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**DRAWINGS**

Drawing 1: Typical current field (m/s) calculated in 675 m during neap period, outgoing flow during dry season
Drawing 2: Typical current flow (m/s) calculated in 675 m grid during neap tide, incoming flow during dry season
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1 INTRODUCTION

DHI Water & Environment undertakes the numerical modelling of hydrodynamic and sediment spreading for the proposed new Lung Kwu Chau Jetty as subconsultant to Maunsell Environmental Management Consultants Ltd., Hong Kong.

The methodology for the study approach has previously been described in the Methodology report for hydrodynamic and sediment spreading, cf. Ref. /1/.

The present report describes the set-up and execution of the local hydrodynamic and sediment spreading models used for the study of the Lung Kwu Chau Jetty impact. Subsequently, assessment of the impacts from the new jetty on the water quality and coastal morphology is presented.
2 SUMMARY AND CONCLUSIONS

The local model has been set up to enable simulations of currents and salinity in the Pearl River estuary based on the model suite applied in the Pillar Point Study.

The model has been extended to include a subset grid containing a nested 75 m - 25 m - 8.3 m dynamically linked grid for simulations of currents around the new jetty. As part of these simulations, two culverts are included in the catwalk, which form part of the jetty.

3D simulations have been performed for both dry and wet season hydrodynamics.

The dry season is simulated as a period during 1993, where the model previously has been calibrated against WAHMO data sets. The wet season is simulated as a period during 1996, where SSDS EIA data has been used for model calibration. The simulations have been compared to previous results obtained in the Pillar Point study, and good agreement is observed.

The results imply that the model can be used for description of the hydrodynamic regime around Lung Kwu Chau.

Mitigation measures have been proposed to minimize the water quality impact and comprise a dredging rate of 500 m$^3$/day and implementation of a silt curtain around the closed grab dredger. A higher dredging rate is proposed to reduce the duration of impact of the dredging works on marine ecological receivers, in particular the Chinese White Dolphin which is the key sensitive receiver in the Marine Park. The highest levels of concentration in the sediment plume are shown to remain close to the source. During mitigated dredging, the sediment plumes would be very narrow and even in the plume, the concentrations of suspended matter would, in general, be only slightly elevated. Furthermore, the surplus suspended matter during the dredging works would be well below natural maximum suspended solids concentrations measured in the assessment area, and the impact on water quality would occur on a very local scale and transient nature.

Chinese White Dolphin
Considering the limited magnitude and the local nature of the impact from the dredging operations on turbidity as well as the large area in which the dolphins are distributed, the dolphins will hardly experience the turbidity regime during the construction to deviate substantially for the natural conditions. However, it cannot be totally excluded that transient and local displacements will occur due to changes in fish distribution caused by fish avoidance of the sediment plumes from the dredging.
The potential threats to the dolphins include habitat loss caused by extensive coastal development and reclamation, intense boat traffic causing disturbance and collisions, incidental entanglement in fishing gear, overfishing of prey species and pollution with e.g. organochlorides such as PCB’s and DDT.

Compared to these general threats, the limited impact of the jetty construction on the water quality around Lung Kwu Chau must be regarded as negligible, even considering the general pressure on the dolphin population.

**Impact on benthic organisms and artificial reefs**

An artificial reef has been established in the Marine Park about 2 km south of Lung Kwu Chau. A biological community will develop or have already developed on this artificial reef. As was the case for the fauna in the area in general, only species adapted to a rather high turbidity will colonise the artificial reef. Furthermore, the model calculations show that the artificial reef will be virtually unaffected by sediment from the dredging operations. Therefore, no impact of the jetty construction on the marine life on the artificial reef is expected. The same conclusion is judged to be valid for the occurrences of Gorgonian soft corals that have been observed at some locations near Tree Island and Sha Chau.

**Morphological assessment**

The potential impact that construction of a jetty and dredging of an approach channel to a level of −2.5 m CD in front of the berth at Lung Kwu Chau, Hong Kong, may have on the morphology of the pocket beach located to the north of the project site has been assessed.

