ANALYSIS OF COASTAL EROSION
AT MIRI CRUDE OIL TERMINAL

by

Mohd Najib Bin Wan Chek

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

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

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ABSTRACT

Miri Crude Oil Terminal (MCOT) is located at Miri Coastline in Sarawak. MCOT is operated by PETRONAS Carigali Sdn. Bhd., Sarawak Operations. It provides facilities to store crude oil form offshore platforms and then will be transported to refinery plant via vessels. Coastal erosion occurs along Miri-Kuala Baram coastline; hence the water margin is retreating to the mainland and affecting stability of MCOT facilities. Timber logs and debris drift to the shore and become a threat to the pipelines and facilities along the coast. This research presents numerical modeling for analysis of coastal erosion problem at MCOT using MIKE 21 and LITPACK. The coastline is subjected to longshore erosion due to currents action during High Water. In this research, the suitability of coastal protection that can incorporate risk and uncertainty as well as evaluate tradeoffs between risk and economic returns are explored. A series of Groynes are recommended to be constructed perpendicular to the shoreline to trap littoral drift and stabilize the coast. A rock bund is proposed for protection against timber logs and debris. Beach nourishment is to replace the sediment on the beach which is lost through littoral drift. This combination system will cost RM 23 Million mainly for Detailed Engineering Design and Construction; however it will provide long term solution to this coastal erosion problem.

ACKNOWLEDGEMENTS

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ABBREVIATIONS

ACD	Above Chart Datum
DHI	Danish Hydraulic Institute
DID	Drainage and Irrigation Department
DOE	Department of Environment
EIA	Environmental Impact Assessment
g	Wave Direction
GPAF	Gas Receiving Facilities
H	Wave Height
HD	Hydrodynamic
ICZM	Integrated Coastal Zone Management
MCOT	Miri Crude Oil Terminal
NCDC	National Climatic Data Centre
NCES	National Coastal Erosion Study
NORF	New Oil Receiving Facilities
NSW	Nearshore Waves
PCSB	PETRONAS Carigali Sdn, Bhd.
PMS	Parabolic Mild Slope
PWD	Public Work Department
SKO	Sarawak Operations
SSMO	Synoptic Meteorological Observations
ST	Sediment Transport

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

MCOT is located between Kuala Baram – Miri coastline and operated by PETRONAS Carigali Sdn. Bhd., Sarawak Operations (PCSB-SKO). MCOT beachfront area has been subjected to extensive erosion over the last several years which caused hazards to the existing assets and facilities located along the beach. The purpose of this research is to gather the data and samples, to investigate the causes of the erosion, and to develop Numerical model using MIKE 21. In this research, the suitability of appropriate Shore protection work is explored to meet the technical and economical criteria. Lastly, to explore the range of understanding of coastal planning and management for shoreline stabilization projects.

1.2 PROBLEM STATEMENT

The water margin over the last years retreated further inland, hence exposed the pipelines with threats of timber logs and debris. These objects wash up to the beach by waves and tides where it will pile up near to the pipelines [Figure 1.1]. Structures along the shore will be undermined as the beach area is in active zone where the soil strength is reduced [Figure 1.2].

1.3 OBJECTIVES

To carry out conceptual study to determine the most effective and economical shore protection works.

Figure 1.1 Timber logs piling up on pipelines

Figure 1.2 Pipelines support is in active zone

1.4 SCOPE OF STUDY

- To perform risk hazard assessment and handling of coastal erosion.
- To develop a numerical model of the coastal processes using MIKE 21 and LITPACK.
- To evaluate different types of coastal protection.
- To develop a plan for coastal management.

CHAPTER 2
LITERATURE REVIEW

2.1 COASTAL EROSION: AN OVERVIEW

In recent years coastal erosion has resulted in damage and loss of agriculture land, mangrove forests, house, roads and recreation beaches. In must cases erosion occurs due to natural causes but there are cases of erosion due to interference of nature by man. The National Coastal Erosion Study, 1985 has found that 1,300 km out of 4,800 km of the Malaysian coastline is eroding (Ghazali, 2005).

2.2 THE COASTAL ENVIRONMENT

The shoreline is defined as the boundary between the land surface and the surface of a water body such as ocean, sea or lake. The coastal zone is that area of land and water that borders the shoreline and extends sufficiently landward and seaward to encompass the areas where processes important to the shore area are active.

The land portion of most of the Malaysia's coastal zone consists of sandy beaches. In some places, the beach is covered with coarser stones known as shingle. Where wave and current action is relatively mild and a river provides large deposits of sediment, a delta may form and extend seaward of the general trend of the shoreline. In some places, there is a break in the shoreline to produce an estuary or inlet to a Back Bay area where the estuary or inlet being maintained by river and/or tide induced flow. Also, some coast may be fronted by steep cliffs that may or may not have a small beach at their toe. Since sandy beaches predominate and have very dynamic and interesting characteristics, this type of coastline will receive the greatest emphasis herein.

Waves are the dominant active phenomenon in the coastal zone. Most apparent and significant are the waves generated by wind. Second in importance is the astronomical tide, which is a wave generated by the gravitational attraction of the sun and moon. Other waves, which on the whole are less important but that may have important consequences in some places, are seismically generated waves (tsunamis) and waves generated by moving vessels.

The wind and related atmospheric pressure gradient will generate a storm surge-the piling up of water along the coast when the wind blows in an onshore direction. This raised water level can cause damage by flooding and it allows waves to attack the coast further inland. The wind will generate currents that move along the coast. Coastal currents are also generated by the tide as it propagates along the coast and alternately floods and ebbs through an inlet or into an estuary. Further, the wind has direct consequences on the shore by moving sand and causing structural damage.

Wind wave action causes the most significant changes to a beach. The shore-normal beach profile changes as sand is carried offshore and back onshore over a period of time. In many locations large volumes of sand are also carried along the shore by the action of waves that obliquely approach the shore. Currents effects often dominate at the entrances to bays and estuaries where higher flow velocities develop.

At present the transport mechanism of sand sediment under the influence of waves and currents is better understood than the transport of clay and silt sediments. This is due to the fact that research in coastal engineering has generally been concentrated on the problems in sandy shores. The clay-silt soil and sandy soil that make up most of the Malaysian coast respond differently to the actions of waves and current. Once mobilized, the clay and silt particles are suspended in the water column and are more easily transported (by longshore and other currents) as compared to the heavier sand particles. Deposition of clay-silt materials is not only influenced by waves and current but also by water salinity, temperature and density differences.

2.3 COASTAL ENGINEERING

Attempts to solve some coastal zone problems such as beach erosion and the functional and structural design of harbors dated back many centuries. Bruun (1972) discusses early coastal erosion and flooding control activities in Holland, England, and Denmark in a review of coastal defense works as they have developed since the tenth century. Inman (1974), from a study of early harbors around the Mediterranean sea, found that harbors demonstrating a superior understanding of waves and currents, which led to development of remarkable concepts in working with natural forces were constructed as early as 1000-2000B.C.

Coastal Engineering is primarily a branch of Civil Engineering which leans heavily on the sciences of oceanography, meteorology, fluid mechanics, structural mechanics, and others. Among the others one could include geology and geomorphology, numerical and statistical analysis, chemistry, and material science.

Areas of concern to coastal engineers are demonstrated by the following list of typical coastal engineering activities:

- Development (through measurement and hindcasts) of nearshore wave, current and water level design conditions.
- Design of variety of stable, effective and economic coastal structures including breakwaters, jetties, groins, revetments, seawalls, piers, offshore towers, and marine pipelines.
- Control of beach erosion by the design of coastal structures and/or by the artificial nourishment of beaches.
- Stabilization of entrances for navigation and water exchange by dredging, construction of structures, and the mechanical bypassing of sediment trapped at the entrances.
- Prediction of inlet and estuary currents and water levels and their effect on channel stability and water quality.
- Development of works to protect coastal areas from inundation by storm surge and tsunamis.

- Functional and structural design of harbors and marinas and their appurtenances including quays, bulkheads, dolphins, piers, and mooring systems.
- Functional and structural design of offshore islands and dredge spoil disposal areas.
- Monitoring various coastal projects through a variety of measurements in the field.

A major source of support for coastal engineers is the available literature on past coastal engineering works along with the design guidance published in the textbook, manuals from government agencies (Drainage and Irrigation Department), and special studies conducted by university, government, and consulting firm personnel. Additional design tools generally fall into one of the following categories:

- Many aspects of coastal engineering analysis and design have a strong analytical foundation. This includes theories for the prediction of individual wave characteristics and the properties of wave spectra, for the calculation of wave-induced forces on structures, for the effect of structures on wave propagation, and for the prediction of tide-induced currents and water level changes.
- Many coastal engineering laboratories have two-and three-dimensional flumes in which monochromatic and spectral waves can be generated to study fundamental phenomena as well as the effects of waves in models of prototype situations. Examples of model studies include wave propagation toward the shore and into harbors, the stability of structures subjected to wave attack and the amount of wave overtopping and transmission that occurs at these structures, the response of beaches to wave attack, and the stability and morphological changes at coastal inlets owing to tidal flow and waves.
- Various computer models that numerically solve the basic wave, flow, and sediment transport equations have been developed. These include models for wind wave prediction, for the analysis of wave transformation from deep water to the nearshore zone, for the surge levels caused by storms, for the resonant

response of harbors and other water bodies to long period wave motion, and for the shoreline change caused by a given set of incident wave conditions.

- An invaluable tool for coastal engineers is the collection of data in the field. This includes measurements of wave conditions, current patterns, water levels, shore plan and profile changes, and wave-induced damage to structures. There is a great need for more post-construction monitoring of the performance of most types of coastal works. In addition, laboratory and numerical models require prototype data so that the models can be adequately calibrated and verified.

The wind wave and surge levels that most coastal works are ultimately exposed to are usually quite extreme. It is generally not economical to design for these conditions. The design often proceeds for some lesser wave and surge condition with the understanding that the structures will be repaired as needed.

2.4 DESIGN BASIS

2.4.1 Beach slope

Slopes should be determined above and below the waterline. The slope below waterline should be representative of the slope for a distance of at least 50 feet.

2.4.2 Offshore depth and wave parameter

Assuming that this area is highly sensitive and can not afford any damage from erosion due to the design for protection work has to be based on the higher wave height. This is still considered low when the effect of the impact by drifting logs and debris is taken into account.

2.4.3 Littoral transport

Erosion occurs when, over a period of time, the volume of sediment transported out is greater is greater than the transported into the coast (not in dynamic equilibrium). This is normally indicated by the formation of beach scarp along the coast. Erosion may be amplified during storm period when high water levels, result in waves breaking directly against the scarp, causing loss of material which might returned to the shore but in limited quantity.

2.4.4 Beach soil type

It is needed to determine the soil type to know the transportation of the particles along the shore. Excessive settlement and slip failure may ensue because the soil is unable to sustain the imposed pressure of any new constructed structure.

2.4.5 Adjacent shoreline and structures

The beach area where rock bund is built would not being affected by any new proposed coastal protection.

2.4.6 Legal Requirements

- ***General Circular No. 5 of 1987***

The General Circular No. 5 of 1987 dated 10 September 1987 was issued with the objective to reduce losses due to erosion and to eliminate the need to undertake expensive protection works in the future. It ensures that any consideration of the risk of erosion and the effects of the development on the coastal system. The construction of coastal structures which are groynes and bund as well as offshore activities such as mining sand for beach nourishment should be carefully planned so that it will not cause or aggravate erosion. To this end, all coastal protection must refer all plans for development in coastal areas to the Coastal Engineering Division (CED), Drainage and Irrigation Department (DID), for consideration.

- ***The Environmental Quality (Amendment) Act (1985),Environmental Impact Assessment Order (1987)***

For development activities in the coastal area, a report on the effects of the proposed development on the coastal system has to be included in the EIA. The EIA report prepared by the prospective developer will be evaluated by a panel which includes representatives of the Coastal Engineering Technical Centre.

- Environmental Quality Act, 1974

- Local Government Act, 1976
- Merchant Shipping Ordinance Sarawak, 1969
- Fisheries Act, 1985
- National Resources and Environmental Ordinance Sarawak, 1993
- The Sarawak Rivers (Cleanliness) Regulation, 1993
- Public Parks and Green Ordinance, 1993
- Water Ordinance, 1994
- Sarawak Biodiversity Centre Ordinance, 1997
- National Parks and Natural Reserves Ordinance, 1998
- Wildlife Protection Ordinance, 1998

2.5 SUMMARY

In this chapter, the earlier works related to Coastal Engineering is summarized. No study of the coastal erosion problem at MCOT area in Miri is reported in literature. Hence, this matter has been considered for research in the Final Year Project.

CHAPTER 3
METHODOLOGY

3.1 INTRODUCTION

A generic concept of Risk Handling & Natural Hazards developed in the early phase ensures generality to different administrative and political levels. The method includes the three interlinked segments of risk analysis, risk evaluation and risk management. A hazard determination is carried out for the different study areas on the coasts of Sarawak and Brunei on the basis of the given hydrological and morphological conditions. The expected damages can then be evaluated through an examination of different scenarios. The specific risk can be calculated for the different areas on the basis of a combination of occurrence probability and damages. Out of these results strategies and measures for preparedness and mitigation shall be diverted in the frame of subsequent risk management. The methodology is useful for both disaster planning and recovery.

3.1.1 Scale

For risk handling in the frame of natural hazard research, level and scale of assessment have to be determined. Three levels can be distinguished; Macro, Meso and Micro- scale [Table 3.1].

Table 3.1 Assessment level

Assessment level	**Macro – scale**	**Meso – scale**	**Micro – scale**
Regarding level	(Inter-) national	Regional	Local
Decision level	(Inter-) national	Coastal defence schemes	Defence measure
Investigation level	Malaysia Coast	Coast of Sarawak	MCOT
Examples	NCES (1984-1986)	ICZM, Sarawak	Miri – Kuala Baram

Macro-scale studies are used for nationwide investigation areas. At this level, political goals and general guiding principles for decision are derived. The Intergovernmental Panel of Coastal Engineering Division, Drainage and Irrigation Department initiated the first vulnerability study on the macro-scale. The objective of this screening approach was to determine the socio-economic and environmental values existing within the countries which could become affected by coastal erosion. More than 70% of the population lives within the coastal area and a lot of economic activities such as urbanization, agriculture, recreation and eco-tourism, fisheries, aquaculture and oil and gas exploration are situated in the area.

Meso-scale methods are applied on regional scales. Due to the comparatively large study area, macro- and meso-scale studies are based on aggregated data. The results are therefore not well suited to generate specific coastal defence measures. The main objective of macro- and meso-scale studies is the development of long-term strategies. In Sarawak more than 80% of the population live along the 800 km coastline, the size and shape of which is constantly changing. An example for the meso-scale level is Coastal Erosion Report in Sarawak (Kee, 2000). In this study, the overall damage potential and mitigation measures for the erosion endangered coastal areas of Sarawak was determined.

Micro-scale studies are focused at local area level and thereby on all the potentially vulnerable objects such as buildings and pipelines in a coastal prone area. Analysis for such small areas can be achieving a high level of precision and accuracy.

3.2 RISK HANDLING AND NATURAL HAZARDS

Figure 3.1 outline the overall methodology for this research. The methodology is divided into three segments – Risk Analysis, Risk Evaluation and Risk Management.

3.2.1 Risk Analysis

Specific risks are determined through risk analysis. Risk analysis involves both the assessment/determination of hazard and of the vulnerability [Figure 3.2]. The hazard determination estimates the probability of erosion. The objective of the vulnerability assessment is to calculate the potential damages and costs of disastrous coastal erosion on the basis of the determined overall damage potential. The specific risk is finally computed through the risk assessment by multiplying vulnerability (damages) and hazard (coastal erosion rate). Specific risk must be carried out for individual coastal segments according to the given standards of coastal defense.

