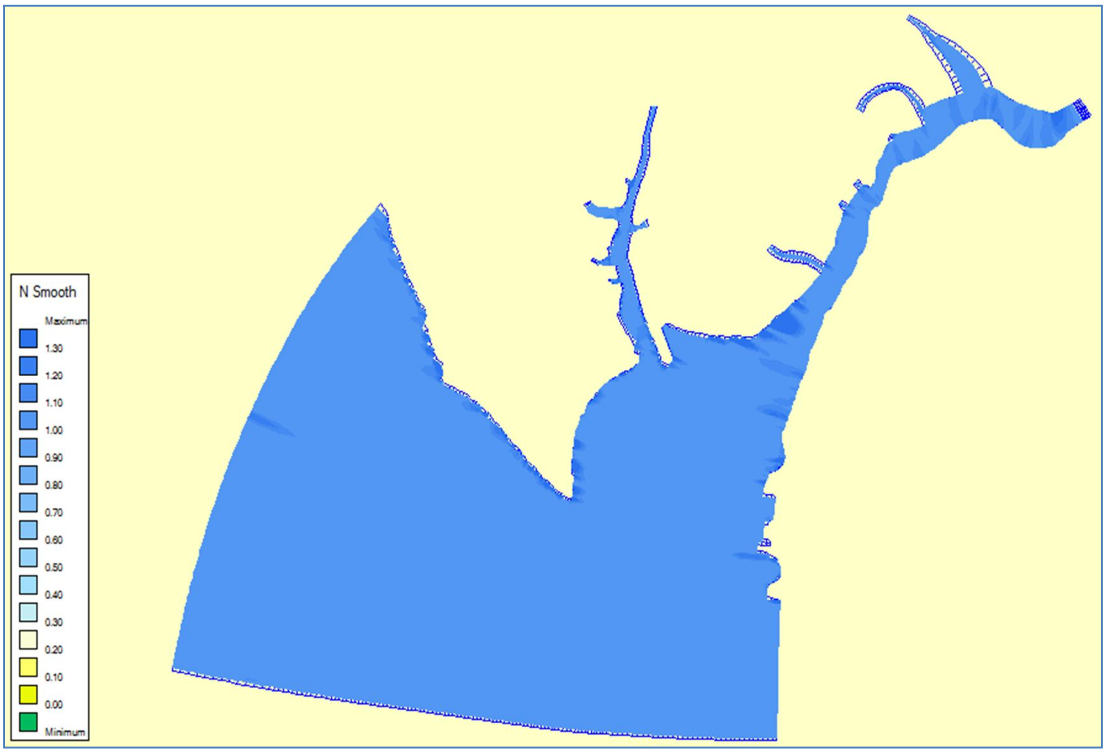


Figure 36 N-smoothness of the finalised nested model

5.1.2 Bathymetry

Tanjung Piai is situated at the junction of Johor Strait, Singapore Strait and Malacca Strait. Johor Strait separates Singapore from Malaysia. The water depths vary from a few meters along the sides to about 10-20 meters at the center of the strait. Sungai Johor at the east and Sungai Pulai at the west are the two main rivers draining into the Johor Strait. Singapore Strait connects the Malacca Strait at the west to South China Sea at the east. The water depths along the strait from the southern end of the Malacca Strait to the South China Sea are generally less than 50; except in a small area off the coast to the south-east of St John’s Island where the depths range more than 100m. However, to the north of Malacca Strait, the water depths deepen swiftly towards the Andaman Sea, reaching thousand meters. To South China Sea side, water depths range from hundreds of meters in the shelf areas to thousands of meters in the basin of east of Vietnam. The depth values are generally obtained from Admiralty charts with additional data around Singapore obtained from local surveys.

Bathymetry is one of the important physical parameters defining the hydrologic model in order to accurately model the flow and transport processes. The water depth data in the form of coordinate point values provided for the Singapore Regional Model was used to generate the depth data for the modified domain decomposition model and the finalised nested model. The depth samples were taken few years back. However, as all model simulations were using the same bathymetry and the studies were comparative, the change in depth over years should not considerably affect the results. The depth samples were interpolated in order to assign a depth value to every grid cell. The triangular interpolation was applied across the model. This method averaged all samples surrounding a cell and inside a cell to interpolate the depth value within the cell. The final interpolated depths across the study area of the nested model were shown as Figure 37. The water depths in the study area range between 51m.

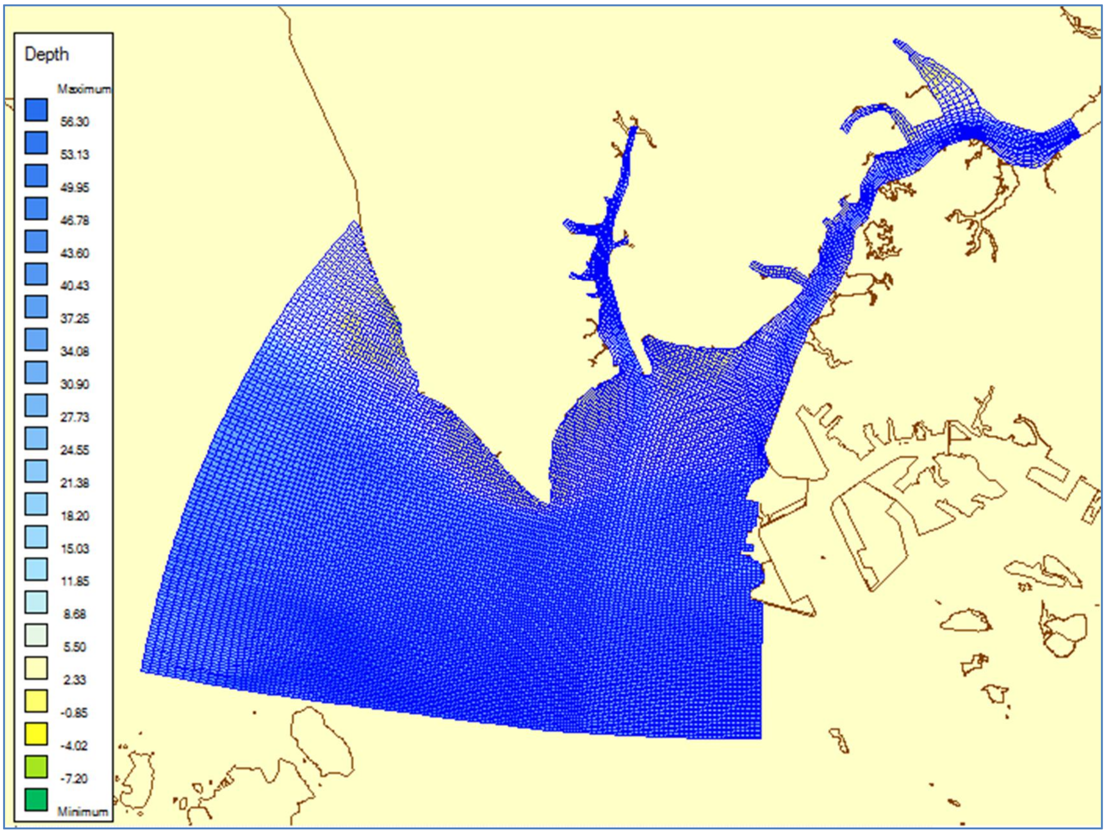


Figure 37 The nested model with final interpolated depths across the study area

5.2 Model forcing

Model forcing was applied to the nested model to represent the effect of natural forces acting on the modelling domain, so that the results would be similar to reality. ‘Information’ was passed to the modelling domain in the form of boundary conditions. Through trials, the combination that gave a stable simulation without any error message was chosen. Water level boundaries were applied to the west of the nested model while current boundaries were applied to the south and the east of the nested model (refer to Figure 38). The water level and current boundaries were derived from Singapore Regional Model domain decomposition model through nesting procedures. The boundaries along the open sea were divided into 48 spatial units to effectively capture the variation of water level and current along the open sea. Each and every spatial unit has a separate water level or current time series of a year (with 20 minutes interval) generated for it. These time series forced the water flow within the nested model for all simulations.