The assessment has been based on the analysis of the changes that construction of the jetty and the dredging of the channel will introduce in the wave conditions existing in front of the beach. The rationale behind this approach is that

- Unchanged wave conditions will preserve a stable beach as it exists today
- Significant gradients in wave height along the beach due to the sheltering of the incident waves by the jetty will generate currents capable of transporting sediment, thus impacting on the beach morphology by changing its equilibrium alignment

Wave conditions in front of the beach were determined through a two-step approach. First, the yearly mean wind-wave climate off the eastern coast of Lung Kwu Chau was established by applying MIKE 21 NSW together with yearly wind statistics at Lau Fau Shan. Secondly, the wave conditions in front of the beach were computed using MIKE 21 PMS for five selected wave cases (combination of significant wave height $H_{\text{m0}}$, peak period $T_p$ and mean direction of wave propagation MWD). The simulations considered both the existing situation and following construction of the jetty and dredging of the channel.

The results obtained showed a relatively mild yearly mean wave climate, in agreement with the protected location of the island and the moderate wind conditions in the area.

It was also found that construction of the jetty and dredging of the access channel will not significantly change the wave conditions in front of the beach for the
predominant (easterly) direction. For waves approaching from more southerly directions (150°N and 170°N), the jetty will have a relatively larger impact. However, the beach is to a large extent sheltered from these waves by the rocky headland existing on its southern side. Furthermore, large waves from southerly directions have associated a very low probability of occurrence.

Based on the analysis and the results summarised above, it is concluded that construction of the jetty and dredging of the access channel to –2.5 m CD as projected will not impact negatively on the morphology of the beach to the north of the project site.
3 CLIMATIC AND HYDROGRAPHIC FEATURES

3.1 Climatic Features

Hong Kong is situated in an area dominated by the monsoons. Traditionally, the climatic year in South East Asia is perceived as consisting of the south-west and north-east monsoons separated by so-called transitional periods. A wet season, lasting from April to September, and a dry season, lasting from October to March dominate the climatic year.

From the monthly offshore wind roses in Figure 3.1 it is observed how October and January are dominated by a strong north-east monsoon, while July exhibits a faint south-west monsoon component, only. On the average, the January north-east component amounts to 7.1 m/s while the July south-west component amounts to 4.6 m/s.

3.2 Hydrographic Features

3.2.1 Tide

Numerous islands break up the bathymetry around Hong Kong. The relatively large tidal ranges MHHW at 2.2 m and MLLW at 0.8 m give rise to complicated tidal circulation patterns in the Hong Kong waters and the Pearl Estuary, cf. Figure 3.2. The tide is composed by both diurnal and semidiurnal tides.

Out in the open South China Sea, the tide is of a less complicated character. The tidal wave is entering the deep northern part of the South China Sea through the Luzon strait. Having progressed into relatively shallow water, the tidal wave bifurcates towards north and south. On the south coast of China, the tidal stream appears to set west on the rising tide and east on the falling tide at a mean rate of one knot, Ref. /5/.

Between the islands, speed and direction depend completely on local bathymetric conditions.

From the numerous tide gauges situated along the South Chinese Coast, numerous sets of tidal constituents have been established. Ten sets of constituents are listed in Table 3.1. The stations are listed from west to east. A certain gradual change in the constituents is observed, typically both the phase lag and the amplitude decrease towards east. Possible deviations may be ascribed to variations in the database for the constituent analysis. A short period affected by unusual wind conditions may bias the analysis.

Tidal constituents represent a curve fit to the astronomical tide experienced at a given gauge. Depending on the duration of the underlying measurement series, the constituents represent average tidal conditions at the location in question.
Figure 3.1  January, April, July and October offshore wind roses in the area south of Hong Kong, Ref. /3/. 
Figure 3.2  Hong Kong waters and the Pearl Estuary.
Table 3.1  Tidal constituents M2, S2, K1 & O1 at various stations along the South Chinese Coast (Ref. /3/). The stations outside inner Hong Kong waters are marked on Figure 5.1.