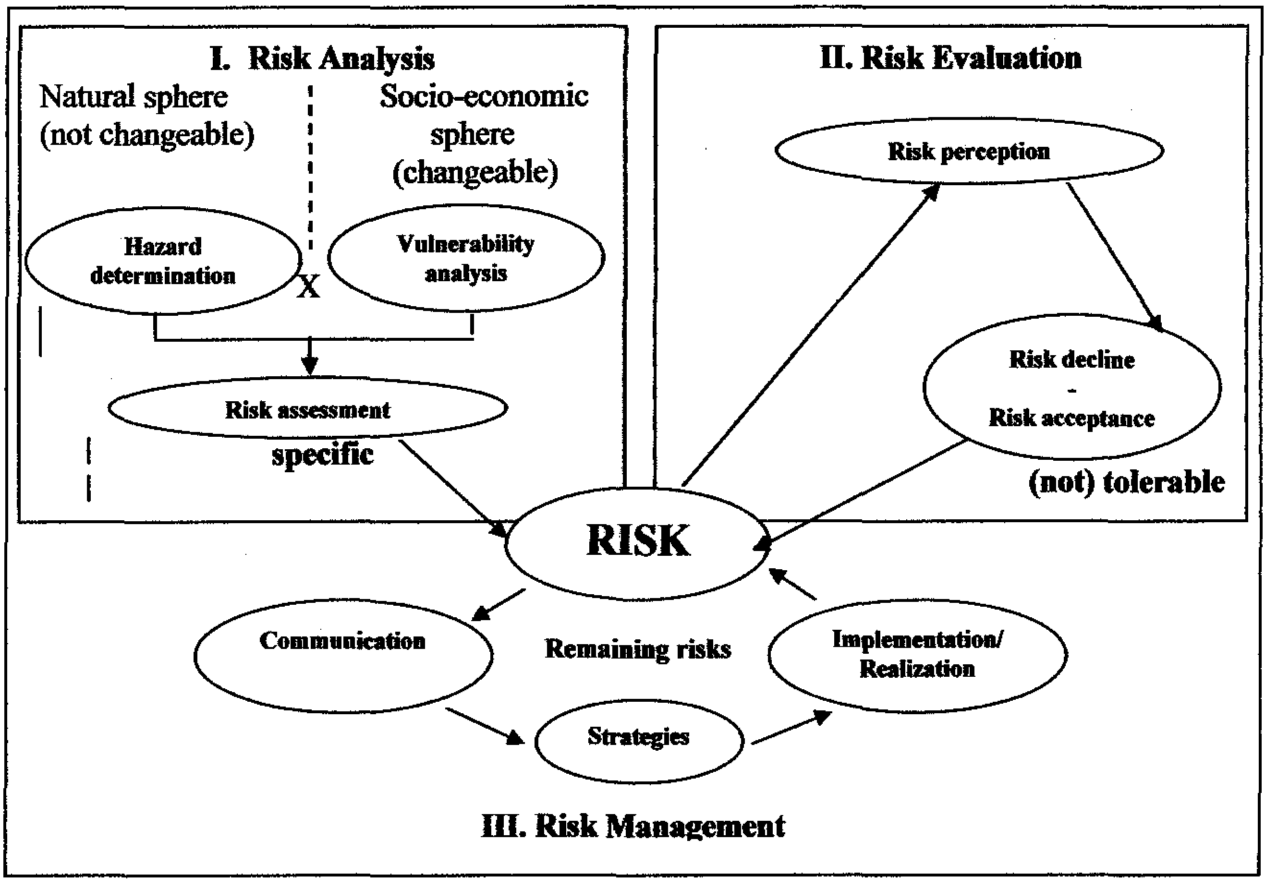

Figure 3.1 Risk Handling & Natural Hazards

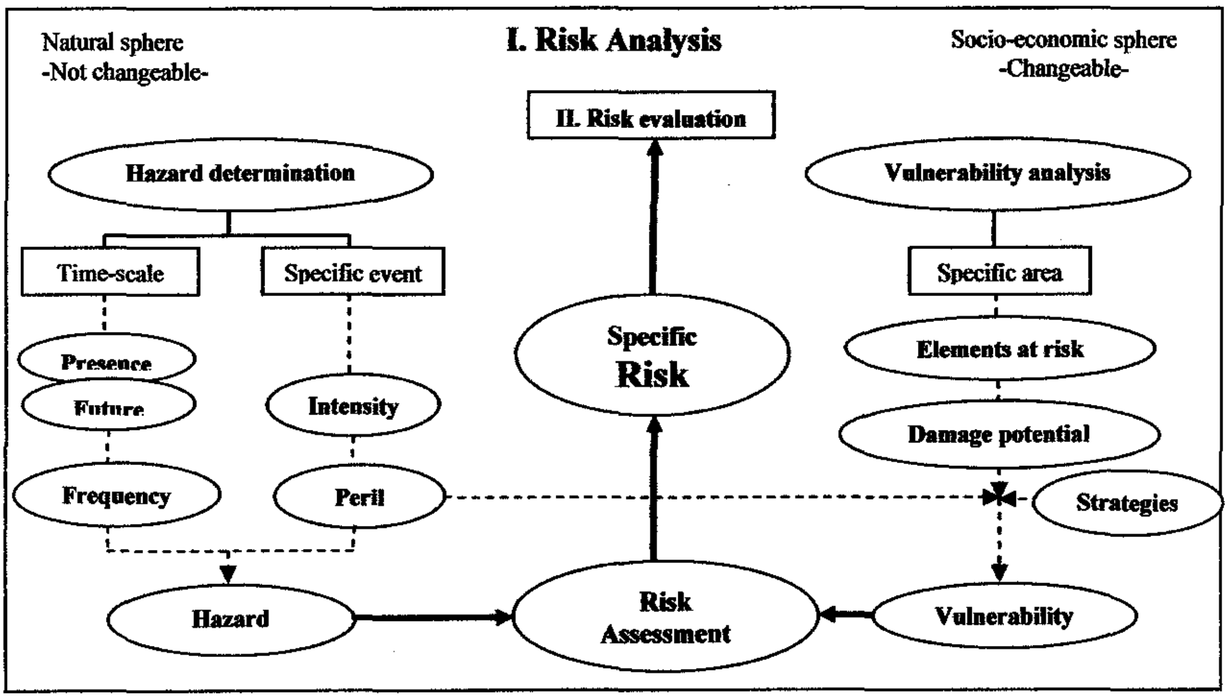

Figure 3.2 Risk Analysis

3.2.2 Risk Evaluation

The specific coastal risk determined from the previous analytical approach leads to the subsequent step of risk evaluation [Figure 3.3]. The objective here is to study the public risk perception, which might be different, depending on the stakeholders' interest, experience and awareness. The stakeholders' decision of risk acceptance or decline leads to a division of risk, into tolerable respectively not tolerable risk.

3.2.3 Risk Management

Based on the parameters determined from risk analysis and risk evaluation, the handling of risk can be facilitated using a risk management tool or procedure [Figure 3.4]. Within the scope of network all involved actors and stakeholders define their own objectives but also try to deduce common visions for their coastal facilities. From the evolving short-term goals and long-term strategies, specific options for preparedness and mitigation can be developed. After successful implementation, continued monitoring enables the control of the remaining risk against changing condition (e.g. change in storminess).

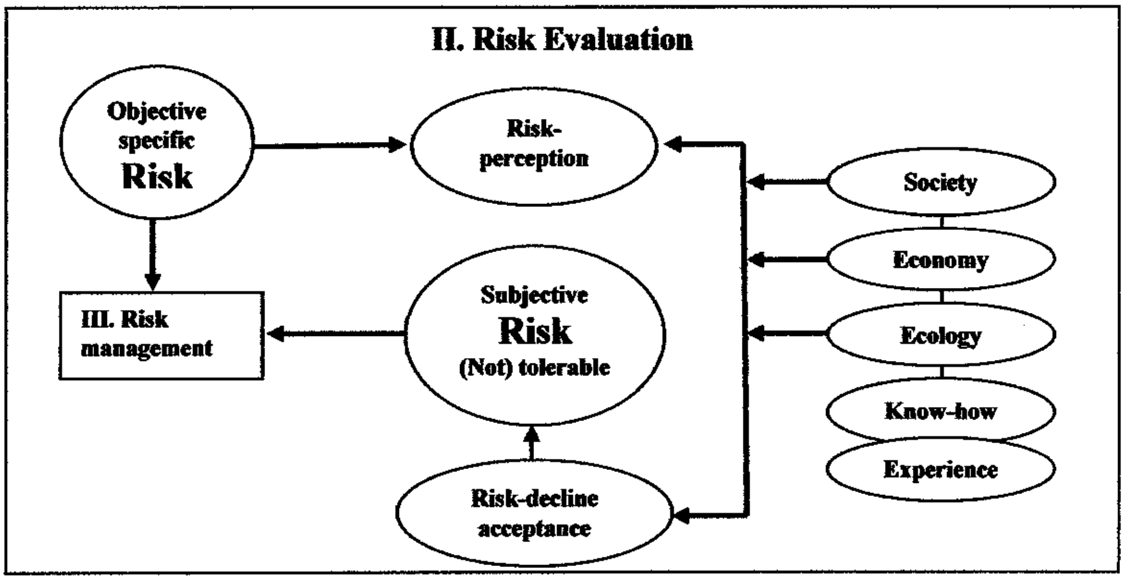

Figure 3.3 Risk Evaluation

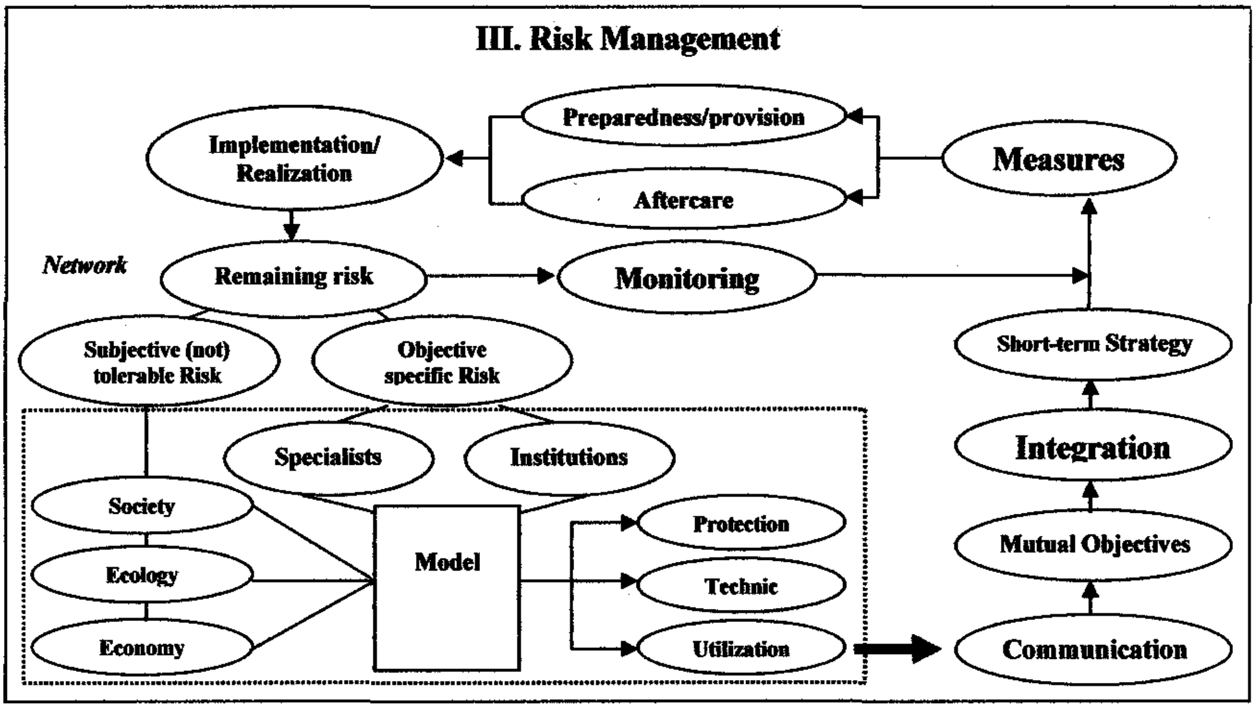

Figure 3.4 Risk Management

3.3 PROJECT RESEARCH

Project Structure

The Structure of the project is based on the concept "Risk Handling & Natural Hazards" as illustrated in Section 3.2. The following segments are part of the project program:

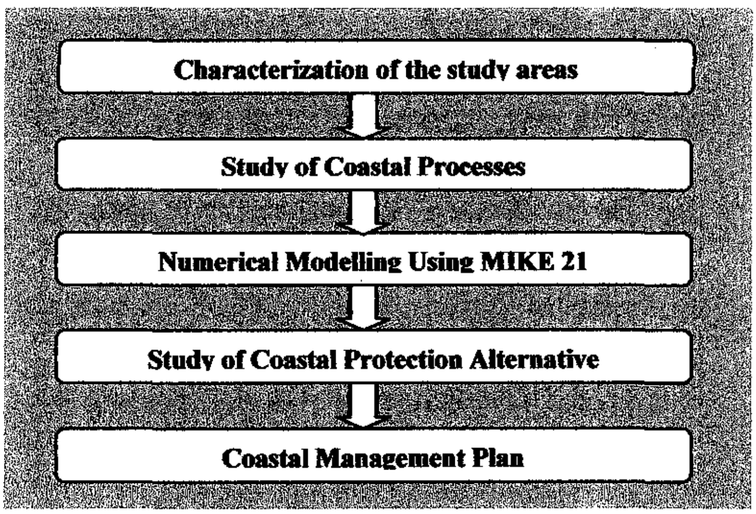

Figure 3.5 Project Structure

3.4 COASTAL MODELLING SYSTEMS

Numerical modeling tools are being increasingly used as support tools to Integrated Coastal Zone Management (ICZM), as their capabilities to simulate the complex processes underlying e.g. coastal erosion increase. These tools comprise:

- Littoral drift models suited for relatively uniform sandy beaches, which, given proper input on variability of the wave conditions along the shore and with time, cast light over the large scale shoreline developments
- 2-dimensional (in plan) wave and hydrodynamic models for the detailed study of waves and flow fields on complex bathymetries and in the vicinity of coastal structures
- Quasi 3-dimensional models for sediment transport
- Coastal profile morphological models
- Coastal area morphological modeling tools to appraise the short- to medium-term morphological response of the coast to e.g. coastal structures, harbors, shore-face nourishments, etc.
- Models for direct simulation of processes close to structures responsible for local scour

In this present paper, examples of the application of some of the above mentioned modeling tools are presented. It is demonstrated how the results from the numerical modeling tools can support the management of critical stretches of shorelines. The modeling tools are developed at Danish Hydraulic Institute (DHI) and comprise LITPACK and various modules of MIKE 21 (A modelling system for Estuaries, Coastal Waters and Seas).

LITPACK is a complex of modules for the simulation of wave transformation, longshore wave driven currents, longshore and cross-shore sediment transport, shoreline evolution and coastal profile evolution. The bed contours are assumed to be parallel and quasi-uniform in the longshore direction and the waves and currents are considered to be quasi-stationary. These two basic assumptions limit the use of tool to cases of long and uniform sandy beaches and cases where the shoreline evolution is the result of the overall gradients in the longshore sediment transport capacity. On the other hand, due to these assumptions, long coastal stretches can be covered over long time spans. The modeling complex, LITPACK, is based on Diegaard et al. (1986).

MIKE 21 consists of a series of modules capable of simulating different wave-related, current and sedimentological processes. The following modules are relevant for coastal morphological studies:

Wave modules. The two modules most commonly used are (i) MIKE 21 PMS and (ii) MIKE 21 NSW. MIKE 21 PMS is based on the parabolic approximation to the mild slope equation (Kirby, 1986) and accounts for the effects of shoaling, refraction, diffraction, breaking, directional spreading, forward scattering and bed friction on the incident waves. MIKE 21 NSW is a spectral wind-wave model, which describe the propagation, growth and decay of short-period waves in nearshore areas by solving the equations for conservation of wave action (Holthuijsen et al., 1989). The model includes the effects of refraction and shoaling, wave generation due to wind, and energy dissipation due to bottom friction and wave breaking. The effect of current on these phenomena may be included.

The hydrodynamic module, MIKE 21 HD, calculates the flow field from the solution of the depth-integrated continuity and momentum equations (Abbott, 1979). In addition to wind and tide, the forcing terms may include the gradients in radiation stress field as calculated by the wave module of the morphological modeling system. The current and the mean water level are calculated on a bed evolving at a constant rate equal to $\delta z/\delta t$ as calculated by the sediment transport module.

The non-cohesive sediment transport module, MIKE 21 ST, is used to calculate the transport rates of graded sediment and the initial rates of bed level change $\delta z/\delta t$ under the combined action of waves and current. MIKE 21 ST uses DHI's deterministic intra-wave sediment transport model STP to calculate the total (bed load + suspended load) transport rates of non-cohesive sediment.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 CHARACTERISATION OF THE STUDY AREA

The site is near Lutong, Miri, Sarawak (approximately 114° E, 4° 29'N). Figure 4.1 shows the location of the project area.