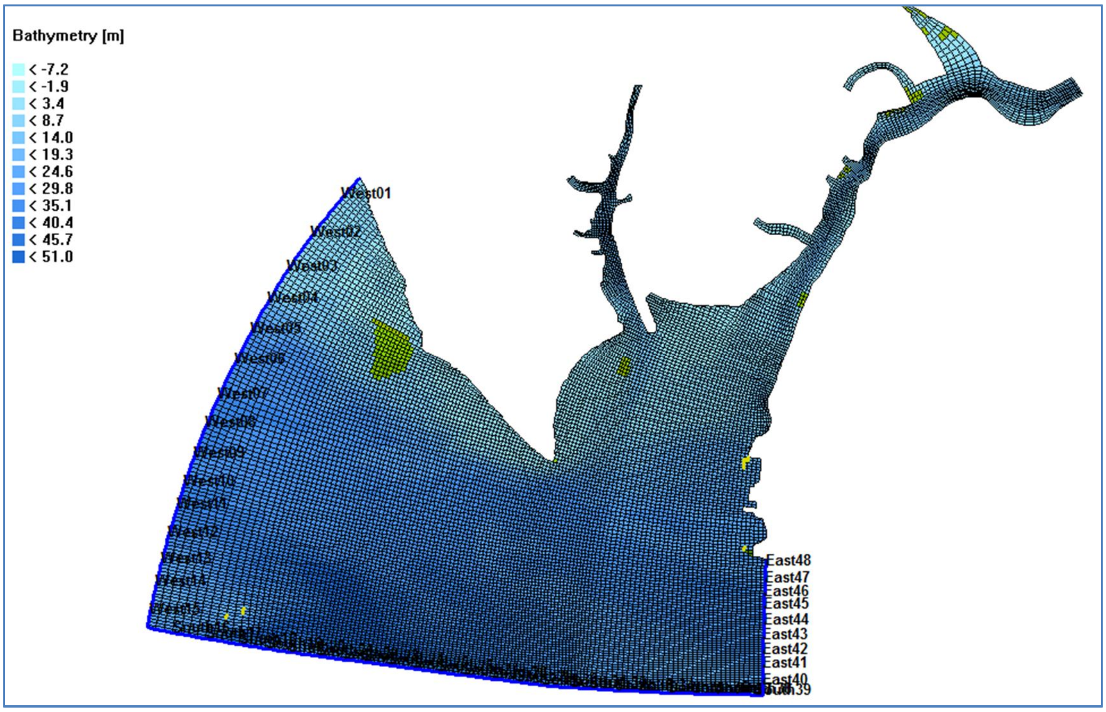


Figure 38 Location of boundaries

5.3 Validation of two-dimensional model

The domain decomposition model was first validated against the SRM data before it was used to generate the boundary condition for the nested model. Subsequent, the nested model was validated against the SRM data before it was used as the finalised model for all analysis and scenarios runs. For validation purpose, all the models were set as two-dimensional with only a single layer and set for simulation from early January to the end of December of 2013. A year data extracted from the SRM was used as base reference for comparison and validation. Both of the models were validated at seven different locations near to study area to ensure that the modify models and grids exhibited similar hydrodynamic behaviour as the existing SRM especially at the study area.

5.3.1 Validation locations

The following seven locations near to Kukup and Tanjung Piai were selected for water level and velocity validation (refer to Table 4 and Figure 39).

ID	East	North	Water level validation	Velocity validation
K01	103.428	1.299	✓	✓
K03	103.473	1.284	✓	✓
K04	103.502	1.260	✓	✓
K05	103.523	1.270	✓	✓
K08	103.533	1.304	✓	✓
K09	103.418	1.267	✓	✓
K12	103.506	1.232	✓	✓

Table 4 Summary of validation points

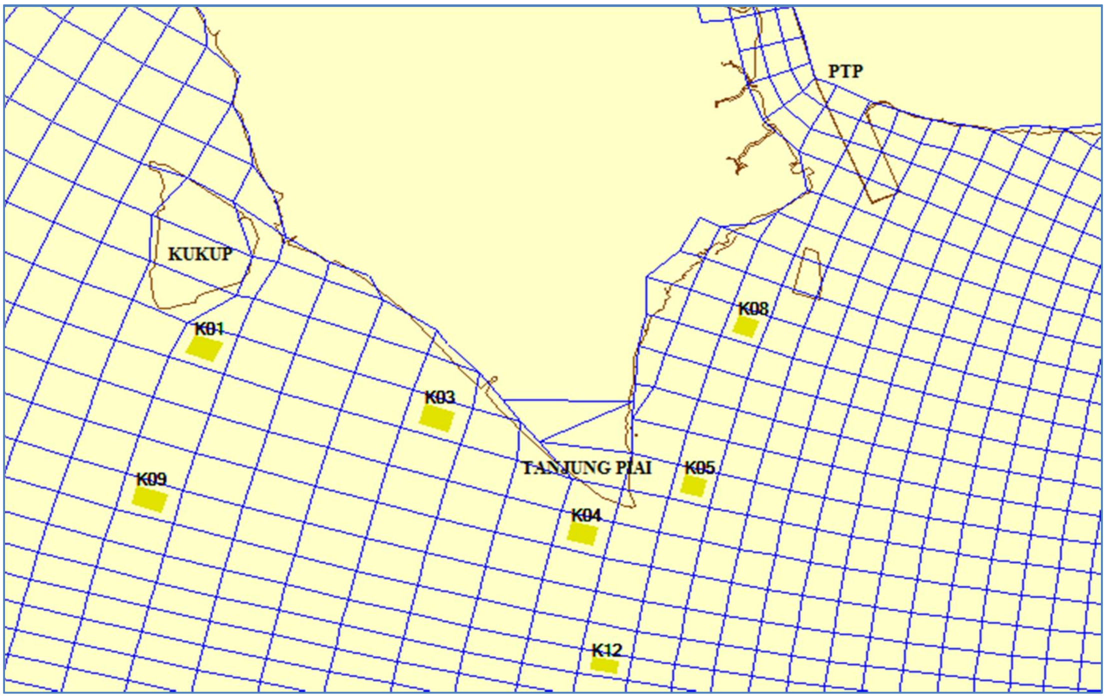


Figure 39 Validation points near to Tanjung Piai

5.3.2 Fitting measure of validation: RMSE and Pearson correlation

The Root Mean Square Error (RMSE) was used to measure the differences between a validation dataset with respect to another simulated dataset based on residuals. RMSE aggregates the magnitude of errors of various time steps to a single number. The value near 0 shows strong agreement between datasets. The RMSE for water level and velocity time series for the different locations of the two-dimensional model was calculated against the validation dataset as below:

$$RMSE = \sqrt{\frac{\sum(x_{s,i} - x_{v,i})^2}{n}}$$

Where superscripts s and v symbolise the simulated and validation datasets; i symbolises the i-th time-series of observation; and n symbolises the total number of observations in the time series.

In addition to RMSE, Pearson correlation coefficient was also used to measure the linear dependence between the simulated and validation datasets. The correlation coefficient value near 1 shows strong agreement between datasets.

$$Correlation\ coefficient, \rho = \frac{n.(\sum x_{s,i}x_{v,i}) - \sum x_{s,i} . \sum x_{v,i}}{\sqrt{\left(n.\sum(x_{s,i})^2 - \left(\sum x_{s,i}\right)^2\right).(n.\sum(x_{v,i})^2 - (\sum x_{v,i})^2)}}$$

Where all symbols used are as showed in the RMSE formula above.

5.3.3 Validation results

5.3.3.1 Domain decomposition model

For the validation of water level for the seven validation points, the analysis showed good result with RMSE well below 0.076 (refer to Table 5). Besides, the correlation for water level was all above 99.5% (refer to Figure 40). Linear dependence of the simulated dataset and the validation dataset was plotted in Figure 41.