<table>
<thead>
<tr>
<th>Station</th>
<th>No</th>
<th>M2 phase Deg</th>
<th>M2 Amp H(m)</th>
<th>S2 phase Deg</th>
<th>S2 Amp H(m)</th>
<th>K1 phase Deg</th>
<th>K1 Amp H(m)</th>
<th>O1 phase Deg</th>
<th>O1 Amp H(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xiachuan Dao</td>
<td>7063</td>
<td>315</td>
<td>0.6</td>
<td>000</td>
<td>0.2</td>
<td>320</td>
<td>0.4</td>
<td>275</td>
<td>0.3</td>
</tr>
<tr>
<td>Gaolan Dao</td>
<td>7066</td>
<td>309</td>
<td>0.5</td>
<td>348</td>
<td>0.2</td>
<td>319</td>
<td>0.4</td>
<td>270</td>
<td>0.3</td>
</tr>
<tr>
<td>Wenwei Zhou</td>
<td>7087</td>
<td>275</td>
<td>0.3</td>
<td>305</td>
<td>0.1</td>
<td>302</td>
<td>0.3</td>
<td>255</td>
<td>0.3</td>
</tr>
<tr>
<td>Tai Mo To</td>
<td>7096</td>
<td>292</td>
<td>0.49</td>
<td>323</td>
<td>0.19</td>
<td>315</td>
<td>0.4</td>
<td>264</td>
<td>0.31</td>
</tr>
<tr>
<td>Tsing Yi</td>
<td>7102</td>
<td>271</td>
<td>0.42</td>
<td>296</td>
<td>0.17</td>
<td>296</td>
<td>0.36</td>
<td>253</td>
<td>0.29</td>
</tr>
<tr>
<td>Yung Shue Wan</td>
<td>7106</td>
<td>264</td>
<td>0.36</td>
<td>301</td>
<td>0.14</td>
<td>294</td>
<td>0.36</td>
<td>247</td>
<td>0.27</td>
</tr>
<tr>
<td>Hong Kong Harbour</td>
<td>7110</td>
<td>269</td>
<td>0.39</td>
<td>297</td>
<td>0.15</td>
<td>299</td>
<td>0.35</td>
<td>250</td>
<td>0.28</td>
</tr>
<tr>
<td>Waglan Island</td>
<td>7122</td>
<td>268</td>
<td>0.33</td>
<td>298</td>
<td>0.13</td>
<td>299</td>
<td>0.35</td>
<td>250</td>
<td>0.28</td>
</tr>
<tr>
<td>Hong Hai Wan</td>
<td>7145</td>
<td>250</td>
<td>0.3</td>
<td>277</td>
<td>0.1</td>
<td>293</td>
<td>0.4</td>
<td>247</td>
<td>0.2</td>
</tr>
<tr>
<td>Jiazi Jiao</td>
<td>7149</td>
<td>315</td>
<td>0.2</td>
<td>000</td>
<td>0.1</td>
<td>292</td>
<td>0.4</td>
<td>247</td>
<td>0.2</td>
</tr>
</tbody>
</table>
4 HYDROGRAPHIC DATA BASIS

As the present Lung Kwu Chau Jetty model is based on the model applied in the Pillar Point Study, Ref. /3/, the following listing of hydrographic data pertain to the model calibration performed during the Pillar Point study. The 900 m, 675 m and 225 m models applied in the present study are identical to the models applied in the Pillar Point study, for which reason the data listed have been applied in the model calibration for these models.

4.1 Reference System

The vertical datum of all bathymetric information is the Chart Datum, which is 0.146 m below Principal Datum Hong Kong.

Time is local Hong Kong time.

The positions are defined according to the Hong Kong projection characterised by the following parameters:

Centre: 114.1785556
Semi Major Axis: 6,378,888.0
Semi Minor Axis: 6,378,888.0
Scale: 1.0
Flatness: 0.003367
False Easting: 836,695.0
False Northing: -1,649,325,988

4.2 Bathymetric Information

The model area bathymetries (land-water boundaries and water depths) for the various model sets are established from

- Digitised depth information provided by CED (WAHMO data)
- Satellite images from 1989 and 1992
- Updated bathymetry information from new 1994 Chinese survey
- Admiralty Charts
- EPD data around Lung Kwu Chau, received in 2002
The density and coverage of the bathymetric information obtained during this study are indicated in Figure 4.1. A close-up of the density of bathymetric information around the Island of Lung Kwu Chau is provided in Figure 4.2.

Figure 4.1  The density and coverage of bathymetric information obtained during the present study. The position of the established 75 m grid is indicated.
4.3 Water Levels

The following information on water levels has been obtained in the calibration phase.