Figure 4.1 Location of Project Area
Source: (Google, 2007)

Sarawak is subjected to two monsoonal seasons with larger Northeasterly Monsoon during the months December to February and a smaller scale Southwesterly monsoon during the months July to October. The Northeasterly Monsoon generally produces longer period swell conditions with wave heights of the order of 1-3m at deepwater. The waves generated during the Southwesterly Monsoon did not usually contain significant swell energy.

According to the National Coastal Erosion Study (NCES), (1985), the coastline of the study area is identified as Reach 8Sk [Table 2]. About 4.4 % or 45.5km of the 1035km in Sarawak has been identified by the NCES as facing coastal erosion problem. The extent of this reach is from Tanjung Payong to Brunei Border. This reach is characterized by a long, straight, or gently- curving beaches with frequent stream and river entrances. Kuala Baram is the only major change in shore orientation [Figure 4.2].

Table 4.1 Critical Erosion Areas Along Sarawak Coast

a)	**Category 1 Erosion Areas (Critical) - 3 Areas (9km)**	
i.	**Miri - Kuala Baram, Miri**	**2.5km**
ii.	Bintulu	1.5km
iii.	Kg. Buntal, Kuching	5.0km

Source: (Kee, 2000)

The coastline of project area is generally straight and is fronted by very gently sloping seabed stretching for approximately 15 – 20 m to the sea during low tide [Figure 4.3]. The orientation of the beach fronting the area is approximately 180° N. The sediments along the MCOT coastline are typically fine grained with particle sizes of the order of 0.1-0.3mm (D50 = 0.2 mm) with slightly coarser grained material being observed on the western extent. Generally, the slopes of the beach profile are relatively flat, ranging from 1:40 to 1:50. The beach faces and geology of the Miri shoreline generally consist of soft cohesive material which easily erodes when subject to heavy monsoonal rainfall and higher wave activity at the base. Once the cliffs erode, the sediment from the cliffs is lost from the shoreline.

Lutong River flows parallel to the beach a few hundred meters inland. Naturally grown Casuarinas and coastal shrubs fringes characterized most of the coastline of the project area. The coastal shrub is quite intact, however, Casuarinas found along some stretches of the coastline is mainly declining in size, thinning and dying [Figure 4.4]. Much erosion was observed in some places based on the fallen trees at site. However, at some places the tree line appears to be stable but is predicted to be retreated in future if no action is taken.

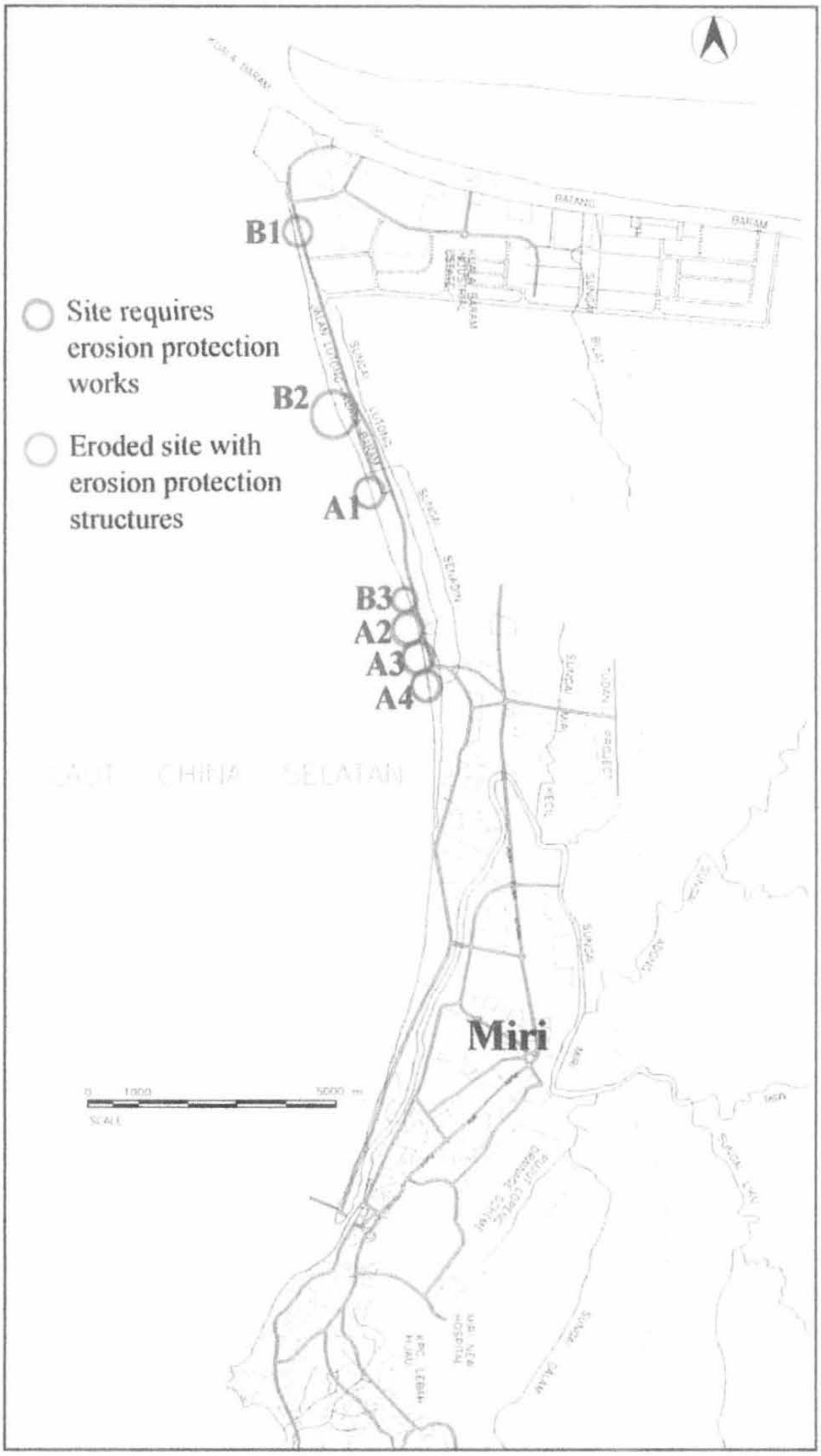

Figure 4.2 Coastal Protection along Miri – Kuala Baram Coast
Source: (Kee, 2000).


Figure 4.3 Overlooking North of MCOT coastline


Figure 4.4 Sign of Erosion (Further South of MCOT Coastline)

The shoreline towards north of the MCOT area is protected by rock revetment, constructed in early year 2000 by Public Work Department (PWD) to protect the Miri-Kuala Baram Highway [Figure 4.5].

Water pipeline lies along the shoreline fronting the flare area [Figure 4.6]. It could be seen that some effort of remedial action to protect this pipeline has been carried out [Figure 4.7]. However, a much better protection work should be constructed to protect these pipelines from the timber logs washed to the shore by wave wand tide [Figure 4.8].

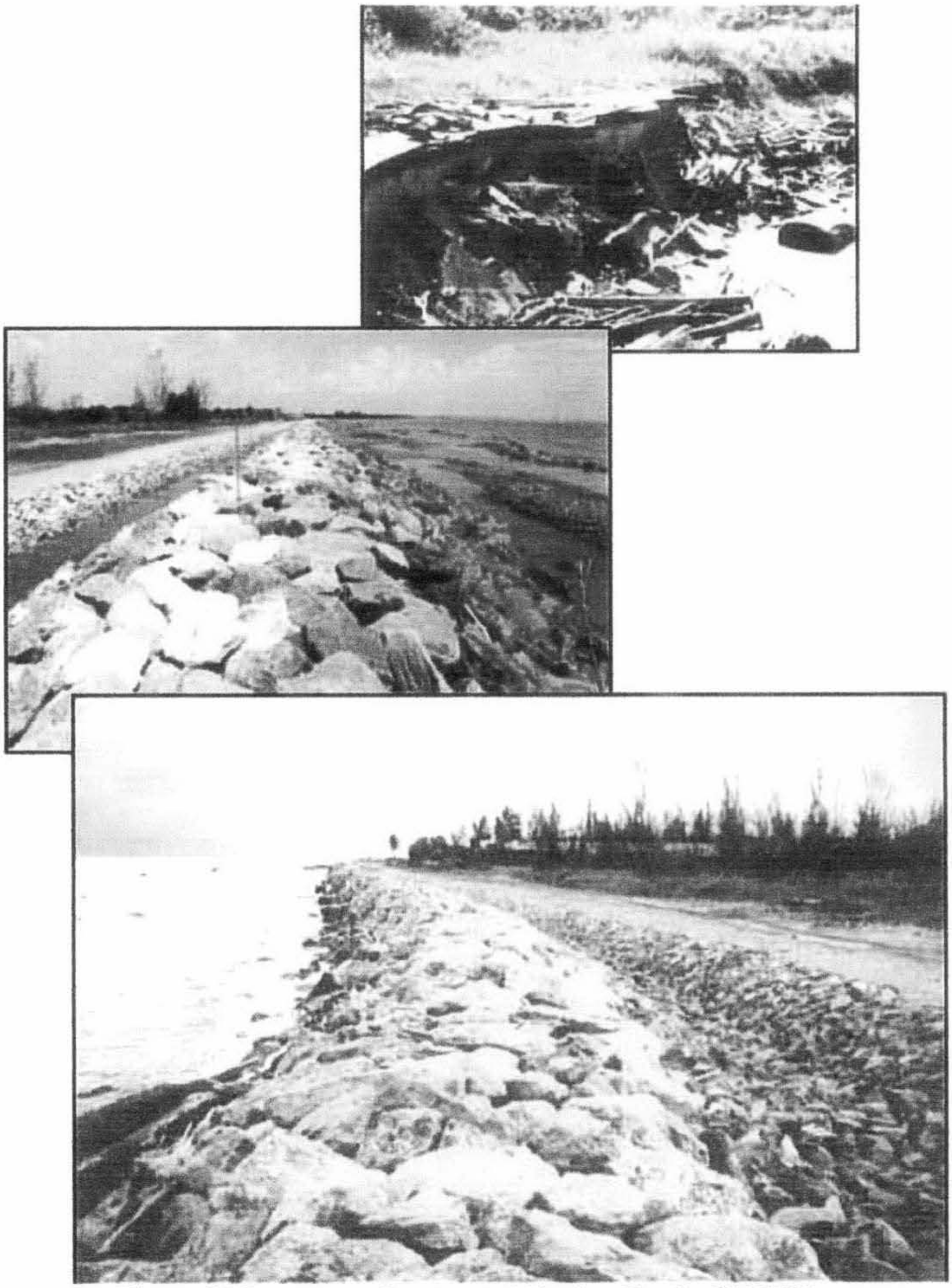

Figure 4.5 Revetment Constructed Further North of MCOT
Source: (Kee, 2000)

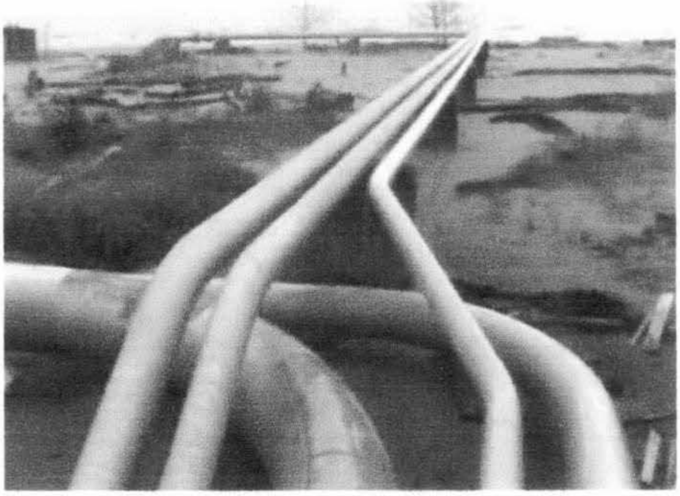
Figure 4.6 Pipelines to be protected


Figure 4.7 Gabion bund wall failures to protect pipelines


Figure 4.8 Threat to pipelines and facilities at MCOT coastline – Timber logs

4.1.1 Tides

The tide for Miri is mainly diurnal type. The various tidal elevations as extracted from the Tide Tables Malaysia (Vol.2) for 2006 published by the Hydrographic Department of the Royal Malaysian Navy are as follows:

Miri:

Highest Astronomical Tide (HAT)	= 2.36 m ACD (Above Chart Datum)
Mean Higher High Water (MHHW)	= 2.10 m ACD (Above Chart Datum)
Mean Lower High Water (MLHW)	= 1.74 m ACD (Above Chart Datum)
Mean Sea Level (MSL)	= 1.22 m ACD (Above Chart Datum)
Mean Higher Low Water (MHLW)	= 0.70 m ACD (Above Chart Datum)
Mean Lower Low Water (MLLW)	= 0.34 m ACD (Above Chart Datum)
Lowest Astronomical Tide (LAT)	= 0.00 m ACD (Above Chart Datum)

4.1.2 Waves

Wave data information relevant to the project site was derived from Ship Board Observations compiled by the National Climatic Data Centre (NCDC), U.S.A. which was made available in the form of magnetic tapes known as Summary of Synoptic Meteorological Observations (SSMO) data. The data was recorded over a period of 40 years (1949 till 1989).

This data is used to transform deepwater waves to the nearshore waves considering various transformation processes such as refraction, shoaling and wave breaking.

4.1.3 Wind

Though the wind over the country is generally light and variable, there are, however, some uniform periodic changes in the wind flow patterns. Based on these changes, four seasons can be distinguished, namely, the southwest monsoon, northeast monsoon and two shorter intermonsoon seasons.

The southwest monsoon is usually established in the later half of May or early June and ends in September. The prevailing wind flow is generally southwesterly and light, below 15 knots.

The northeast monsoon usually commences in early November and ends in March. During this season, steady easterly or northeasterly winds of 10 to 20 knots prevail.

The winds during the two intermonsoon seasons are generally light and variable. During these seasons, the equatorial trough lies over Malaysia.

It is worth mentioning that during the months of April to November, when typhoons frequently develop over the west Pacific and move westwards across the Philippines, southwesterly winds over the northwest coast of Sabah and Sarawak region may strengthen reaching 20 knots or more.

As Malaysia is mainly a maritime country, the effect of land and sea breezes on the general wind flow pattern is very marked especially over days with clear skies. On bright sunny afternoons, sea breezes of 10 to 15 knots very often develop and reach up to several tens of kilometers inland. On clear nights, the reverse process takes place and land breezes of weaker strength can also develop over the coastal areas.