Validation points	RMSE for water level
K01	0.06706
K03	0.06943
K04	0.07173
K05	0.07494
K08	0.07584
K09	0.06626
K12	0.07296

Table 5 RMSE of water level

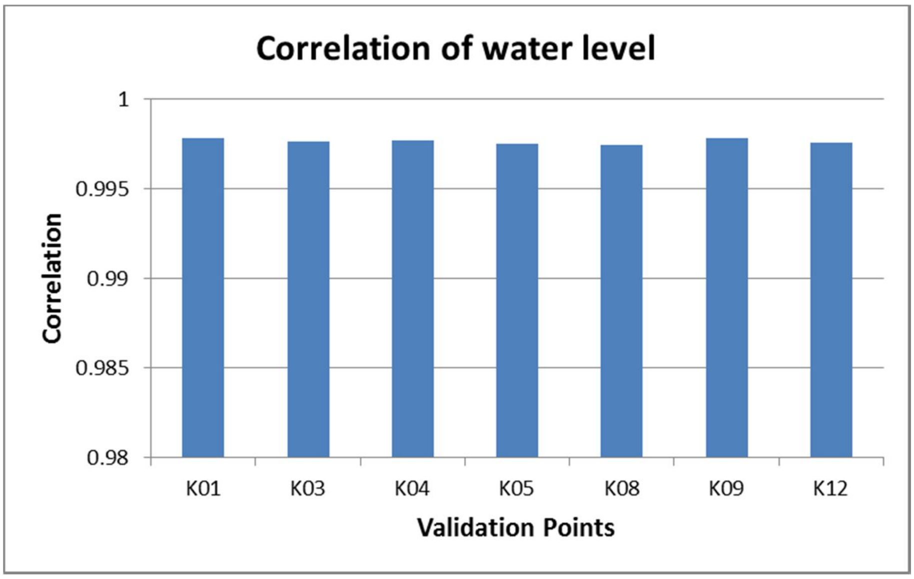


Figure 40 Correlation of water level at different validation points

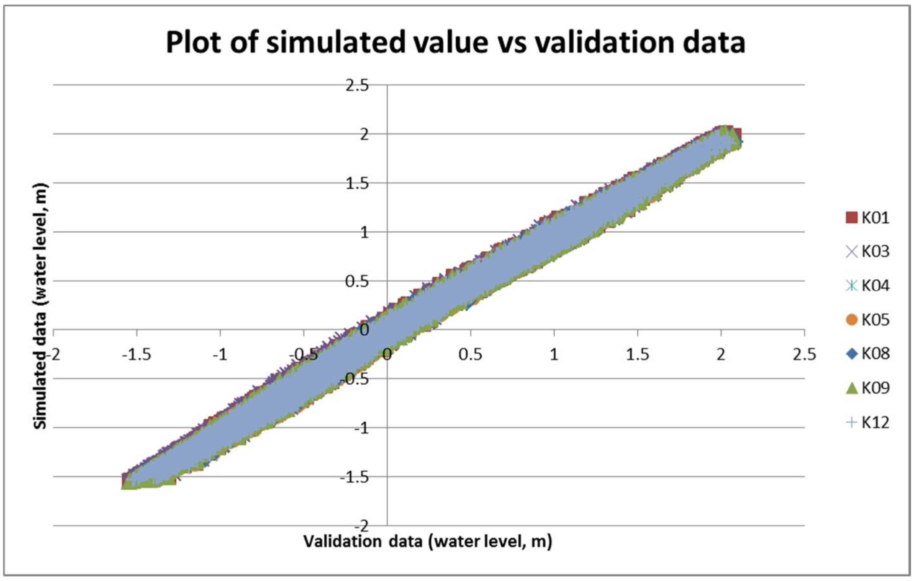


Figure 41 Plot of simulated value vs validation data

The RMSE of depth-averaged velocity for all validation points was within 0.21 (refer to Table 6). For the correlation of depth-averaged velocity, the x-component, y-component, magnitude and angle were checked. All seven validation points showed good correlation with coefficient above 89% for x-component and coefficient above 74% for y-component (refer to Figure 42). However for magnitude-component and angle-component, only six out of the seven points showed good correlation with coefficient above 70% except point K12 with a slightly lower correlation of about 68%. The marginally suboptimal result for velocity validation was most probably due to the discrepancy in pin-pointing the exact same location (or coordinates) for comparison; and the imperfect smoothness and orthogonality of the nearby grid cells. However, the model was deemed satisfactory with a minimum correlation of about 70% for water level and depth-averaged velocity at all validation points selected.

Validation points	**RMSE for depth-averaged velocity**	
	X-component	**y-component**
K01	0.06684	0.03178
K03	0.04809	0.05074
K04	0.19353	0.05849
K05	0.05636	0.03559
K08	0.01463	0.01940
K09	0.19147	0.11994
K12	0.20819	0.05986

Table 6 RMSE for depth-averaged velocity

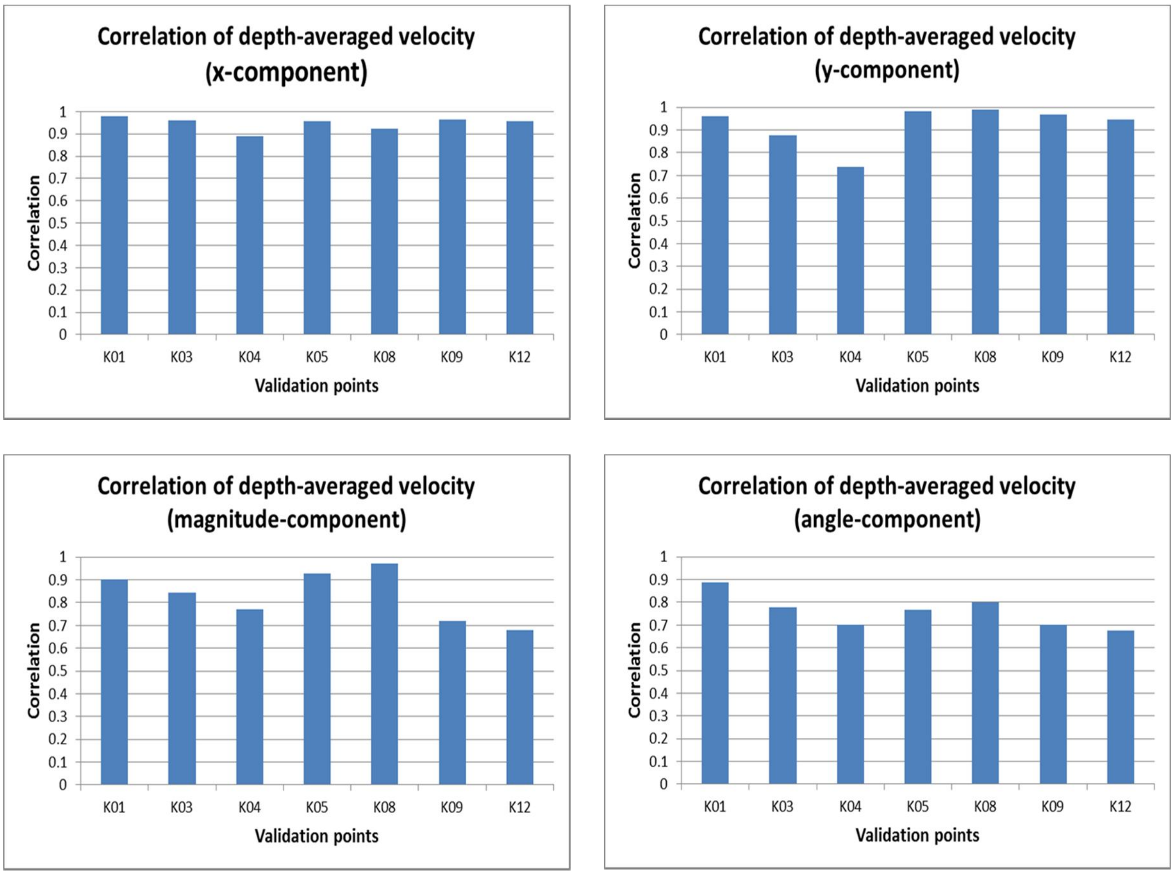


Figure 42 Correlation of depth-averaged velocity at different validation points

5.3.3.2 Nested model

For the validation of water level for the nested model, the analysis also showed good result with RMSE well below 0.077 and correlation of water level all above 99.5% (refer to Table 7 and Figure 43).