Royal Observatory of Hong Kong: Amplitudes and phases of major constituents (30) used for tidal prediction in Hong Kong. Constituents have been used from 8 stations: Chi Ma Wan, Lok On Pai, Tai O, Tai Po Kau, Ko Lau Wan, Quarry Bay, Tsim Bei Tsui and Waglan island.

Environmental Protection Department, Hong Kong: Deep Bay Water Quality Regional Control Strategy Study (by AXIS, CES, Delft Hydraulics, etc.) Draft Pearl Estuary Model Report, August 1996.

4.4 Current and Salinity

For the dry season simulations, the 1993 field survey campaign (named WHAMO) was used for calibration of the model set-up.

The campaigns in 1993 included measurements of current (speed and direction) over the water column during approximately 30-hour periods in both spring and neap tide in a number of stations in the area.
In order to perform a valid comparison of simulated and measured current, the measured current is depth-averaged. This is done by calculating the arithmetic mean of the vector components of the measured current in the different sampling depths.

An extensive field campaign was performed in the Hong Kong waters during the wet season in August-September 1996. During this campaign, current (speed and direction) and salinity over the water column were measured.

The campaign in 1996 (named SSDS EIA) included measurements during approximately 30-hour periods in both spring and neap tide distributed over a total period of approximately 9 days. The stations are distributed spatially covering the Pearl Estuary, the inner Hong Kong waters and some offshore areas.

The comparison between simulated and measured variables (current and salinity) during the wet season was carried out at two different depths: at the surface and at mid-depth, though they have been measured at different levels over the vertical.

All comparison have been reported in the Pillar Point study, cf. Ref. /3/.

4.5 Wind

The wind measurements applied in the calibration for the wet season have been derived from the following stations:

1. Green Island (GI)
2. Hong Kong Observatory Headquarter (HKO)
3. Star Ferry (SF)
4. Central (CEN)
5. Hong Kong International Airport (SE only) (AMO)
6. Lau Fau Shan (LFS)
7. Chek Lap KoK (CLK)
8. Tuen Mun (TUN)
9. Cheung Chau (CCH)
10. Waglan Island (WGI)

Time-series of wind speed and direction for the wet season calibration period, i.e. end August through beginning of September 1996, are depicted in Figure 4.3.
Figure 4.3  Time-series of wind speed and direction in 8 selected stations during calibration period August-September 1996.

4.6 River Discharge

For the period of January 1993, information on the river discharge was obtained from four outlets in the upper section of the Pearl Estuary. These flow rates were obtained under the SSDS Stage II study, cf. Ref. [2].

For the period of August-September 1996, information was obtained from China on the river discharge from eight outlets in the Pearl Estuary. It has been assumed that the flow rates correspond to the fresh water discharge, i.e. excluding tidal flows.
5 MODEL SET-UP

5.1 Model Areas

5.1.1 Regional model

The large regional 900 m model was established to ensure that the tidal wave enters correctly among the numerous islands around Hong Kong, see Figure 5.1. The regional model is forced by applying the tidal water level from tidal station Xiachuan Dao (St. 7063) on the shore of the western open boundary and Jiazi Jiao (St. 7149) on the shore of the eastern open boundary. The objective is to deduce tidal constituents in the offshore corner points of the regional model in order to make a tidal wave enter correctly into the inner part of the regional model. The three open boundaries of the regional model are forced by assuming a linear variation of the water level between the shore stations and the offshore corner point. On the southern offshore open boundary, the level variations are described linearly between the western corner point and a so-called 'mid point' (co-ordinate 140.0) and the level variations are described linearly between the mid point and the eastern corner point. The background for this approach is the propagation of the tide, i.e. the phase of the tide is not assumed to be linearly distributed along this southern open boundary.

Characteristics of the regional model are shown below:

\[ \Delta x : 900 \text{ m} \]
\[ \Delta y : 900 \text{ m} \]
\[ \text{Dimensions (0:Nx)} : 0 \text{ - } 438 \]
\[ \text{Dimensions (0:Ny)} : 0 \text{ - } 255 \]
\[ \text{Dimensions} : 394 \text{ x } 230 \text{ km}^2 \]
\[ \text{Origin (lat., long.)} : 20.41615 \text{ o, } 112.97144 \text{ o} \]
\[ \text{Orientation relative to North} : -20 \text{ o} \]
\[ \Delta t : 240 \text{ s} \]
Figure 5.1  Regional model grid with a grid spacing of 900 m. The model is aligned with the coastline of southern China. Tidal stations along the coast are indicated.