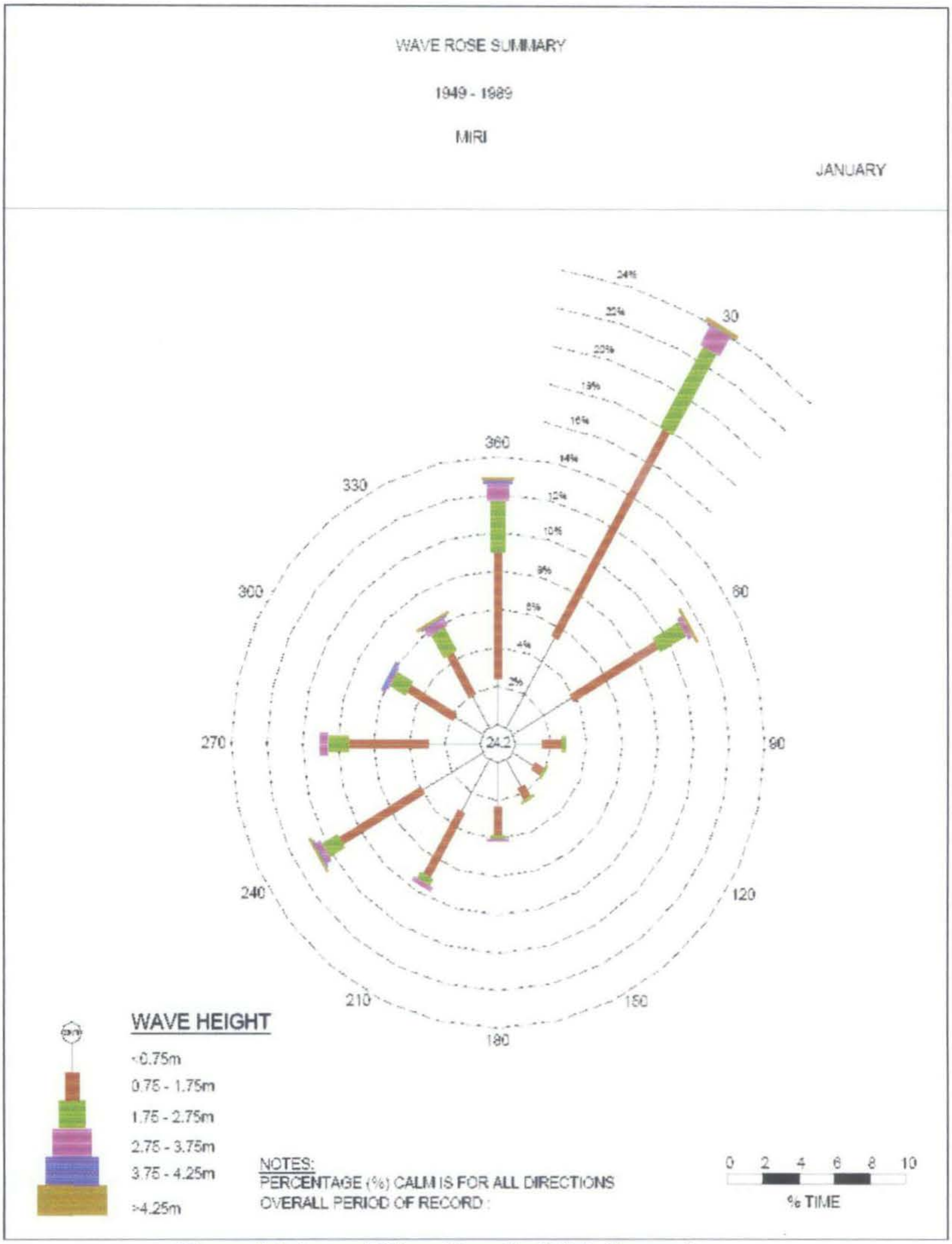

Figure 4.9 Annual Wave Rose for Miri, Sarawak

Figure 4.10 South West Monsoon Wave Rose for Miri, Sarawak

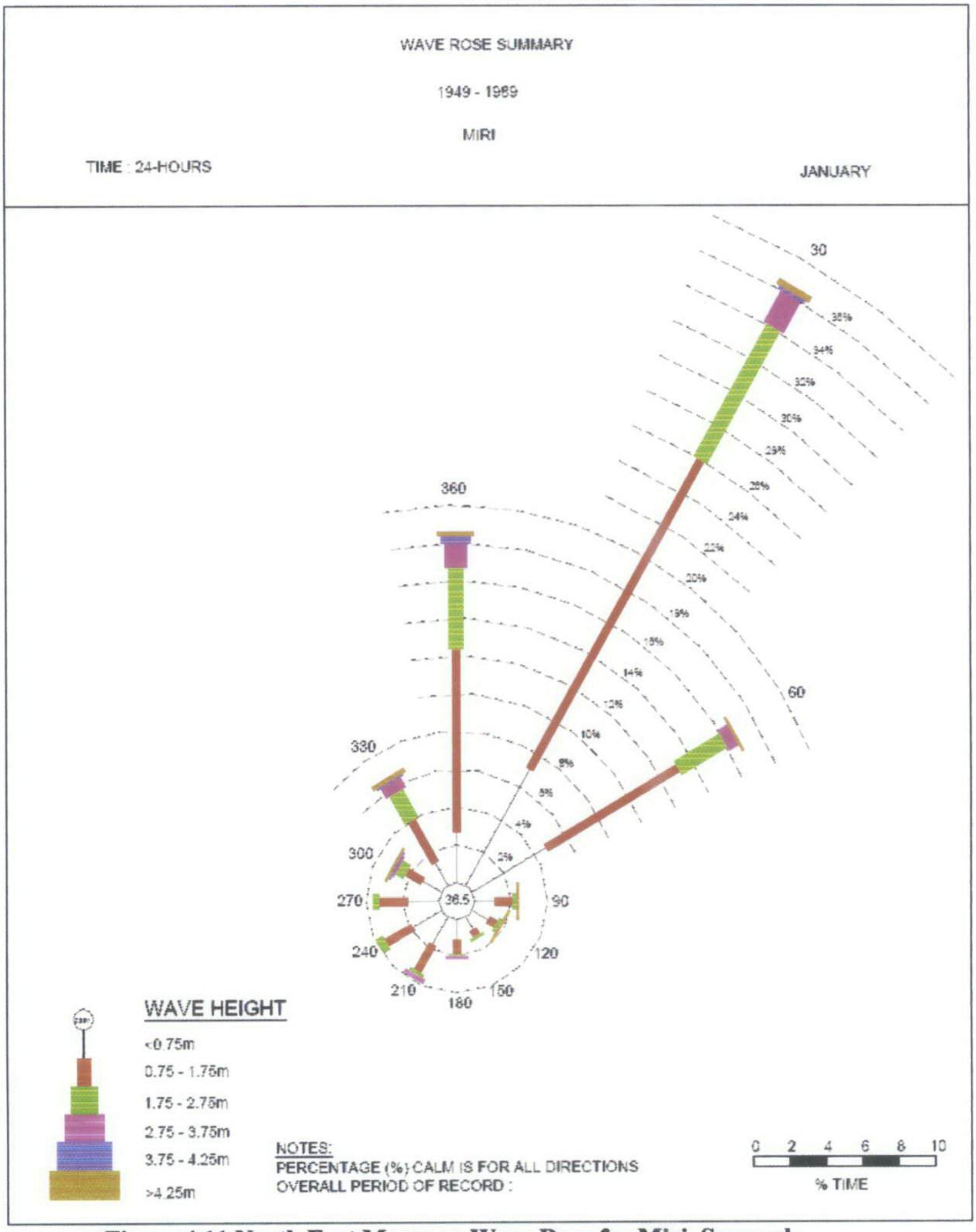

Figure 4.11 North East Monsoon Wave Rose for Miri, Sarawak

4.2 MIKE 21 HYDRAULIC SETUP

4.2.1 Model Set-Up

In order to obtain optimum output for any modeling studies, the existing conditions have to be modeled as accurately as possible. Only after the existing conditions are accurately modeled, investigations into the predicted changes in the processes due to bathymetric changes on the model can be done. The first step in modeling is usually called model set-up.

Existing conditions including existing bathymetry, boundary conditions, and bed roughness are put into the area to be modeled. A model area large enough to model the project area and the waters fronting it was prepared.

4.2.2 Bathymetry

The bathymetry of the model area was digitized based on Admiralty Chart No. 3838 where small corrections have been made to the chart until 1993. Hydrographic survey data carried out by the surveyor in September 2006 was also used.

A general circulation model was set up using a grid spacing of 100 m x 100 m to simulate overall hydrodynamic condition of the study area. Figure 4.12 shows the digitized bathymetry for the study area.

4.2.3 Boundary Conditions

This model has two open boundaries. The boundary conditions for the general circulation were generated based on the tidal constituents predicted for Kuala Baram and Miri published in the Admiralty Tide Tables.

Table 4.2 The tidal constituents used as the boundary conditions.

Station	Semidiurnal Principal Lunar M_2		Semidiurnal Principal Solar S_2		Diurnal Lunisolar K_1		Diurnal Principal Lunar O_1	
	g (°)	H (m)	g (°)	H (m)	g (°)	H (m)	g (°)	H (m)
Kuala Baram	335	0.17	11	0.08	319	0.35	269	0.30
Miri	334	0.18	5	0.09	316	0.37	267	0.32

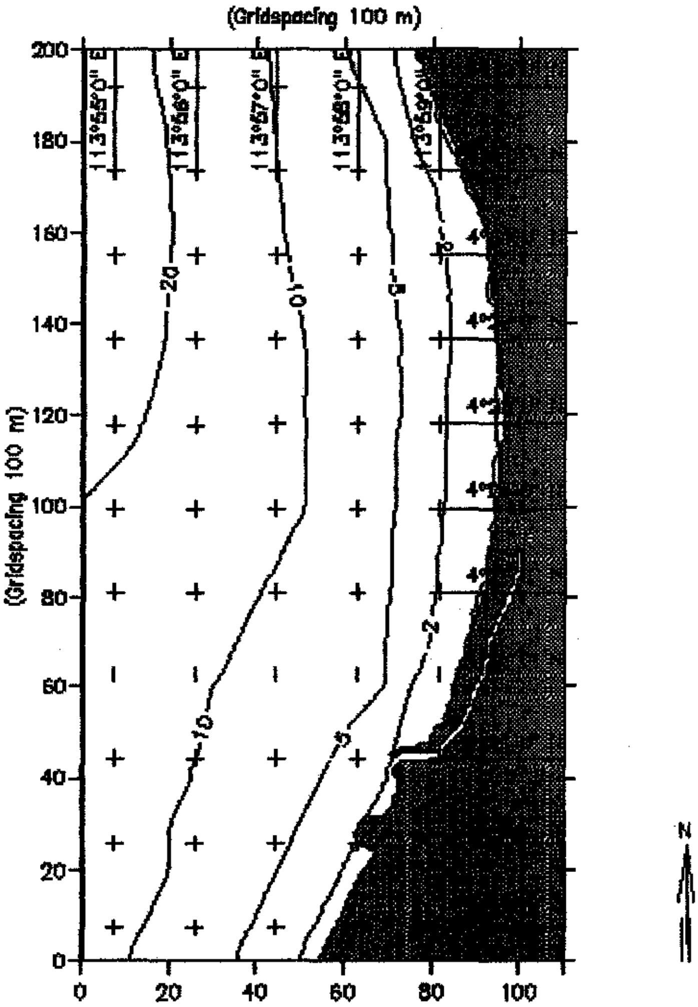

Figure 4.12 Bathymetry Plot – Coarse Grid Model

4.3 MODELLING RESULTS

4.3.1 Hydrodynamic Model

Figures 4.13 (a-d) show the current patterns of the study area during spring tide and Figures 4.14 (a-d) show the current pattern during neap. The figures show that the currents are nearly straight and running along the shoreline. The circulation direction is generally north during ebb tide and south during flood tide.

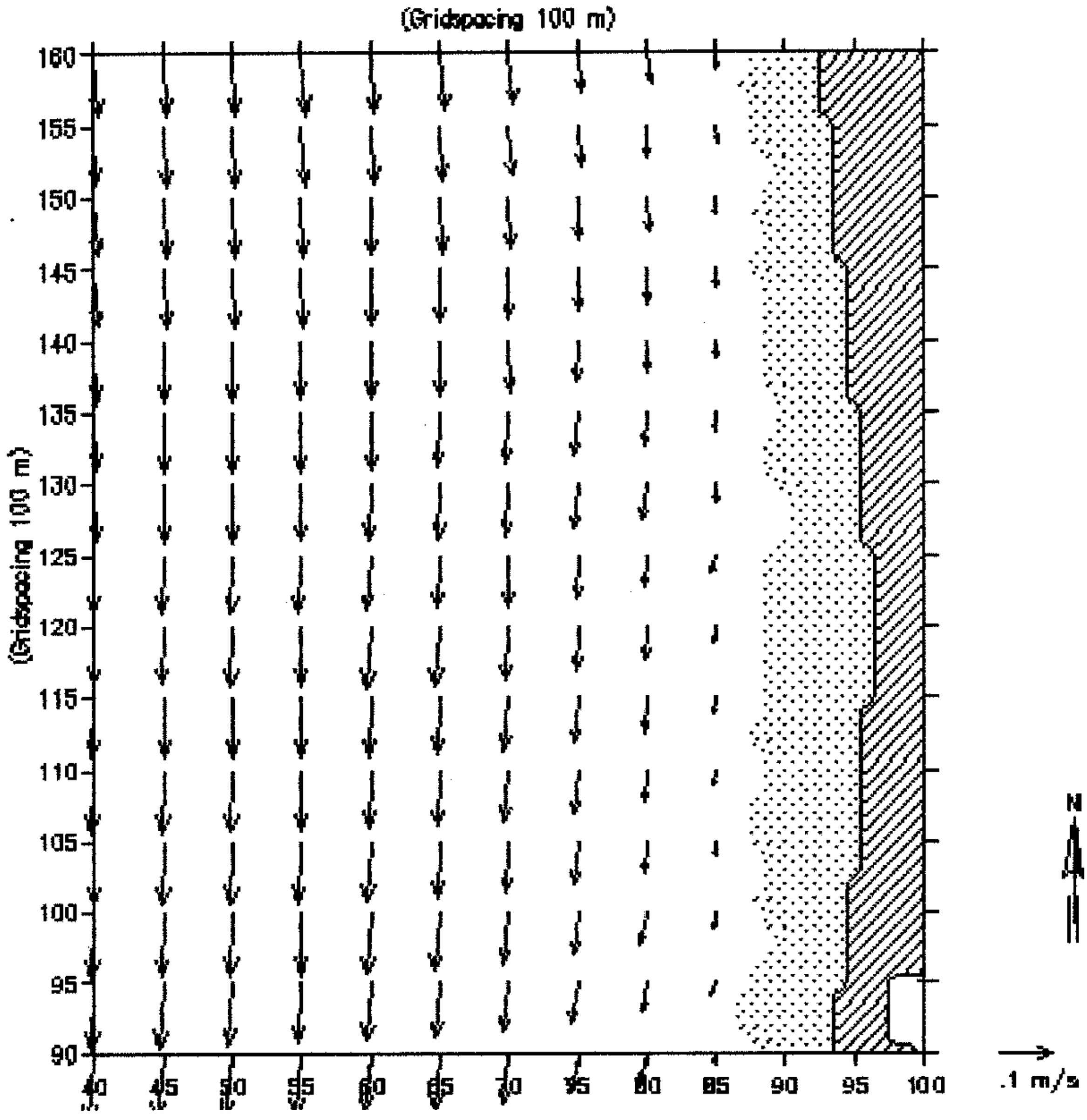

Figure 4.13 (a). Hydrodynamic Model - Existing Condition
Current Pattern during Low Water (Spring Tide)

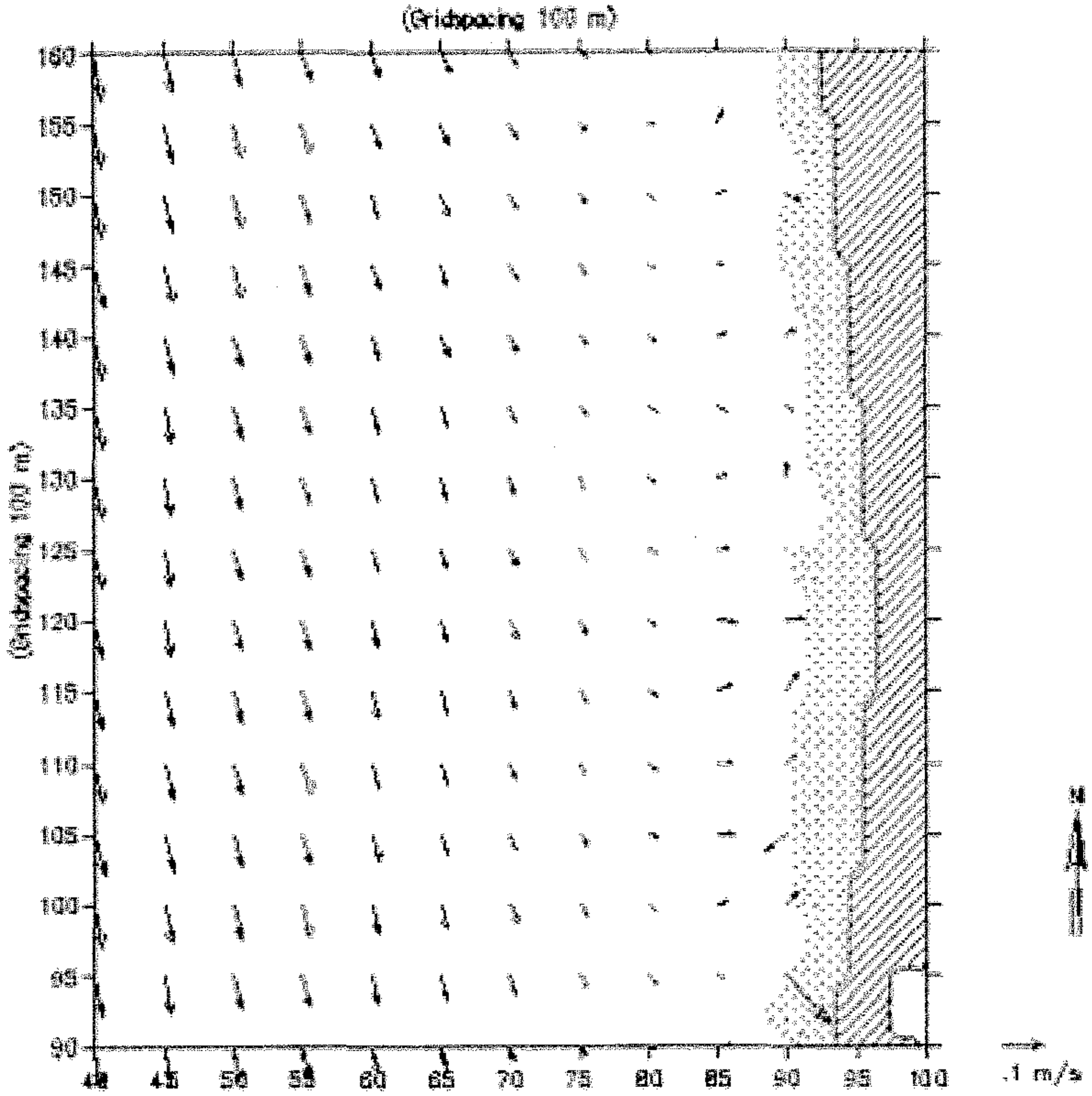

Figure 4.13 (b). Hydrodynamic Model - Existing Condition Current Pattern during Flood Tide (Spring Tide)