Validation points	RMSE for water level
K01	0.06719
K03	0.06904
K04	0.07682
K05	0.07471
K08	0.07562
K09	0.06617
K12	0.07176

Table 7 RMSE of water level

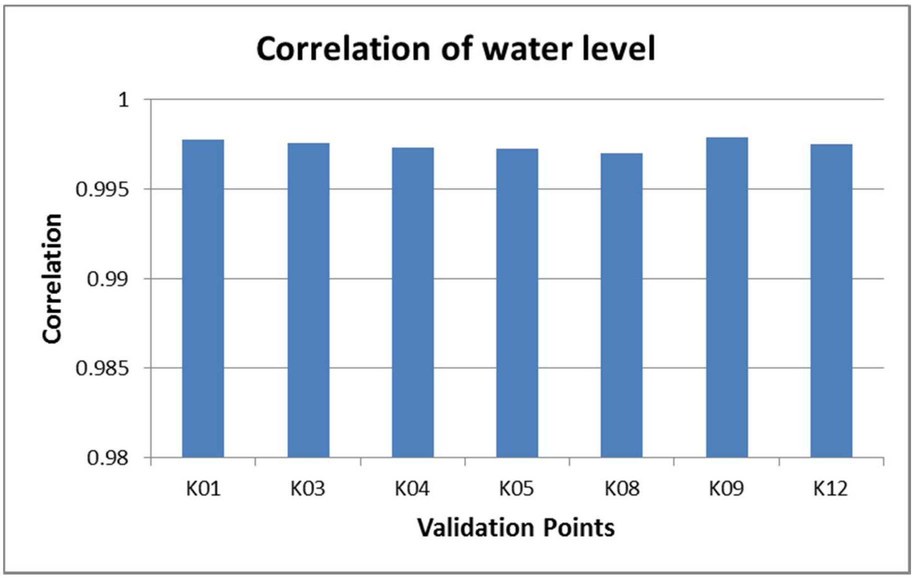


Figure 43 Correlation of water level at different validation points

The RMSE for depth-averaged velocity for all validation points was within 0.18 (refer to Table 8). For the correlation of different components of depth-averaged velocity, all seven validation points showed good correlation with coefficient above 70% (refer to Figure 44). The model was deemed satisfactory with a minimum correlation of about 70% for water level and depth-averaged velocity at all validation points selected.

Validation points	**RMSE for depth-averaged velocity**	
	X-component	**y-component**
K01	0.07125	0.06509
K03	0.05882	0.05003
K04	0.11681	0.05213
K05	0.05161	0.05435
K08	0.01420	0.02520
K09	0.17606	0.11762
K12	0.16504	0.05096

Table 8 RMSE for depth-averaged velocity

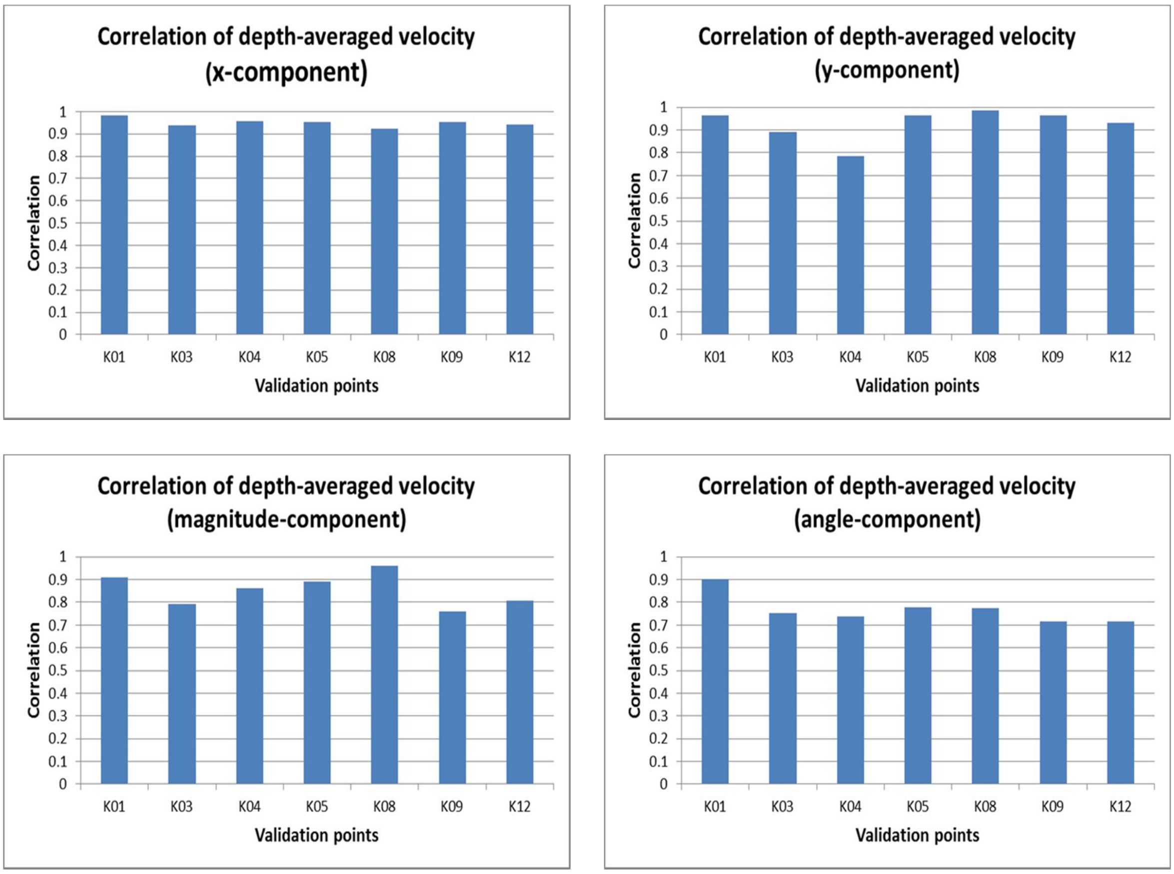


Figure 44 Correlation of depth-averaged velocity at different validation points

5.4 Expansion to three-dimensional model

A number of 10 vertical layers were added to the nested model using σ-model after the validation of the two-dimensional model. The number of layers added was constrained by total computational time. 10 layers were considered to provide enough vertical resolution for the model accuracy within the acceptable computational time frame. The 10 layers were distributed equally with 10% each.

5.4.1 Addition of sediment and morphology parameters

Large amount of mud is found at the southern side of Malacca Strait to Singapore coastal zone as supplied by the various rivers draining Malaysia. The percentage of silt and clay covering the seabed (mud with median grain size less than 63μm) varies from several percent to 40%. Mudflats edge along the Johor estuary; marine clay (often covered with a thin surface layer of shell and sand) is the most common soil type along the mud coast, with depths exceeding 25m. (An Overview of the Marine Physical System of Singapore, 2011)

Referring to the discussion with student who has collected some samples from the top layer of the river bed of Sungai Johor some distances away, the sediment samples were classed as silty sand with a sediment size of 65μm. Combining the literature finding on the soil type along the Johor mud coast and the finding from the student, sediment size of 65μm was applied in the simulation for the settlement field analysis. A virtual sediment layer thickness of 5m was prescribed on the bottom as the sediment source. Sediment and morphology parameters as set in the simplified 3D channel test cases were applied in the 3D nested model. Default values were applied to the sediment data and morphological data due to the lack of morphological data for validation and calibration. The model parameters for the sediment and morphology sections were summarised in Table 2.

Parameter	**Value**
Processes	Constituents = Sediment (non-cohesive)
Initial condition	Water level = 0 meter Sediment concentration = 10kg/m^3
Gravity	9.81m/s^2
Water density	1000kg/m^3
Roughness	Manning, 0.022
Background horizontal viscosity/diffusivity	Uniform horizontal eddy viscosity/diffusivity of 1 m^2/s
Background vertical viscosity/diffusivity	Uniform vertical eddy viscosity/diffusivity of 10^{-6} m^2/s
Reference density for hindered settling	1600kg/m^3
Data for non-cohesive sediment	Specific density = 2650kg/m^3 Dry bed density = 1600kg/m^3 Median sediment diameter = 65μm Initial sediment layer thickness at bed = 5m

Table 9 Model parameters for finalised nested model

5.4.2 Addition of porous plate

From chapter 3, it showed that the coastlines along Tanjung Piai between Parit Che Uda to Sungai Perepat Pasir were seriously eroded with the whole stretch of mangrove belt depleted. As the coastline areas from the tip of Tanjung Piai to Sungai Perepat Pasir (northeast side of Tanjung Piai) were projected for future reclamation and development, these areas were excluded out of the selection of the settlement field location. Thus, the settlement field (the porous plates) were to be placed along the coastlines from Tanjung Piai towards Parit Che Uda area, the northwest side of Tanjung Piai (refer to Figure 45).