Figure 5.2  675 m intermediate grid area for execution of 2D and 3D model simulations with local 225 m and detailed 75 m grids outlined.
5.1.2 Inner model areas
A set of inner model areas has been established, according to the description outlined in the Methodology Report, Ref. /1/.

The model set-up is configured as a three-level dynamically nested grid system (Figure 5.2) with a 675 m grid, a 225 m intermediate grid and two 75 m local grids. In this way, the model covers the entire Hong Kong area, including the Pearl Estuary, and still resolves the flows of Victoria Harbour and the adjacent straits and channels to a certain detail.

Details of the grids are given in Table 5.1.

Table 5.1 Hong Kong model grids.

<table>
<thead>
<tr>
<th>Spacing (m)</th>
<th>Dimension (grid points)</th>
<th>Geographical position (lat.; long.)</th>
<th>Orientation (deg. N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>675</td>
<td>242x172</td>
<td>21.78;112.99</td>
<td>-0.35</td>
</tr>
<tr>
<td>225</td>
<td>241x139</td>
<td>22.15;113.77</td>
<td>0</td>
</tr>
<tr>
<td>75</td>
<td>142x76</td>
<td>22.32;114.01</td>
<td>0</td>
</tr>
<tr>
<td>75</td>
<td>37x61</td>
<td>22.27;114.22</td>
<td>0.1</td>
</tr>
</tbody>
</table>

5.1.3 New Lung Kwu Chau models
A local nested model around Lung Kwu Chau is introduced to enhance the resolution at Lung Kwu Chau. A 75 m, 25 m and 8.3 m nested grid area has been introduced to describe the details of the hydrodynamics around the proposed new jetty, cf. Table 5.2.

Table 5.2 Local nested model around Lung Kwu Chau.

<table>
<thead>
<tr>
<th>Spacing (m)</th>
<th>Dimension (grid points)</th>
<th>Origo in enclosing grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>51x84</td>
<td>30,40</td>
</tr>
<tr>
<td>25</td>
<td>42x57</td>
<td>14,48</td>
</tr>
<tr>
<td>8.3</td>
<td>42x45</td>
<td>19,21</td>
</tr>
</tbody>
</table>

The additional grid refinement is necessary to resolve the proposed jetty, so that hydrodynamic conditions around the jetty can be simulated.

The 75 m model domain covers the entire area around Lung Kwu Chau and Sha Chau, while the 25 m grid area covers the eastern side of Lung Kwu Chau Island and the 8.3 m grid area covers the local area around the jetty.
For description of local hydrodynamic conditions around the proposed jetty, the 75 m - 25 m - 8.3 m model has been applied using transferred boundaries from the larger 225 m model.

Two inner and internally dynamically linked model complexes have thus be applied:

- **225 m - 75 m** for hydrodynamics in the Pearl River Estuary
- **75 m - 25 m - 8.3 m** for description of hydrodynamic conditions around the jetty and spreading of sediments

The full suite of models ranging from 675 m to 8.3 m has not been run dynamically, since the inclusion of an 8.3 m horizontal resolution will increase the computational time. This is due to the added nodes, but more significantly because of the reduced time step to be applied in the model. The vertical resolution is set to be 2 m.
Figure 5.4  Bathymetric land contour applied in the 8.3 m model for the present situation relative to site plan, drawing P20276-1B, Ref. /11/.

Figure 5.5  Bathymetric land contour applied in the 8.3 m model for new jetty. Relative to site plan, drawing P20276-1B, Ref. /11/.
The jetty and the catwalk are located in the innermost model grid, which has a grid spacing of 8.3 m. In this grid, the jetty is represented by 2 grid points, which are both defined as land points. The catwalk is represented by 2 grid points, which are defined as 'structure' points with a north-south aligned culvert structure each. The representation of the jetty and catwalk in the model grid is illustrated in Figure 5.5.

5.2 Culverts

Two culverts are placed in the catwalk to enable a flow through the structure and minimise the impact of the structure on the flow pattern, cf. Figure 5.6.