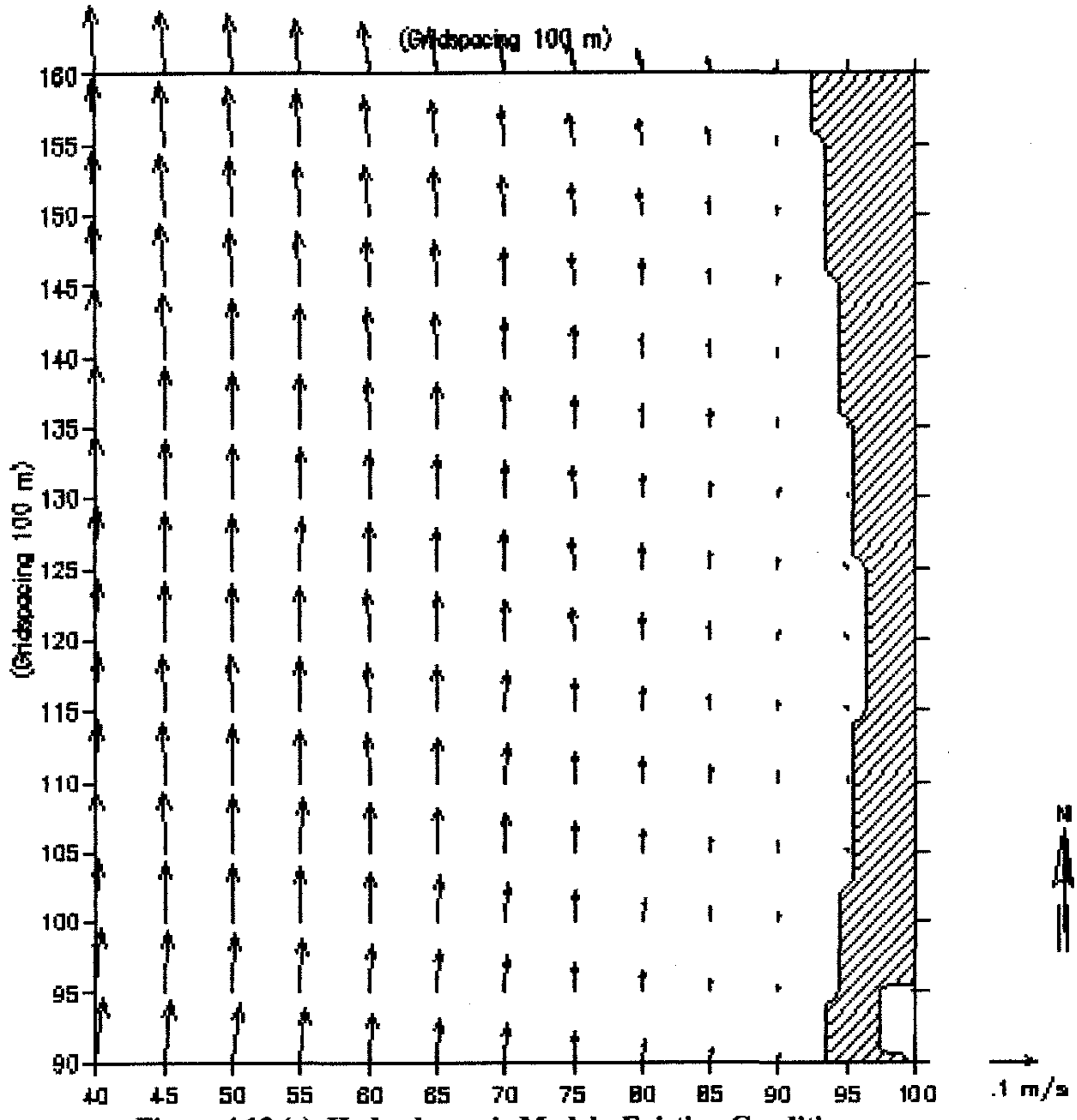

Figure 4.13 (c). Hydrodynamic Model - Existing Condition Current Pattern during High Water (Spring Tide)

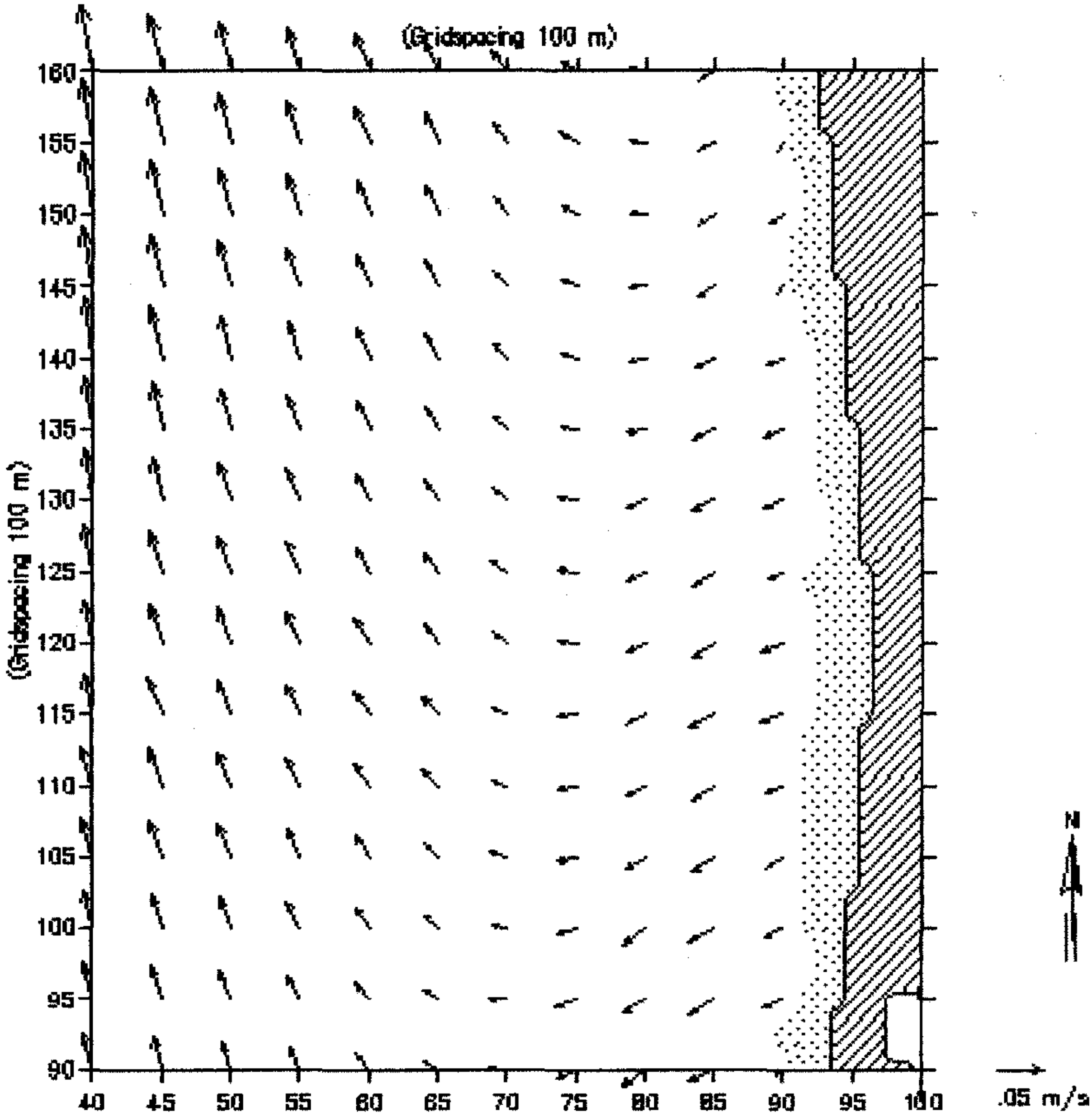

Figure 4.13 (d). Hydrodynamic Model - Existing Condition Current Pattern during Ebb Tide (Spring Tide)

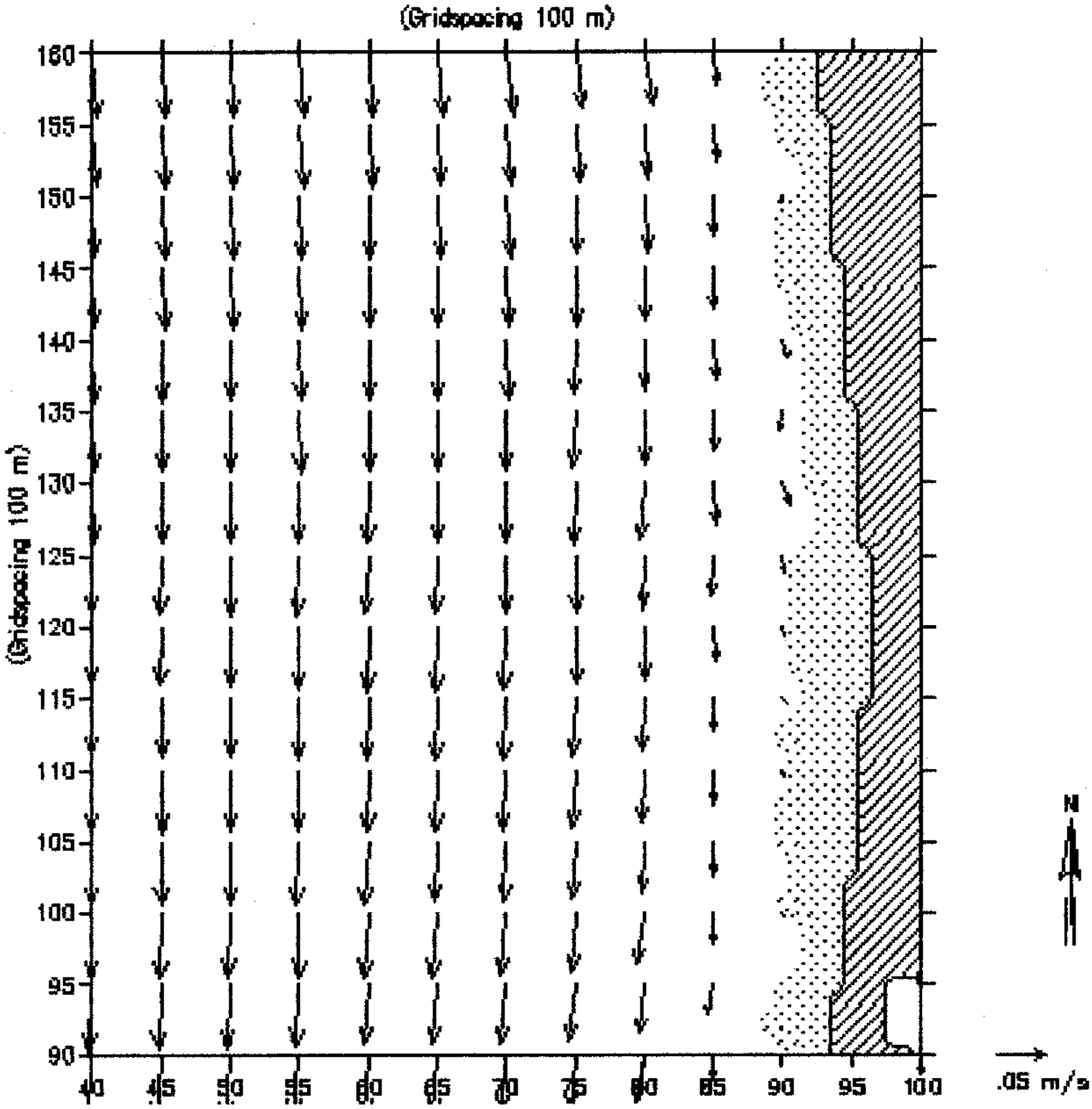

Figure 4.14 (a). Hydrodynamic Model - Existing Condition Current Pattern during Low Water (Neap Tide)

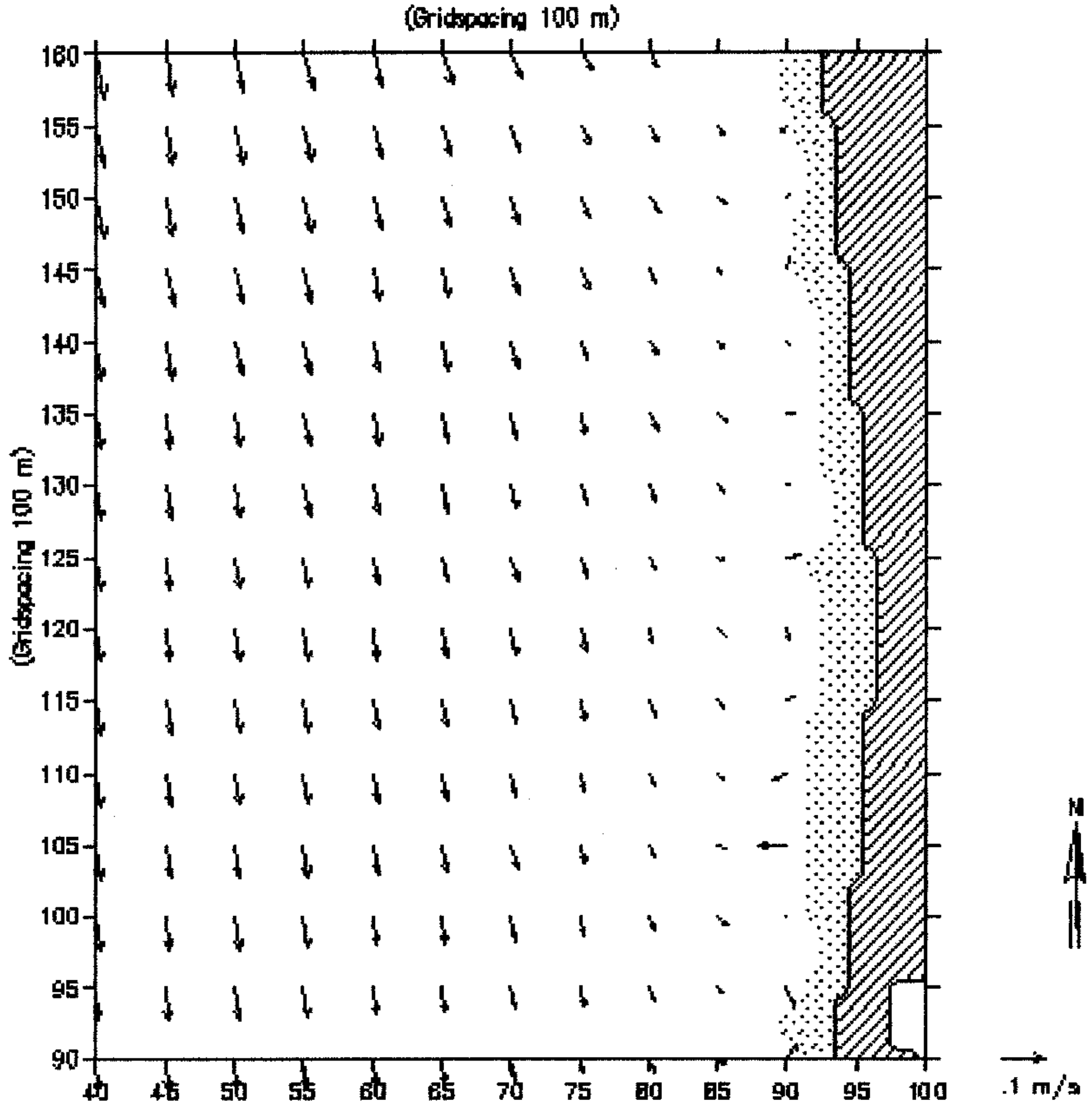

Figure 4.14 (b). Hydrodynamic Model - Existing Condition Current Pattern during Flood Tide (Neap Tide)