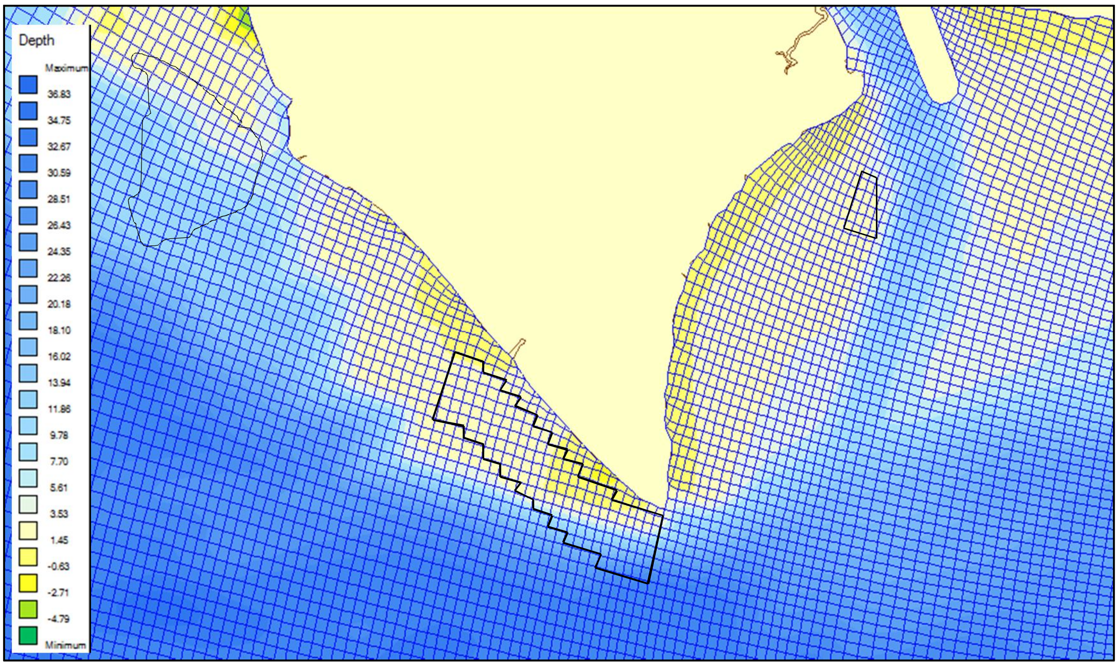


Figure 45 Location of settlement field/porous plates (areas marked in black)

The settlement field layout as described in chapter 2 was simplified in this model. Four grid cells were fenced up with porous plates to represent the 400m square main compartment of the settlement field. The porous plates were placed around the grid cells, spaced at around 150m to 200m apart, extending from water surface to the bed. The varying porous plates spacing was due to limitation of grid generation as it was very difficult to normalise the grid cells sizes in the curvilinear grid. Soil dams and ditches which were used to divide the main compartment into smaller 100m square subfield were left out as limited by the grid cells sizes. As selected from the 3D channel test cases, friction coefficient of 1, 2 and 10 were applied as the input for the porous plates in the models.

4 different simulations were established for the finalised nested model for sediment sizes of 65μm. Case 1 was the simulation without porous plate which was used as base reference; case 2 was the simulation with porous plate for friction coefficient of 1; case 3 was for the simulation with porous plate for friction coefficient of 2; and case 4 was for the simulation with porous plate for friction coefficient of 10. The results and analysis were presented in the next chapter.

6 ANALYSIS RESULT AND DISCUSSION

6.1 Erosion problem at Tanjung Piai

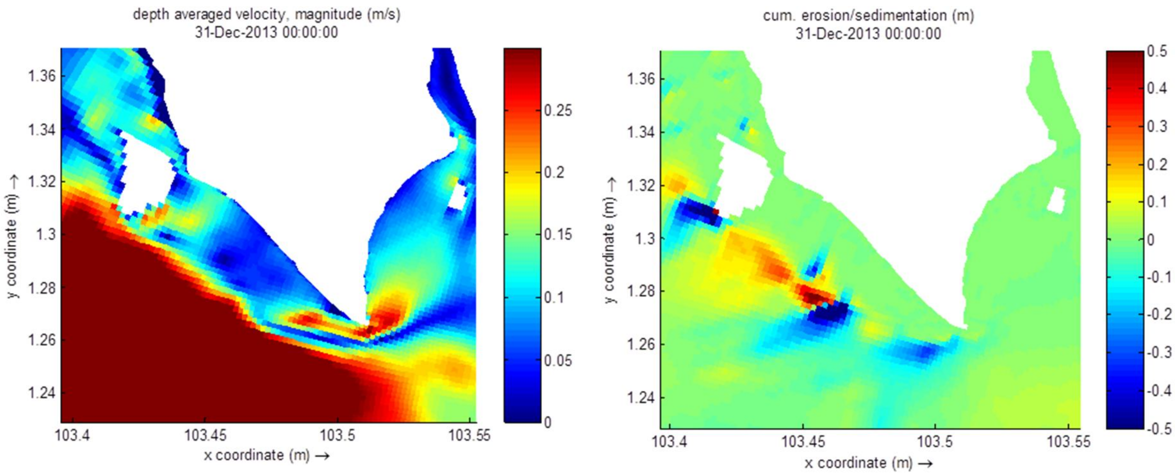


Figure 46 Analysis result. Left: depth-averaged velocity around Tanjung Piai area. Right: Cum erosion/sedimentation around Tanjung Piai.

As discussed in chapter 3, Tanjung Piai coastlines are seriously eroded over years; the existing mangrove forest at the areas located between Parit Che Uda to Sungai Perepat Pasir (the areas around the tip) has depleted due to the extreme erosion and damage by the tidal surges, swift currents and storms. The finding from the simulations is consistent with the situation (refer to the right diagram of Figure 46 where the eroded areas were marked with blue colours). Located at the junction of Malacca Strait, Johor Strait and Singapore Strait, Tanjung Piai tip is susceptible to swift currents (refer to the left diagram of Figure 46 for the areas marked with red colour). The swift currents are one of the main reason contributing to the serious coastal erosion and mangrove forest depletion problems at Tanjung Piai. Kukup Island from the south eastern part to the whole of the western part of the island has the similar problem in which the mangrove forest along the coastlines is disappearing fast due to the erosion caused by the swift currents.

Referring to the cum erosion/sedimentation diagram, no sign of serious erosion was observed at the near-shore areas along the coastlines; contrary sedimentation was seen. However, from the literature finding, the areas from Tanjung Piai to Sungai Perepat Pasir (the coastlines near to Sungai Pulai/Tanjung Pelepas port) are seriously eroded. This showed that sediment budget plays a role in coastal erosion problem. The maintenance dredging from the nearby Tanjung Pelepas port may have greatly reduced the existing sediment supply to the coastlines.

6.2 Results for model with sediment size of 65μm: with and without settlement field

The possibility of the settlement field being built to assist the restoration effort of the mangrove forest would be explored in this section of the report. 4 different simulations were run with the finalised nested model for sediment sizes of 65μm. Case 1 was the simulation without porous plate which was used as base reference; case 2 was the simulation with porous plate for friction coefficient of 1; case 3 was for the simulation with porous plate for friction coefficient of 2; and case 4 was for the simulation with porous plate for friction coefficient of 10. The results obtained from the modelling were compared and summarised herewith. The result section was divided into sub-heading based on comparison of depth averaged velocities and bed level changes for cases with and without the settlement field.