To enable a model description of the two culverts placed in the catwalk, the model has been extended with the ability of describing structures on the following basis:

The headloss, $\Delta H$, over one culvert is given by:

$$\Delta H = 0.5 \cdot \frac{V^2}{2g} + L \cdot \frac{V^2}{M^2 R^{4/3}} + 1.1 \cdot \frac{V^2}{2g} \quad \text{(Inflow + pipe + outflow)}$$

In which

- $V$: velocity
- $L$: length of jetty value: 15 m
- $M$: Manning number value: 85 m$^{1/3}$/s
- $R$: hydraulic radius value: 0.19 m
- $G$: gravitational acceleration value: 9.82 m$^2$/s

The flux, $Q$, through one culvert is calculated as:

$$Q = V \cdot A = 4\pi \cdot R^2 = 0.45V$$

which, inserted in the previous equation, provides a relationship between $Q$ and $H$:

$$Q = \sqrt{2\Delta H}$$

This enables a description of the flow through a culvert in a single cell grid point based on the water level difference over the cell. The water level difference between the ends of the culverts (across the catwalk) will occur as a result of the tidal wave propagation in the area, and the subsequent water level set-up in front of the jetty.
5.3 Simulation Periods

The simulation period has been chosen identical to the calibration periods previously used in the Pillar Point study. These were chosen based on available data from the monitoring campaigns conducted in the Hong Kong Waters, described in Section 4.
Calibration has previously been conducted on the following data sets and periods:

<table>
<thead>
<tr>
<th>Corresponding data sets</th>
<th>Year</th>
<th>Season</th>
<th>Simulation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSDS EIA</td>
<td>1996</td>
<td>Wet</td>
<td>27/8 - 5/9</td>
</tr>
<tr>
<td>WAHMO</td>
<td>1993</td>
<td>Dry</td>
<td>1/1 - 17/1</td>
</tr>
</tbody>
</table>

5.4 Model Forcing

The main forcing of the hydrodynamic model consists of the tide, which was generated in the regional model and the freshwater inflow from the Pearl River. Moreover, wind is included.

5.4.1 Tide

The calibration of the 900 m regional model surrounding Hong Kong has required a long procedure due to the very limited data available at the boundaries. Furthermore, these boundaries are rather long (approximately 150 km for the west and east boundaries and 400 km for the south boundary), and the tidal propagation over the model domain is complex. For example, the behaviour of the tide along the west and east boundaries is different. In the first case, where the propagation is parallel to the coastline, the phase differences are very small along the boundary; for the east boundary the phases undergo an important variation due to propagation with a large component towards the coast.

This also implies that within the model domain, a large inflection in the tidal propagation has to happen, and there is no data on which to base a detailed description of this phenomenon, as required for an accurate calibration of a mathematical model. Therefore, to calibrate the 900 m regional model it has been necessary to decompose the study of the tidal propagation over the area and to perform a number of sensitivity analyses, from which enough information could be generated to infer the correct behaviour of the boundaries.

For the 900 m regional model, only the further offshore stations (Tai O, Chi Ma Wan and Waglan Island) have been considered. The other stations are analysed in the intermediate 675 m model and finer grid models.

5.4.2 Initial and open boundary conditions

The 675 m model is forced on the open lateral boundaries by water level variations at west and south and by transfer boundary conditions (fluxes and levels) at east. These boundary conditions have been extracted from the regional model. Applied as a "boundary-condition-generator" for the wet season 3D model, the regional model has been run using the same time variant and spatially constant wind as in the 675 m model. Because the regional model supplies depth-averaged (i.e. vertically constant) velocities, the vertical velocity profile at the eastern model boundary has been improved by adding a parabolic wind term from the surface and down to a depth of 20 metres.
$u_{\text{wind}}(z) = U_0 \left( \frac{z + 20}{20} \right)^2$

where $z$ is the vertical co-ordinate in metres measured positive upwards from the sea surface, and $U_0$ was chosen to be 3% of the wind speed. This term proved to be important in order to maintain the eastern model boundary as an outflow boundary, consistent with the wind-driven seasonal surface current.