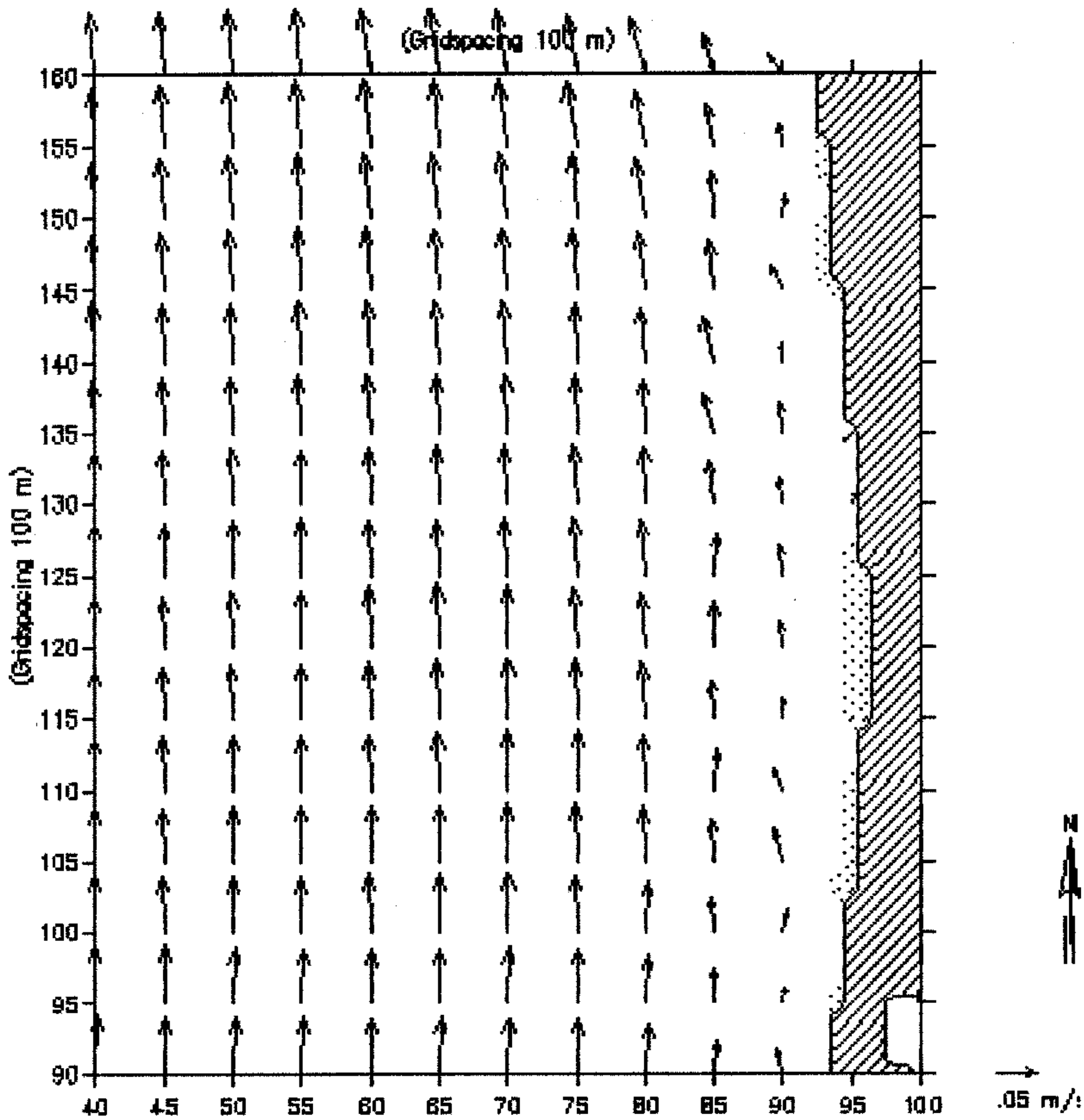

Figure 4.14 (c). Hydrodynamic Model - Existing Condition Current Pattern during High Water (Neap Tide)

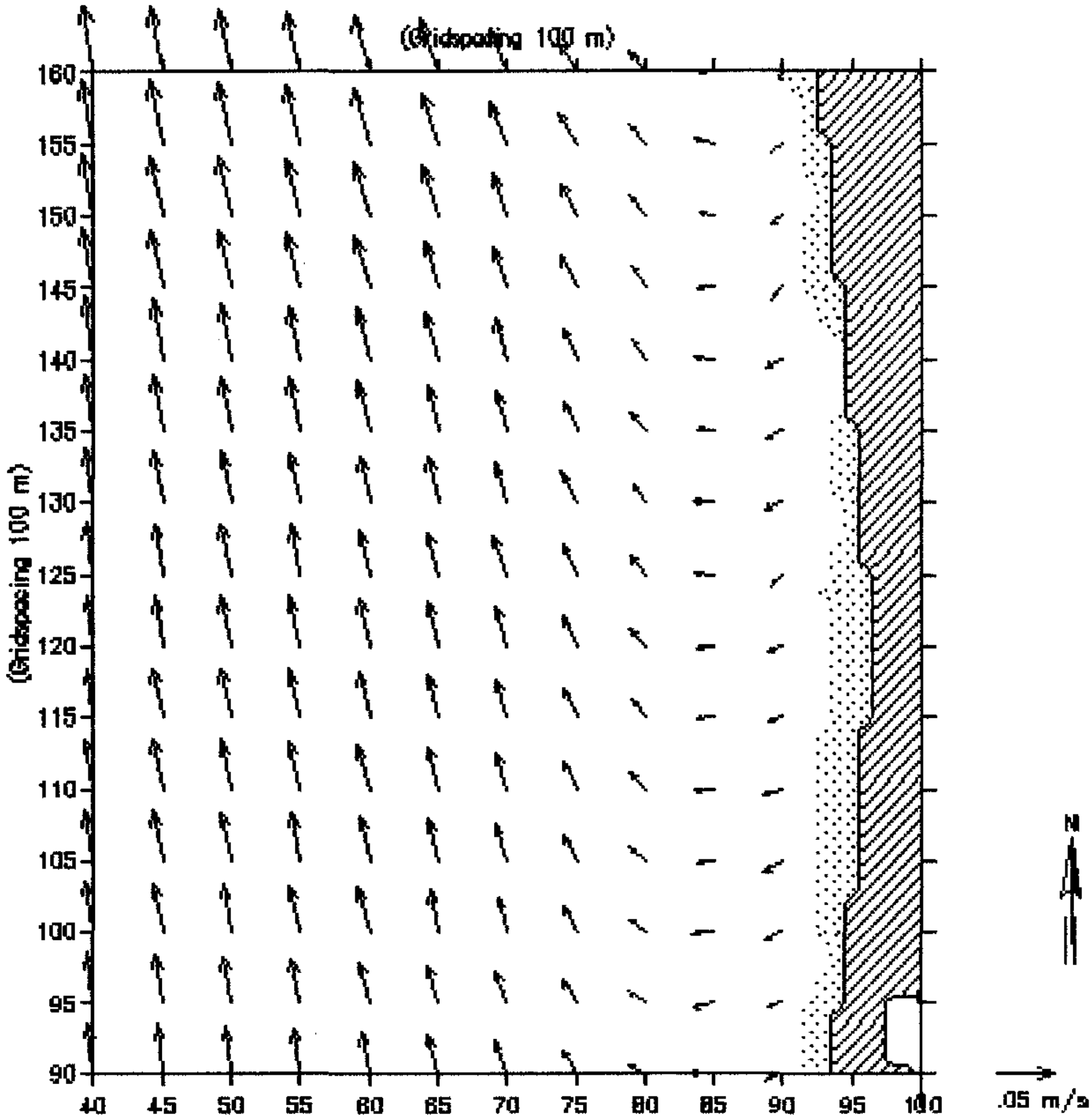

Figure 4.14 (d). Hydrodynamic Model - Existing Condition Current Pattern during Ebb Tide (Neap Tide)

4.3.2 Wave Modelling

The study of waves that would be experienced in the study area was carried out using the MIKE 21 NSW module. MIKE 21 NSW is a wind-wave model describing the propagation, growth and decay of short-period and short-crested waves in nearshore areas. The model takes into account effects of refraction and shoaling due to varying depths, local wind generation and energy dissipation due to bottom friction and wave breaking. This model is a stationary, directionally decoupled parametric model. The basic equations are solved using Eulerian finite difference technique.

Wave modelling was carried out for the existing condition. Table 4.3 shows the wave height and period for the various wave directions used in the model.

Table 4.3 Wave Heights and Periods for Various Wave Directions

Case	Wave Height, H (m)	Wave Period, T (s)	Wave Direction (°)
1	2	8	240
2	2	8	270
3	2	8	300

Waves that actually reach the existing coastline are of variable heights. Figures 4.15 (a-c) shows the wave results for existing condition. The wave height experienced by the shoreline ranges between 0.8 m to 1.2 m.