The cross sections as shown in Figure 45 were used to elaborate the findings:

1) Sec 01: cross sections along gridline m=73
2) Sec 02: cross sections along gridline n=71

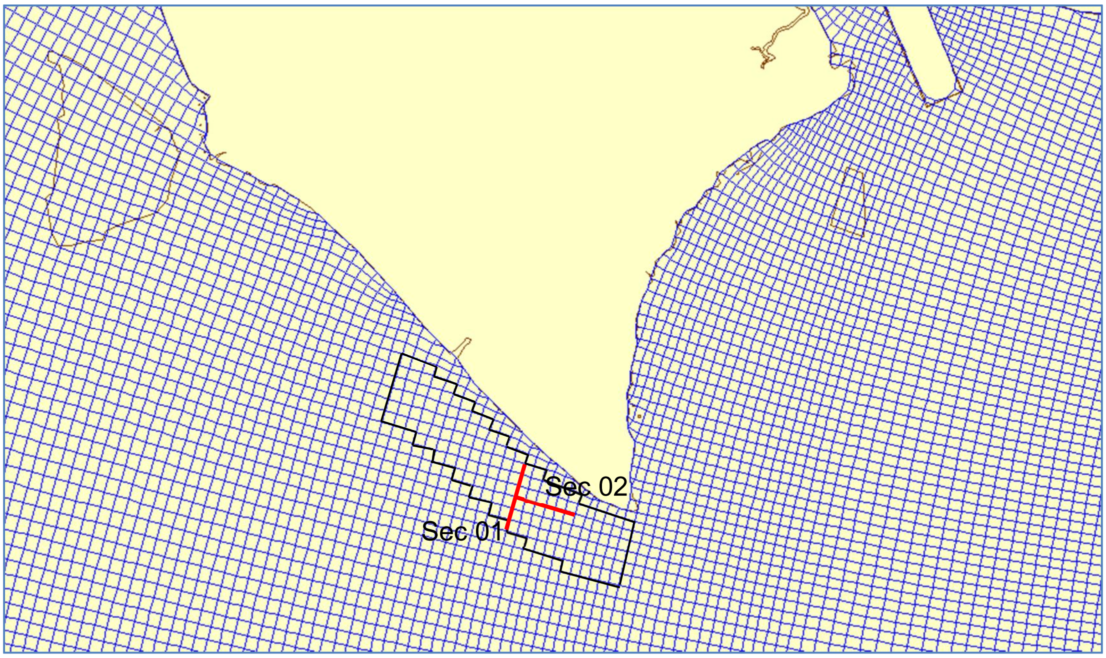


Figure 47 Location of settlement field/porous plates (areas marked in black) and observation sections

6.2.1 Velocities

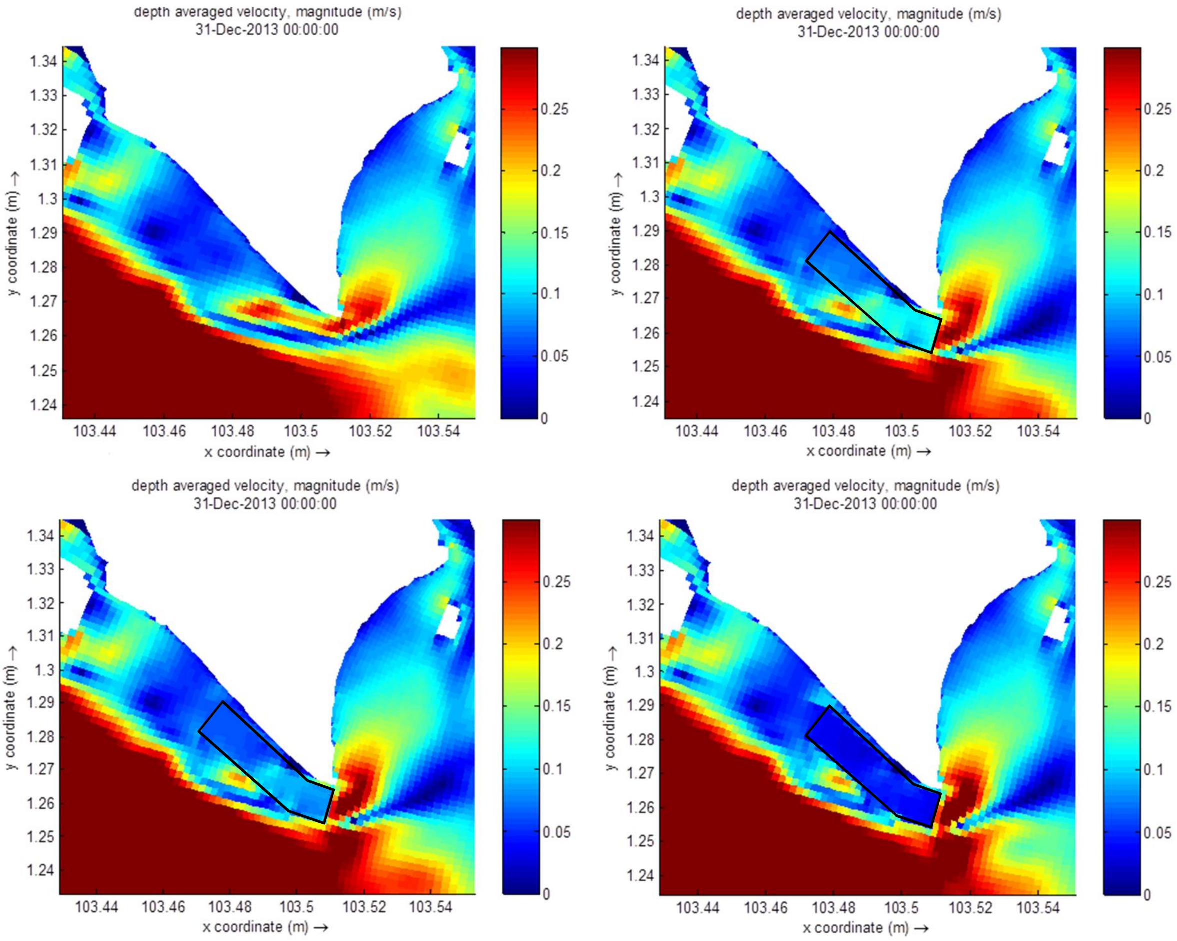


Figure 48 Depth-averaged velocity around the Tanjung Piai area. Top left: case 1, simulation without porous plate which was used as base reference. Top right: case 2, simulation with porous plate for friction coefficient of 1. Bottom left: case 3, simulation with porous plate for friction coefficient of 2. Bottom right: case 4, simulation with porous plate for friction coefficient of 10. (Black lines indicate the settlement field fenced up with porous plates)

Referring to Figure 48, the simulations accorded with the hypothesis; the porous plates (representing the temporary breakwaters of the settlement field) would affect the seawater velocity around the areas. The flow velocity within the settlement field was greatly reduced. With the addition of porous plates with friction coefficient of 1 (as in case 2), the velocity around the southernmost tip (within the settlement field) was reduced by approximately 2 times, from ~0.25m/s to ~0.125m/s. It could be seen from the figures at the Top left and the Top right where the higher magnitude represented by red colour in the figure at the Top left was replaced by lower magnitude cyan colour in the figure at the Top right. When the plate porosity was reduced, in which the porous plate coefficient value was increased to 2 (as in case 3) and to 10 (as in case 4), the water velocity within the settlement field was even lower. The porous plate works well in reducing the water velocity at the lee side which is beneficial for sediment deposition process. The percentage of flow velocity reduction depends on the plate porosity, in turn denoting to the layout of the temporary breakwaters (the spacing within bamboo poles and the stones distribution and compactness held within the two rows of bamboo poles).

6.2.2 Bed level changes

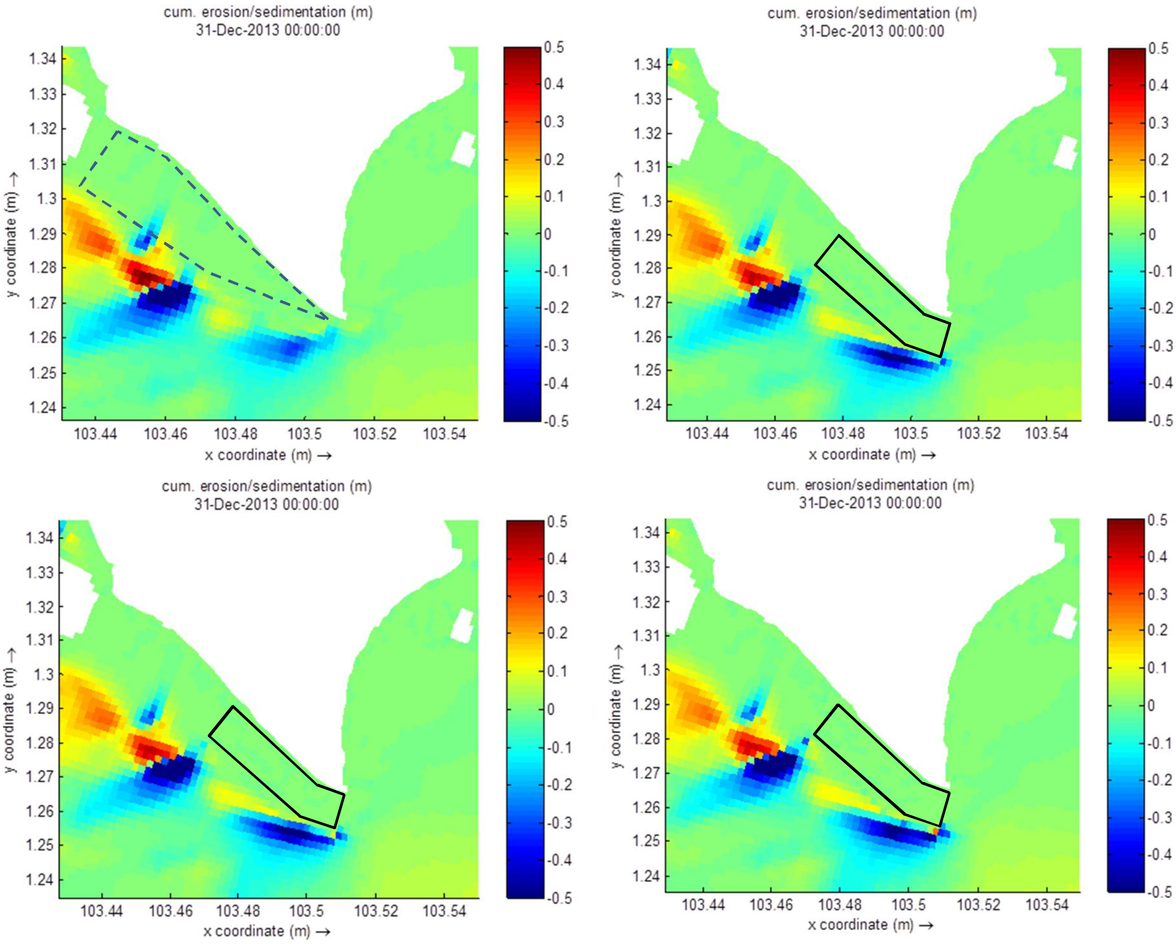
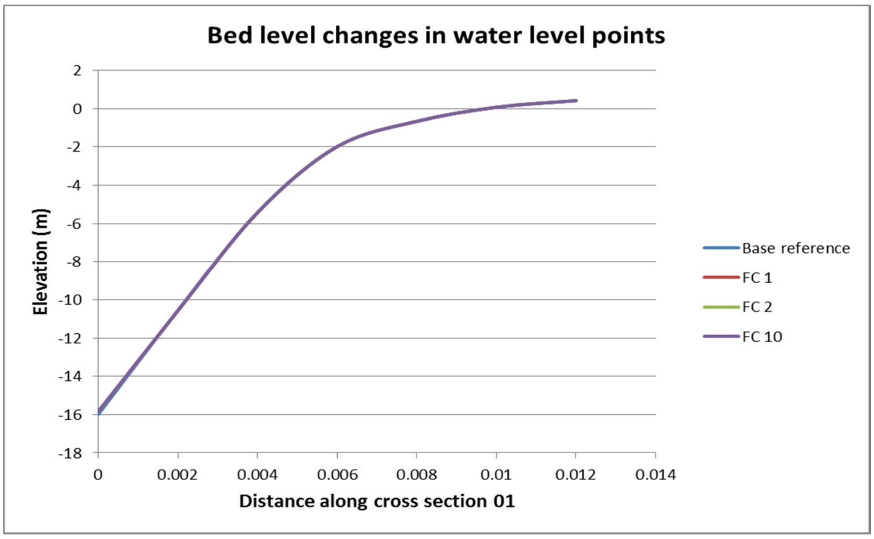


Figure 49 Cum erosion/sedimentation around the Tanjung Piai area. Top left: case 1, simulation without porous plate which was used as base reference. Top right: case 2, simulation with porous plate for friction coefficient of 1. Bottom left: case 3, simulation with porous plate for friction coefficient of 2. Bottom right: case 4, simulation with porous plate for friction coefficient of 10. (Black lines indicate the settlement field fenced up with porous plates)

Referring to the Top left figure of Figure 48 and Figure 49, the figures showed that the region circled up with dashed line is rather calm with low flow velocity. There was sedimentation even without the addition of settlement field as the region was protected within Kukup Island and Tanjung Piai. Although the sedimentation magnitude was very small, the sedimentation still could be observed by the light yellow colour. The region is favourable for sediment accretion process, with the proviso that there is sediment supplied to the inshore.

Comparing the remaining three figures with the additional settlement field at Tanjung Piai area, the sedimentation rate inside the settlement field area appeared similar with only slight increment in sedimentation. This was probably due to the low flow velocity at the region; the sediment deposited offshore was not able to be moved coastward. In addition, there was the lack of sediment reaching the region as only a virtual layer of sediment at bed was assumed in the model; no sediment source from river discharges or main land erosion was taken into account due to the shortage of relevant data. The settlement field has not able to trap in more sediment as limited by the sediment supply. Besides, the sediment deposition is pretty much time-dependant, it may take years to top up the bed level. Nevertheless, the sedimentation rate right before the settlement field did increased.

Sections as shown in Figure 45 were used to further examine the sedimentation within the settlement field. The cross sections were plotted as in Figure 50. The bed level changes in those two sections were not obvious too as the magnitude was very small as mentioned before.



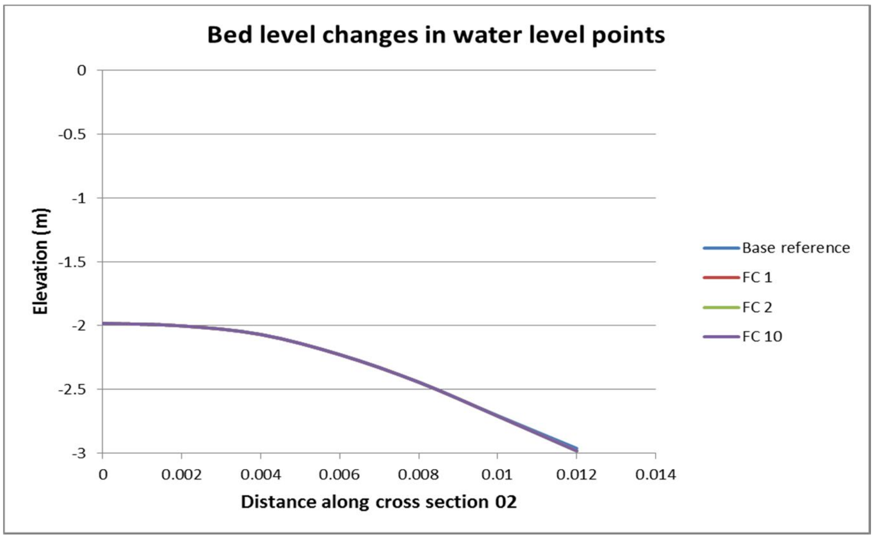


Figure 50 Bed level changes in water level points along cross sections 1 & 2 for case 1 to case 4. Top: cross section 1. Bottom: cross section 2.

6.3 Scenarios

As the velocity at the settlement field region was low, there was no much local scouring near shore and no much sediment being transported towards the region to be trapped and deposited within the settlement field. This result can be attributed to the sediment supply from the rivers not being included in the model as there was no available data on the sediment sources and quantities in the region to be used as input or for validation purpose. In reality, the sediment would be supplied from the seabed and from the sediment brought along by the river discharges.

An additional model simulation was carried out with sediment concentration placed at the nearby Sungai Pulai as the supply source. The existing sediments from the river are no longer feeding the mud flats along Nusajaya (a rapid developing town located in close proximity to Port of Tanjung Pelepas at Sungai Pulai river mouth) as the mud flats and the mangrove forest along the coast are disappearing fast due to the rapid urbanisation. This existing sediment budget from the river and the additional sediment eroded from the mud flats will be transported to somewhere else, in which this was represented as the sediment discharge or source at Sungai Pulai in the model.