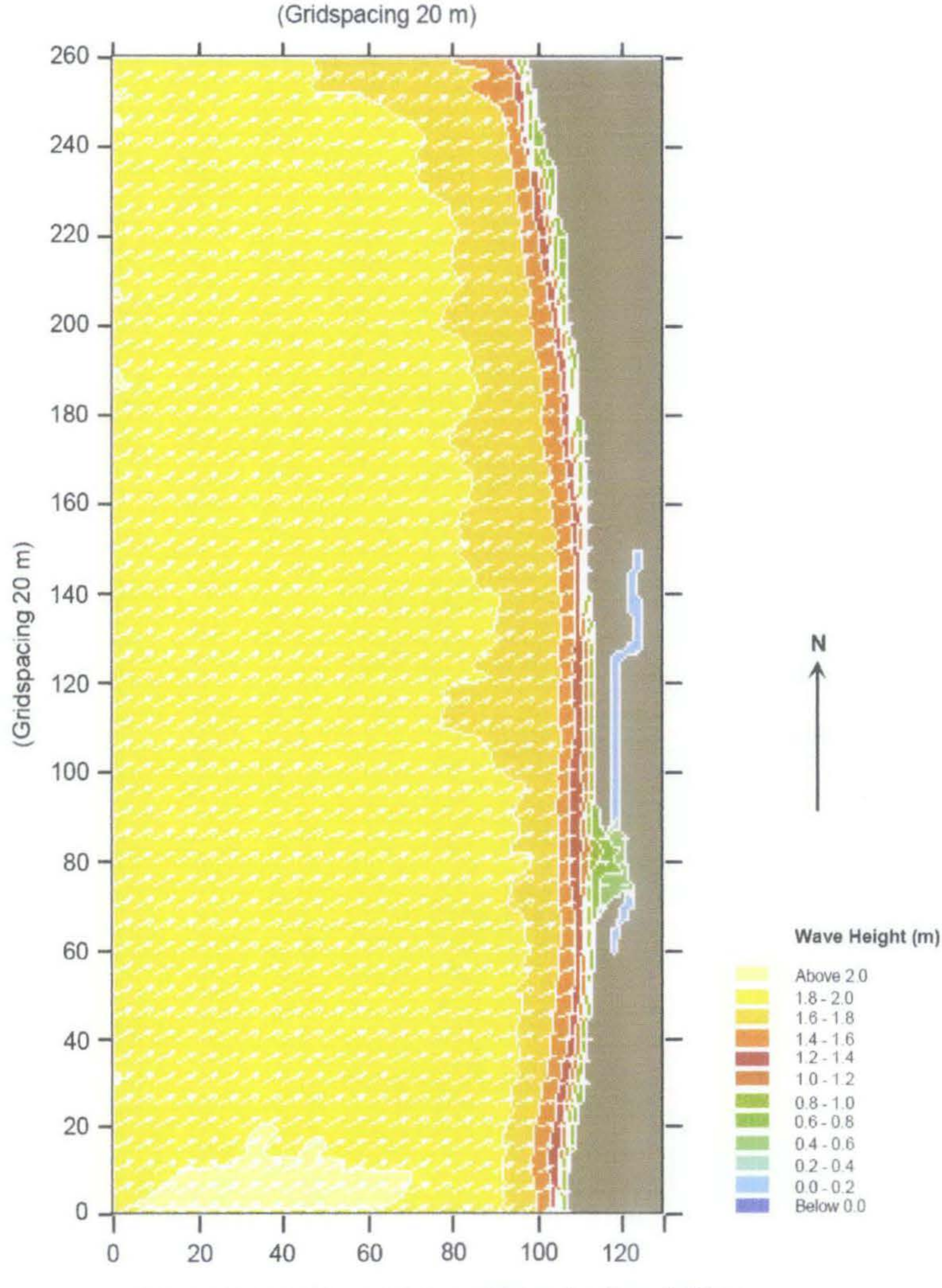

Figure 4.15 (a). Wave Height and Direction from 240° N

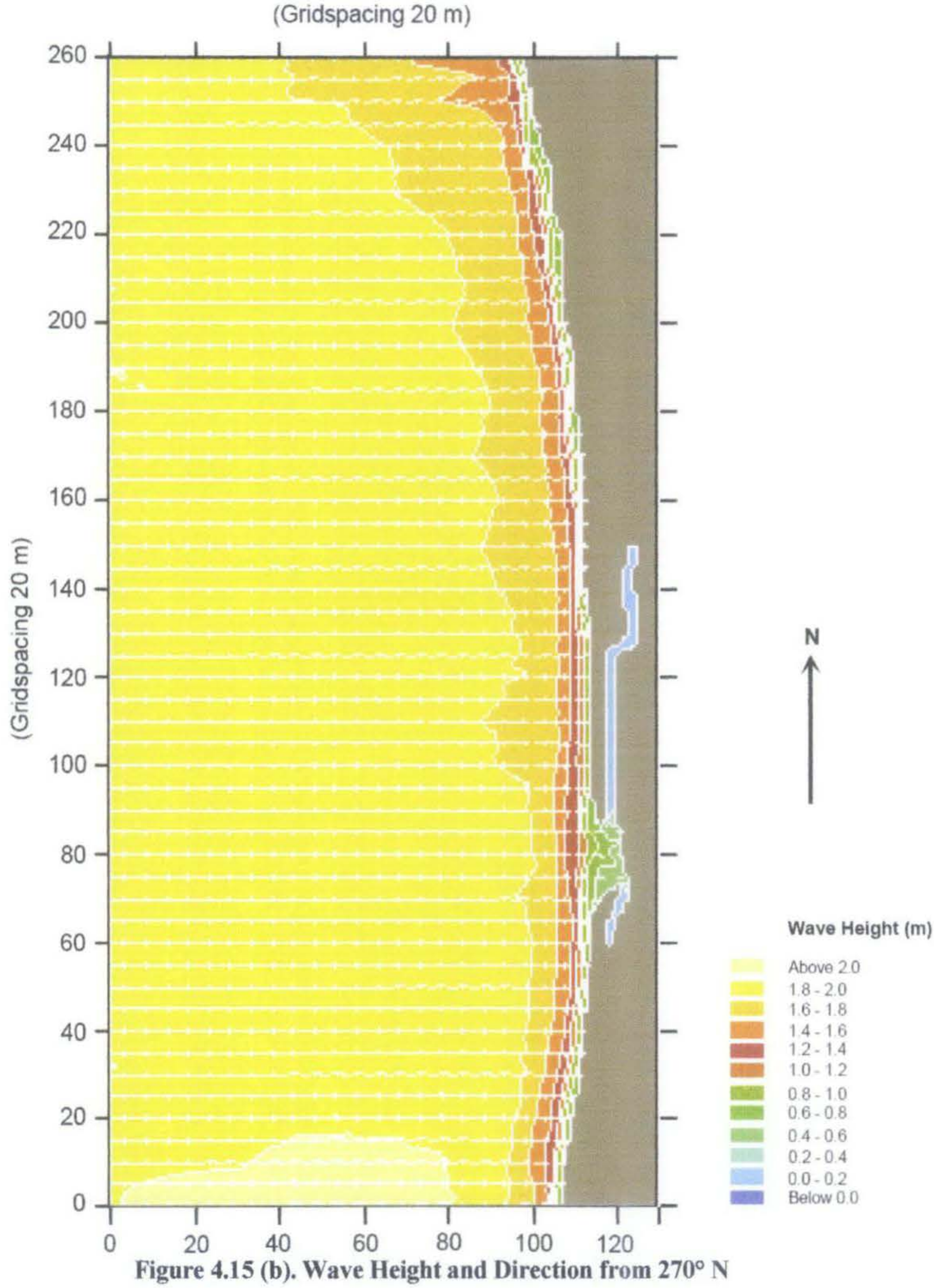

Figure 4.15 (b). Wave Height and Direction from 270° N

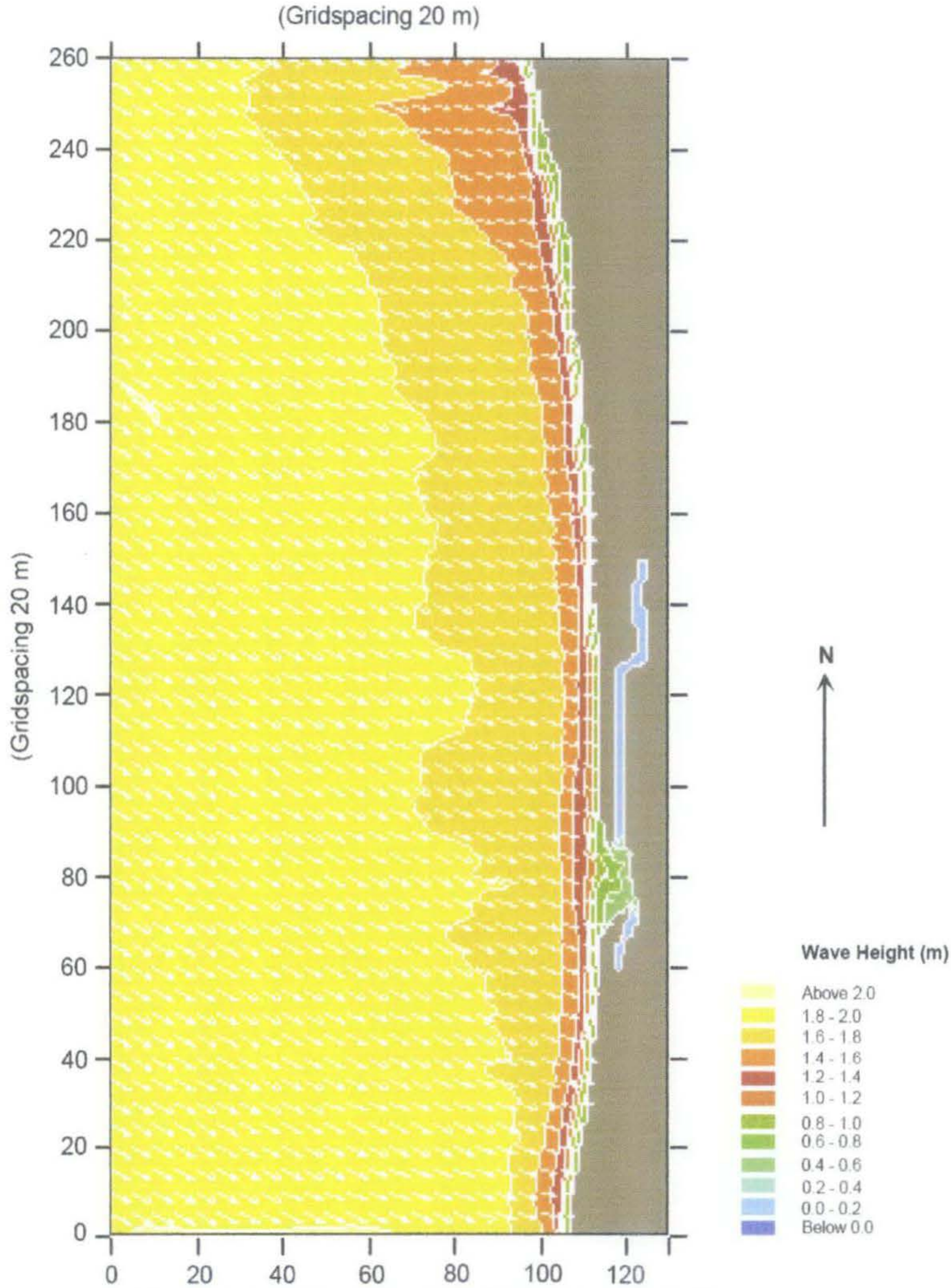

Figure 4.15 (c). Wave Height and Direction from 300° N

4.3.3 LITPACK Modeling – Changes in Shore Profile

Beach profiles, measured normal to the shoreline over the active zone, are of great importance to coastal engineering studies. This active zone typically extends from the onshore dune or cliff line to a point offshore where there is little significant sediment movement owing to wave action.

Depending on the wave action on the shore, the beach profile can change. This change in beach profile is most predominant during storms. A storm of 80 hours with a maximum wave height of 4 meters was simulated using the LITPACK software. The original beach profile is taken from the survey provided by the Client. The resultant beach profile is as shown in Figure 4.16.

The beach is very gentle and is stable against liquefaction due to tidal fluctuations. Thus the important factor to consider is the movement of the beach material under stormy conditions.

Based on the modelling results and also information gathered from Department of Irrigation and Drainage, the rate of erosion in the area is about 3 m per year.

If erosion is not arrested, the pipelines will be exposed in 5 to 10 years time. The new beach profile at 5,10 and 30 years is compared with existing pipelines in Figure 4.17.

Figure 4.18 compared the predicted shoreline after 10 and 30 years with the existing shoreline.

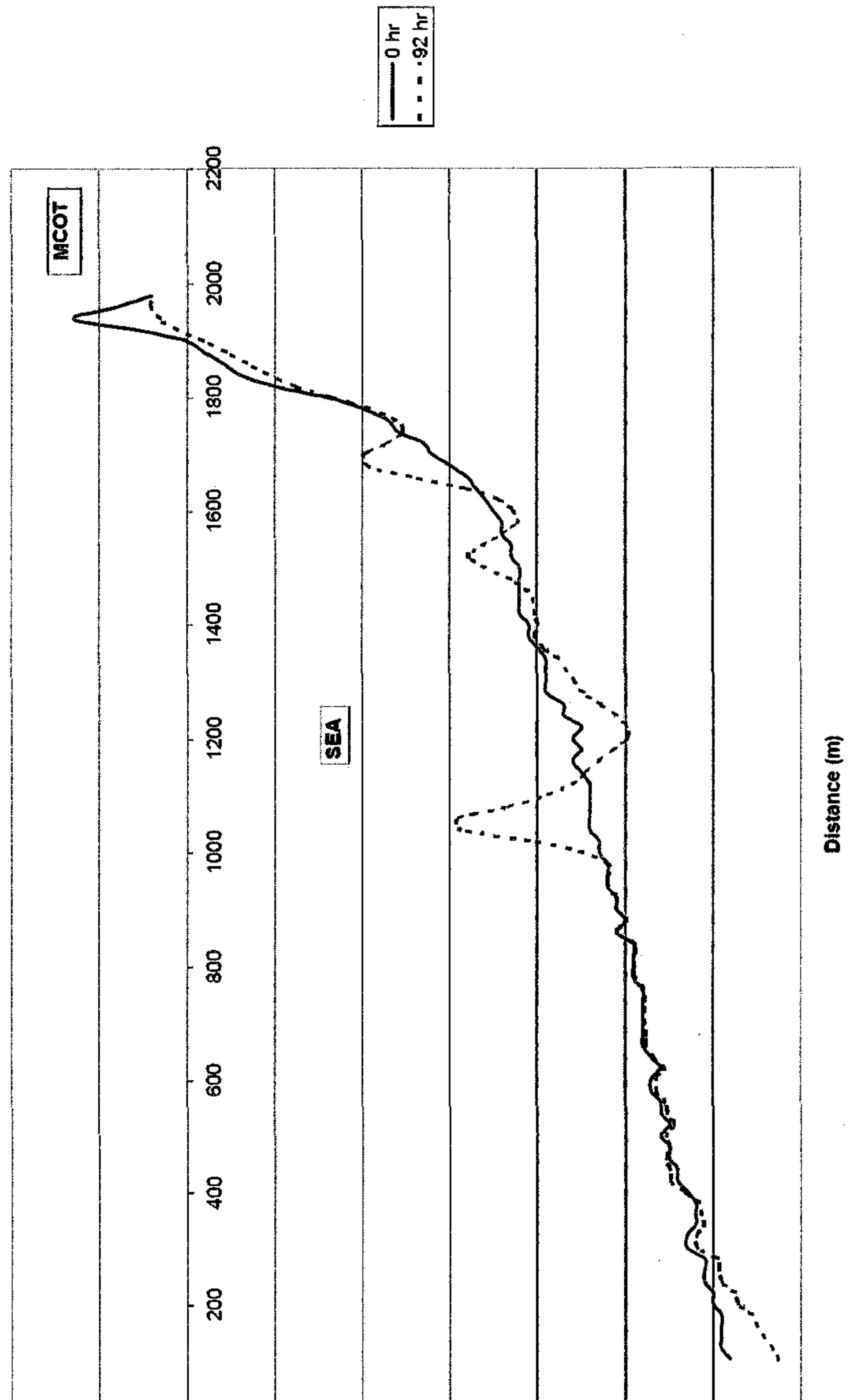

Figure 4.16 Cross Shore Profile at MCOT

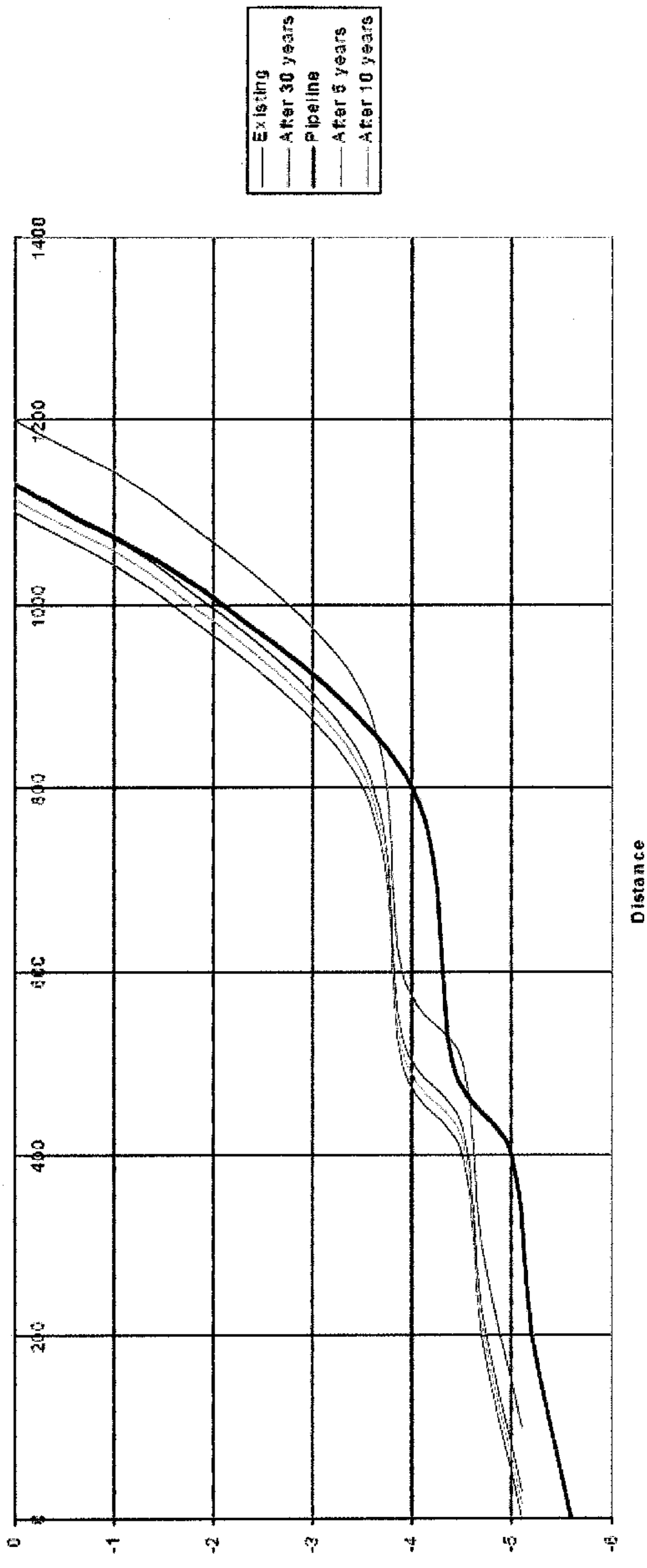

Figure 4.17 Changes in Beach Profile at MCOT

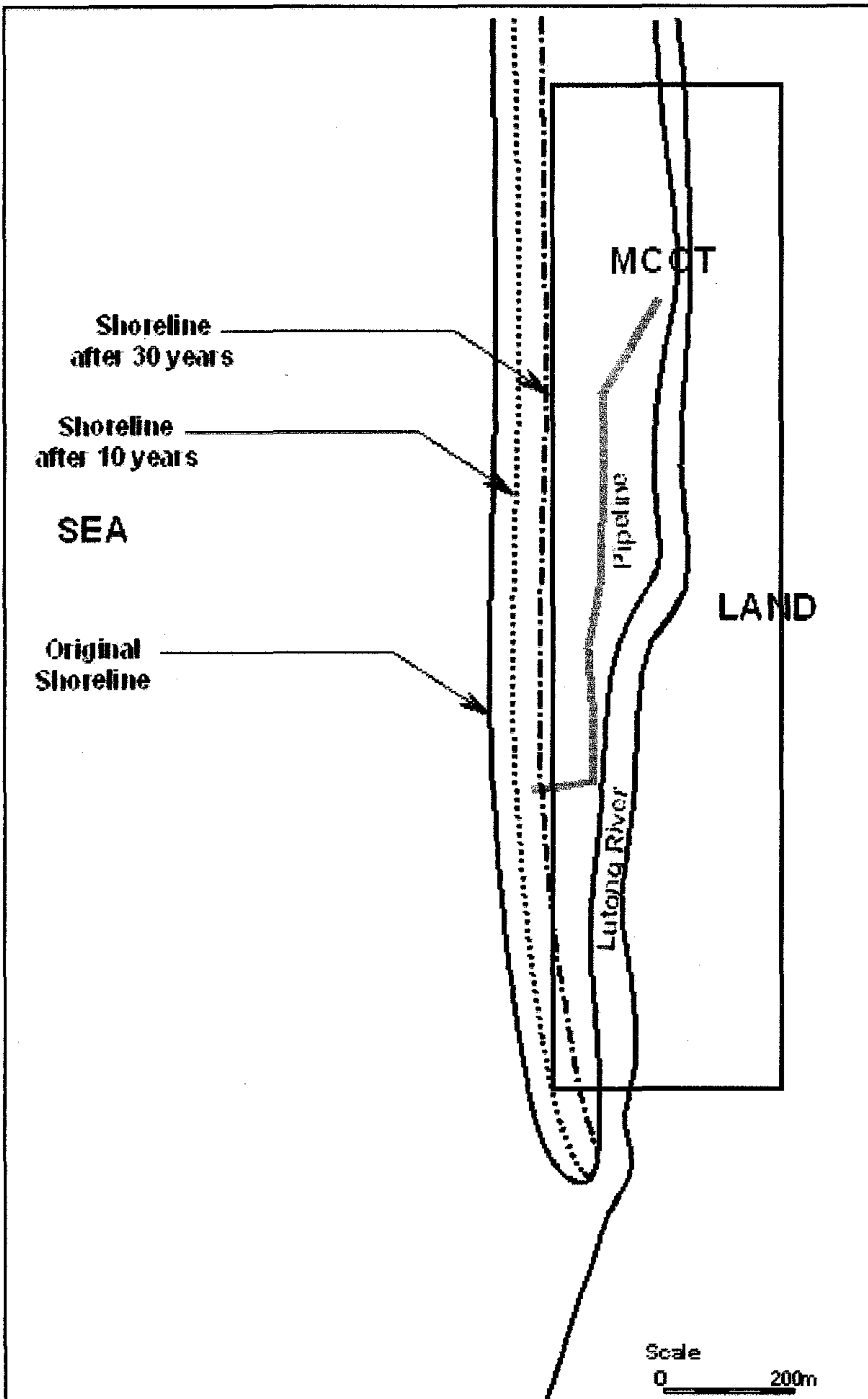

Figure 4.19 Predicted Shoreline at MCOT

4.4 ALTERNATIVES FOR SHORE PROTECTION

4.4.1 Technical and other considerations

The analysis and design of shoreline protection measures are often complex and require special expertise. For this reason the following discussion is limited to revetments, bund, gabion and groynes no higher than 4 feet above mean high water, as well as soil bioengineering used alone or in combination with structural measures. The aim is to make MCOT available in good condition for the next 25 to 30 years. Consideration must be given to the possible effects that erosion control measures can have on adjacent areas. These will not be designed to change any current operation philosophy of MCOT. Explored alternatives considered are as below:

a) Continue with existing condition:

- One management alternative is to do nothing. This means that beach is allowed to change without intervention. The problem with this is that water margin has reached the pipelines and is threatening to expose the pipelines, putting the pipelines in imminent danger. While in the past, this may be a wise option, i.e. to allow the erosion to occur and just observe the retreat, the situation has come to a point that action must be carried out to stop the erosion or the pipelines will be damaged.
- It can be granted that the pipelines can be abandoned and new pipelines will be put in place, with the shore approach ending much further inland. However, high remedial cost will be incurred to install new lines, due to one off mobilization of offshore resources for this one activity.
- Moreover, major installations such as the flare are also quite close to the active zone of the beach. The distance of the flare from the Highest Astronomical Tide Contour is only around 3 meters. At the present rate of erosion (3m/year), the flare will be undermined within 1 year. If the flare is undermined, the plant will have to shutdown. Other facilities (Gas Receiving Facilities, GPAF and New Oil Receiving Facilities, NORF) are also to face the same problem as the active zone is coming further to MCOT area. This could happen within 5 to 10 years.