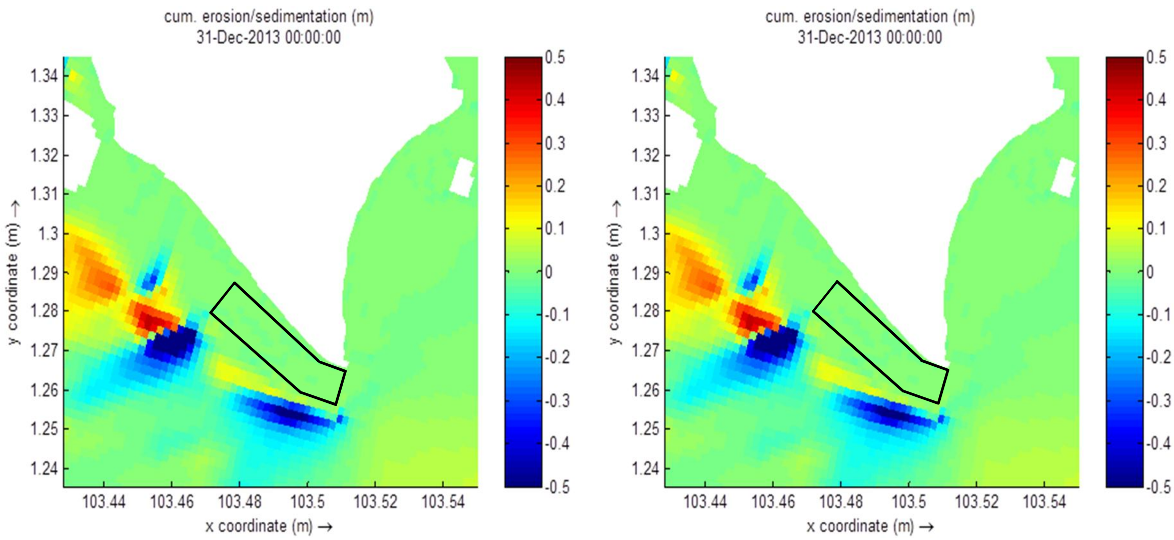


Figure 51 Cum erosion/sedimentation around the Tanjung Piai area. Left: case 1, simulation with porous plate for friction coefficient of 1. Right: simulation with porous plate for friction coefficient of 1 with additional sediment discharge at Sungai Pulai.

Comparing the figure with the additional sediment discharge, the sedimentation rate inside the settlement field area appeared similar with only slight increment in sedimentation. As mentioned, the sediment deposition is time-dependant and it may take years to top up the bed level. In addition, it requires adequate sediment supply and appropriate hydrodynamic conditions; inclusion of wave-current interaction in the model may have different effect on the results obtained. In this test scenario, the sediment discharged at Sungai Pulai may not have reached the area or the quantities applied might be too little to affect the erosion and sedimentation pattern at the study area. The input selection of physical processes and physical parameters for sediment are essential in producing an accurate model.

7 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The research objectives were translated to the following questions:

- What are the main causes of Tanjung Piai coastal erosion and mangrove depletion problems?
- Is settlement field with temporary breakwater a feasible method of mangrove forest restoration along Tanjung Piai coastline?

The results analysis of the models provides a base to answering the questions.

Tanjung Piai is located at the junction of Malacca strait, Johor Strait and Singapore Strait where the hydrodynamic condition is highly complex due to the influences of Andaman Sea and South China Sea. Located at the tip, Tanjung Piai tip is susceptible to swift currents. The swift currents are one of the main reason contributing to the serious coastal erosion and mangrove forest depletion problems at Tanjung Piai. The existing mangrove forest at the areas located between Parit Che Uda to Sungai Perepat Pasir are seriously depleted (the areas around the tip where the flow velocity is high). Besides swift currents, sediment shortage is one of reason contributing to coastal erosion problem. On the other hand, the near-shore flow velocity along the coastlines from Kukup to Tanjung Piai is calm. Sediment accretion is observed along the coastlines. The analysis of the depth-averaged velocity and the erosion/sedimentation pattern supports the earlier literature finding.

The porous plate function works well in representing the temporary breakwater for the settlement field. The porosity of the plate affects the velocity and energy dissipation which will then affects the deposition rate at its lee side. Despite the lack of sedimentation data for validation and calibration, the sedimentation hypothesis analysis is still useful in giving the estimation of the erosion and sedimentation pattern at the study area. From the test cases, it is proven that the settlement field (made of porous plate) is capable of capturing the sediment within the contained areas. The sedimentation rate is depended on the porous plate porosity, the flow velocity and the sediment sizes. When the settlement field was applied in the nested model, the increment of sedimentation rate within the contained areas was very little to be able to see clearly the difference with the base reference case. Inclusion of rivers discharges, sediment concentration parameters and wave-current interaction in the model is vital in refining the model in order to give a more accurate result. Wave parameters was not included in the model initially as the region was tide-dominated; however from the scenario testing, it showed that wave-current interaction should be considered in.

The selection of coastal management method is influenced by the consideration of the construction cost. At present, geotextile tubes breakwaters were applied on site. Construction cost of geotextile tubes breakwaters were influenced by the availability of suppliers and equipment or machinery, distance of materials from the installation site and the maintenance requirement. The cost for the geotextile tubes breakwaters at Tanjung Piai was approximately USD 700,000 per kilometre which was about RM 2,226,000, based on the exchange rate used for July 2014 (1 USD = RM 3.18). The construction cost of the geotextile tubes breakwaters at Tanjung Piai was higher as compared to other countries like Vietnam with USD 300,000 per kilometre, due to the lack of suppliers and equipment. Besides, the purchase of the tube in-filled materials from the dredging operations over 100km away from the site which required state permits and royalties payment to the source state has topped up the construction cost and made it economically unfavourable. (Lee, S.C., Hashim,R., Motamedi,S. & Song,K.I., 2014; Isaac, L., Howard, M., Trainer, E. & Tack, W.Y., 2012)

In view of the above, settlement field with temporary breakwater is a feasible method of mangrove forest restoration along Tanjung Piai coastline as the hydrodynamic conditions near-shore is calm. Besides, the construction materials are locally available; and the construction and maintenance of the temporary breakwater are straight forward. However, the site selection of the settlement field and the layout of the temporary breakwaters should be analysed and its performance should be tested in experiments.

7.2 Recommendations

Due to data limitations and software computational time and memory restrictions, a few assumptions were made, which may limit the analysis results. The model could be improved by tackling the limitations and restrictions. To begin with, the grid resolution could be increased to better capture the bottom changes and to enable an even more detailed settlement field set-up with earth bunds and drainage included in. The smallest grid size in the nested model around the study area is about 150x150m as to keep the computational time within the practical limit; the existing model run is within 5 days with an 8-cores computer. With the higher capacity computer backup, the grid size might be reduced to 100x100m or even smaller as 10x10m.

The validation of the model is difficult due to the lack of field data of sediment sources and sediment distribution. To produce an accurate and reliable hydrodynamic and sediment transport model for Tanjung Piai area, a more detailed study with up-to-date bathymetry survey should include the bed type mapping and surficial sediment sampling at the study areas to be used as the boundary conditions for model calibrations and validations. Sea bed type mapping and sampling are important in defining the sediment grain size distribution. Study regarding the sediment sources and quantities within Tanjung Piai catchment areas can be carried out too to establish the sedimentation and erosion rates and to determine the effect of land use changes within the catchment areas. The results of these measurements and samplings are of significance for defining the performance of the model.

In the nested model a number of runs are made in which the temporary breakwater of the settlement field is represented by porous plate with different friction coefficients. Representation of the temporary breakwater in this way could provide reasonable results if the porous plate friction coefficient is validated and calibrated well. Laboratory experiments or on-site testing with measurement should be made to cross check the computational results to validate and calibrate the porous plate friction coefficient used. The location and configuration of the temporary breakwaters could be adjusted and tested to get the best result.

In addition, improvements to this study can be made with inclusion of wind and wave in the hydrodynamic model to account for the interaction between tides and waves although tides dominate the region; and the inclusion of the effect from the shipping traffic to the nearby Tanjung Pelepas Port. The model could be run for a longer period (for example 2 years) with the inclusion of the multiplication factor on the morphological settings to evaluate the long-term changes. These different settings may have different impact on the sediment transport and additional studies on these parts are required.

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