- These pipelines also happened to face direct impact timber logs and debris. These pipes might leak or break and causing potential adverse environmental reputation with statutory bodies especially Department of Environment (DOE).

b) **Construct a bund wall:**

- Bund will reduce the wave overtopping and prevent the logs from drifting to the pipelines area. The bund is constructed with limited width and may receive direct wave action on their faces when wave height or water level increases during storm action. The bund structure may be constructed of rocks.
- While it may address as the original scope of work for the conceptual study, i.e. protecting the pipeline against debris and logs that are carried over by tides, it does not solve the issues such as beach erosion over the next few years.

c) **Construct a Revetment**

- The objective of the revetment alternative is to fix or harden the shoreline so as to prevent further retreat to the shoreline. Revetments are usually composed of thick armor rock or cover layer directly withstanding the full impact of the waves. The under layer stones act as a filter layer which is designed to weigh one-tenth of the cover layer stones and help to distribute the wave energy. Adequate toe protection in the form of apron/filter is required to prevent scouring in front of the structure. Revetments have to be designed for wave run-up so that wave overtopping the crest is minimized.
- They dissipate the energy of storm waves and prevent further recession of the backshore if well designed and maintained. Revetments may not prevent on going shoreline recession unless they are maintained, and if necessary extended. If the foreshore continues to erode, the rock revetment may slump down. Revetment design must anticipate ongoing erosion that

may result in toe scour, overtopping or outflanking and may cause partial structure failure.

- Another problem in using revetments as coastal protection for MCOT is that there are pipelines coming onshore at many points along the coastline. Revetments are heavy structures and cannot be constructed on the existing pipelines as the revetments will crush the pipelines. Revetments will also restrict the location of new pipelines, which may not be desirable for the development of the shoreline. Furthermore, revetments do not prevent beach loss in front of the revetments. This beach material is important to prevent undermining of the pipelines.

d) Construct a Gabion

- Gabions are wire mesh baskets filled with cobbles or crushed rock. They are filled in-situ, often with locally available material. Gabions are flexible and porous and can absorb some wave energy, thereby reducing the scour problems associated with impermeable sea defenses such as concrete seawalls.
- Gabions can be placed as sloping mattress or as near vertical cubic baskets. The latter are intended for bank or cliff stabilization and are not normally suitable for use in shoreline situations. Their application is restricted to the upper part of sandy beaches, since they are not sufficiently durable to withstand regular direct wave action.
- They should not be installed on beaches because wear and tear will rapidly cause damage to the baskets. Once the cages are broken the stones will be dispersed rapidly creating an unpleasant sight. Released cobbles are not a problem to coastal processes, but can detract from the general beach environment and may accelerate damage to adjacent baskets.

e) Construct a Groynes

- Groynes are somewhat permeable to impermeable finger-like structures that are installed perpendicular to the shore. They generally are constructed in groups called groin fields, and their primary purpose is to trap littoral drift. The entrapped sand between the groynes acts as a buffer between the incoming waves and shoreline by causing the waves to break on the newly deposited sand and expend most of their energy there.

- Groynes are extremely cost-effective coastal defense measures, requiring little maintenance, and are one of the most common coastal defense structures. Groynes have the advantages of simple construction, long-term durability and ability to absorb some wave energy due to their semi permeable nature. One of the benefits is that groynes encourages upper beach stability and reduces the maintenance for nourishment.
- Moreover, groynes do not protect the beach against storm-driven waves and if placed too close together will create currents, which will carry sand material offshore.

f) Beach Nourishment

- Beach nourishment is a process by which sediment (usually sand) lost through longshore drift or erosion is replaced on a beach. It involves the transport of the nourishment material from one area to the affected area.
- It has been demonstrated from both field studies and theory that a wide beach provides significant benefits in the form of storm damage reduction. During storms with elevated water levels and high waves, a wide beach performs as an effective energy absorber with the wave energy dissipated across the surf zone and wide beach rather than impacting on the upland structures and infrastructure. The storm damage reduction benefits of beach nourishment projects have been well established.
- This process is relatively expensive, depending upon the source (and thus the cost) of the sand. Beach nourishment can be part of a coastal defense scheme. Well designed beach nourishment can result in a much improved beach health (a capital investment into beach health). However, if care is not taken to deal with the sustainability of the littoral environment then it requires replenishment as time progresses to ensure continuing beach health (maintenance investment into beach health).

- The construction process however involves dredging, transport and placement of sand in a marine environment which causes water quality problems and temporary disruption to marine habitat.

4.5 PROPOSAL FOR COASTAL PROTECTION AT MCOT

Based on these alternatives, the proposed measure for the shore protection is a combination of:

I. Bund
II. Groynes
III. Beach Nourishment

Figure 4.19 shows the proposed bund and erosion control.
The general characteristics of each component are described as below.

Bund

The length of the bund required is approximately 850 m. The bund will be constructed along the beach starting from about 50m south of the export line up to the pond area. This will protect the pipelines along the MCOT area. The total length of the pipelines is around 800 meters and the bund will prevent debris and logs from entering this area.

Groynes

Groynes can influence the movement of a shoreline on either side of the groynes between 2 to 5 times the lengths of the groynes. Thus if a groyne is 100 meters in length, the length of the shoreline that will be affected by the groyne will be between 200 to 500 meters updrift and downdrift of the groyne. If the shoreline is running North South and the net littoral drift is going south, the updrift part of the shoreline is the section of the to the North of the groyne, and the downdrift part is the section to the South of the groyne.

Most of the pipelines are coming ashore within the 1 km area where the bund is located. This area of beach needs to be stabilized. One method is to build two groynes, which will contain the beach material between the groynes. The sand placed in between the groynes will not be eroded out of the system but will stabilize in the form of a crenulated bay. This type of beach is called a pocket beach.

Since the dynamic zone of the beach is around 400 meters from the highest water contour seawards, the length of the groynes should be 425 meters. With beach nourishment placed in between the groynes, this area can be stabilized and the pipelines can be protected from undermining.

Groyne No 1, which is the northern most groyne, will cause sediments to trap on the northern side, since the net littoral drift is to the south. This will stabilize the beach where the flare and the new pipeline is. If this is the case, one may question why not just construct a long groyne on the southern most end of the coastline in front of MCOT. This is not possible because the length of the groyne will have to be long, around 1 km, to create stable beach that will protect all the pipelines along the shore. Since the impact of the groyne on the down drift shoreline can be up to 5 times the length of the groyne, the length of shoreline that can be affected by this groyne can be 5 km long. This will be unacceptable to the authorities. Furthermore, it is best to provide a pocket beach so that those designing the shore approach of future pipelines can be certain of the beach profile. Since imported sand for beach material is expensive, it is more economical to stabilize the beach material by creating a pocket beach.

Creating a groyne system in this way will cause erosion on the down drift side of Groyne No. 2 if there is no mitigation measure taken. Thus, a series of return groynes with beach nourishment is placed along the coastline on the southern side of Groyne 2 to prevent erosion on the downdrift side. The groynes should be built prior to beach nourishment.

The proposed lengths of the return groynes are:

a) Groyne 3 – 300 m

b) Groyne 4 – 200 m

c) Groyne 5 – 100 m

d) Groyne 6 – 50 m

Beach Nourishment

The beach area to be nourished is approximately 1.9km and the width of beach varies between 50m to 400 m. The average beach width is around 200m. The average depth of fill is around 2 m. The volume of sand required for the beach nourishment is 890,000m^3.

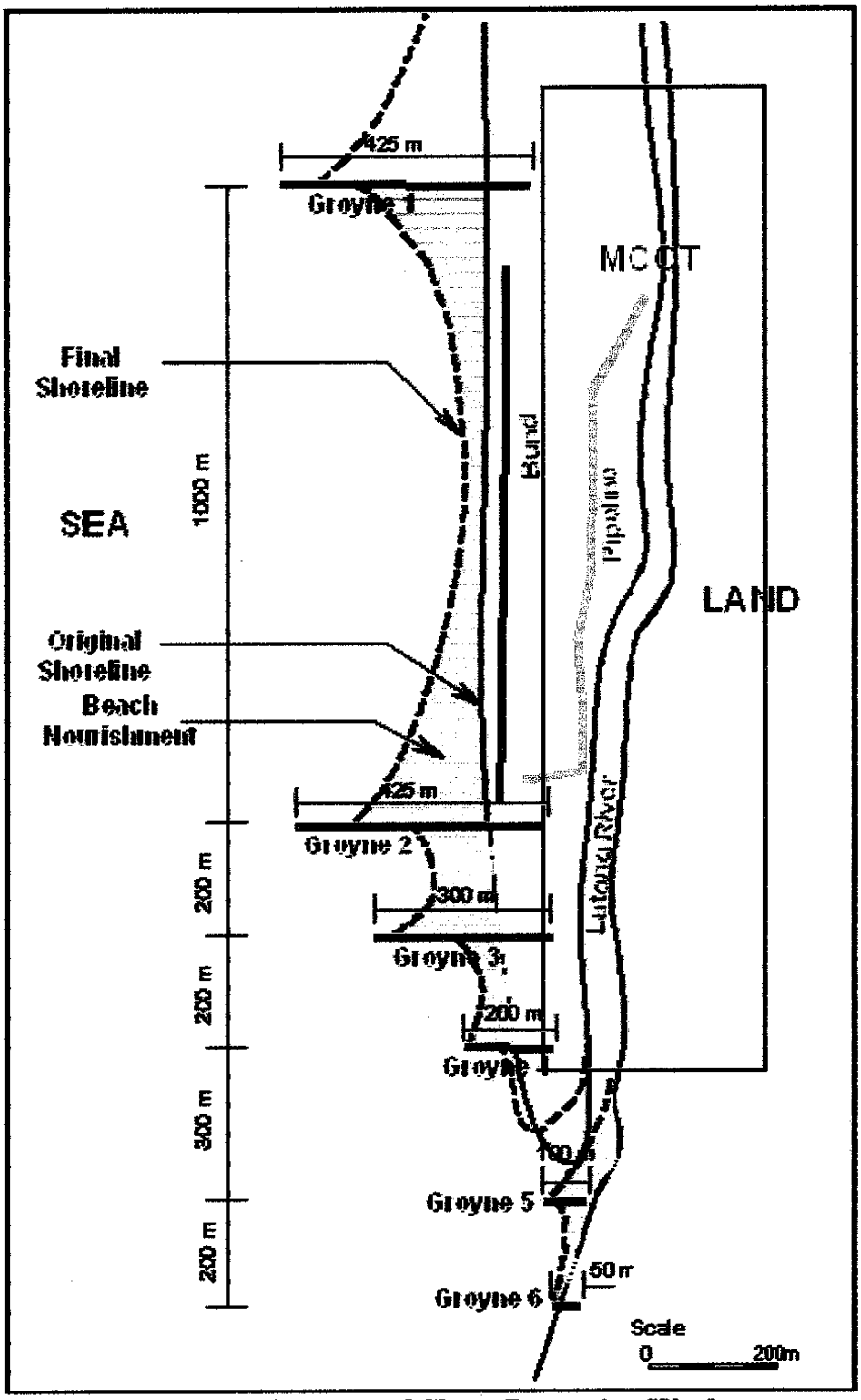

Figure 4.19 Proposed Shore Protection Work

4.6 COST ESTIMATES

The estimated total cost of the protection works is around RM 23 million. The unit rate is based on construction of coastal protection at Miri coast in year 2000-2007. Table 4.4 shows the cost of the protection works.

Table 4.4 Estimated Cost of Protection Work

Cost of Beach Nourishment		Unit
Volume of sand	890,000.00	m^3
Unit Rate	23.00	RM/ m^3
Cost	**17,800,000.00**	**RM**
Cost of Bund		
Average height of Bund	1.50	m
Width of Crest	1.50	m
Cotangent of Slope	3.00	
Bottom width	10.50	m
Volume of rock per meter run	9.00	m^3
Unit Rate per cubic meter	150.00	RM/ m^3
Cost per meter run	1,350.00	RM/m
Distance	500.00	m
Total cost of Bund	**675,000.00**	**RM**
Cost of Groynes		
Average height of Groyne	2.00	m
Width of Crest	3.00	m
Cotangent of Slope	3.00	
Bottom Width	15.00	m
Volume of rock per meter run	18.00	m^3
Unit Rate per cubic meter	150.00	RM/ m^3
Cost per meter run	2700.00	RM/m
Distance	1,500.00	m
Total cost of Groynes	4,050,000.00	**RM**
Total Cost of Construction	**22,525,000.00**	**RM**
Cost of Detailed Engineering Design	**450,500.00**	**RM**
Supervision Costs		
Unit Rate	15,000.00	RM/month
Duration	10.00	Month
Total Cost of Supervision	**150,000.00**	**RM**
Total Cost of Project	**23,125,500.00**	**RM**

4.7 METHOD OF CONSTRUCTION

The method of construction of the proposed works will be as follows.

Bund

a) Lorries will bring rocks from quarry to site and dump on the alignment of the bund.
b) A hydraulic excavator will be used to arrange the rocks.

Groynes

a) Lorries will bring rocks from quarry to site and dump on the alignment of the groynes.
b) A hydraulic excavator will be used to arrange the rocks.

Beach Nourishment

a) Sand will be pumped from a site about 4 km away from the coastline using a cutter suction dredger.
b) Sand will be pumped via a pipeline to a booster pump 2 km away from the dredger.
c) The sand will be pumped from the booster pump to the coastline via a pipeline.
d) A grader will be used to level the sand on the beach.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The pipelines and facilities at MCOT is under threat of erosion and damage from debris and timber logs which being carried along with tide and wave. The following conclusion are based on this study:

I. The existing pipeline buried under the coast will be undermined within 5 to 10 years and may cause hazards to the environment.

II. Bund, groynes and beach nourishment system are proposed to protect the pipelines and facilities at a cost of RM 23 Million.

III. For the short-term mitigation, it is recommended to construct the rock bund at the earliest as a temporary measure to prevent pipelines from being damaged by debris and timber logs.

5.2 PROJECT RISKS & UNCERTAINTIES

The main risks and uncertainties are in the construction and monitoring phase at the shore approach as below:

a) Approval of DID for the construction and the associated environmental management plan is need to be obtained.
b) Scope of the shore approach is still to be defined which may result in cost escalation depending on the beach profile and the amount of dredging required for beach nourishment.
c) To remove the timber logs along the shore to the approved dumping site.
d) Inappropriately designed or misplaced coastal engineering structures which may destroy or reduce the effectiveness of neighbouring natural and engineered structures leading to storm damage, flooding and encroachment by the sea.

e) Undermining of the structure by wave action or surface water runoff.

f) Hydrostatic pressure behind the bund wall and groynes.

Many of the coastal development and investigations use comprehensive physical hydrodynamic model is explain the complex relationship between waves and currents. Although much effort had been exerted in this field, the available information on coastal hydraulics and its impact evaluation using numerical method is still inadequate. Studies done using hydrodynamic model via numerical method for Coastal Engineering problem will prove to be a key area of scientific research and application in the future decades.

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