Prior to the simulations, a 3D initial salinity distribution has been established based on the available measurements as well as on trial model runs during model calibration for the wet season. This salinity field should provide the vertical and horizontal distribution in consistency with the salinity at the boundaries (see below) as well as with the wind-driven flow (see above). Also, the initial salinity field should in the Pearl Estuary contain a sufficient amount of fresh water originating from river inflows prior to the start of the simulation period. At the position of each station, a vertical salinity profile has been interpolated from the measurements to match the computational grid. Vertical profiles were constructed in areas remote from the measurements, e.g. near the model boundaries and in the northern part of the Pearl Estuary. All vertical salinity profiles have then entered an objective analysis procedure to define a salinity value at each computational grid point. The objective analysis has been performed in the horizontal planes only so as not to damage the vertical stratification. The salinity field has then been smoothed horizontally. Due to insufficient amount of measurements, it has been necessary to perform adjustments of the initial salinity field (e.g. shape and position of fronts) as part of the model calibration.

The stratification in the model area during the wet season is maintained through the river run-offs together with the salinity boundary conditions. The baroclinic forcing at the open lateral model boundaries is obtained from prescribed salinity distributions. Since there has been no measured salinity data available to impose on the model boundaries, the boundary salinity distributions have been part of the model calibration. During the wet season, the eastward flowing, wind-generated current carries brackish surface water into the model area from river outlets west of Macau. It is important to include the oceanic current as well as the brackish (~5-15 psu) water supply into the model, since otherwise the modelled salinities in the Hong Kong area will be too much affected by the oceanic water (~34 psu) flushing the area during flood. The salinity boundary conditions must be adjusted to take this into account. This adjustment is, however, complicated due to the very limited temporal and spatial coverage of measured salinities. The final salinity boundary conditions may be schematically described as follows: The salinity is oceanic, 34 psu, at all boundaries below a depth of approximately 8 m. At the surface, a salinity of 32 psu is applied to the north-eastern model boundary, decreasing to 25 psu at the south-eastern model corner, to 16 psu at the south-western model corner and to 12 psu near the coast at the western boundary.
5.4.3 **River discharge**

In the dry season simulations, the model included 4 outlets of the Pearl River freshwater outflow. The flows applied in the four outlets are shown in Table 5.3.

<table>
<thead>
<tr>
<th>Model source</th>
<th>Distributary</th>
<th>Distribution of Total flow</th>
<th>Discharge 1993 (m$^3$/s)</th>
<th>Position in 675 m grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Humen</td>
<td>49%</td>
<td>900</td>
<td>(95,169)</td>
</tr>
<tr>
<td>2</td>
<td>Jiaomen</td>
<td>37%</td>
<td>740</td>
<td>(88,157)</td>
</tr>
<tr>
<td>3</td>
<td>Houggqizhi</td>
<td>10%</td>
<td>200</td>
<td>(91,134)</td>
</tr>
<tr>
<td>4</td>
<td>Hengmen</td>
<td>4%</td>
<td>80</td>
<td>(84,131)</td>
</tr>
</tbody>
</table>

In the wet season model calibration, the Pearl River fresh water inflow is described by eight model sources located in the Pearl Estuary (Table 5.4).

The values of Table 5.4 have been calculated as average discharge values over the periods of calibration for the simulation. It appears that the distribution of the outflow for the eight tributaries follows a fixed relation with respect to the upstream flow. These fixed relations (calculated as average values for the simulation periods) are included in Table 5.4.

<table>
<thead>
<tr>
<th>Model source</th>
<th>Distributary</th>
<th>Percentage (%)</th>
<th>Discharge 96 (m$^3$/s)</th>
<th>Position in 675 m grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Humen</td>
<td>18.5</td>
<td>3798</td>
<td>(95,169)</td>
</tr>
<tr>
<td>2</td>
<td>Jiaomen</td>
<td>17.3</td>
<td>3551</td>
<td>(88,157)</td>
</tr>
<tr>
<td>3</td>
<td>Houggqizhi</td>
<td>6.4</td>
<td>1314</td>
<td>(91,134)</td>
</tr>
<tr>
<td>4</td>
<td>Hengmen</td>
<td>11.2</td>
<td>2299</td>
<td>(84,131)</td>
</tr>
<tr>
<td>5</td>
<td>Modaomen</td>
<td>28.3</td>
<td>5809</td>
<td>(53,85)</td>
</tr>
<tr>
<td>6</td>
<td>Jidimen</td>
<td>6.1</td>
<td>1254</td>
<td>(43,51)</td>
</tr>
<tr>
<td>7</td>
<td>Hutiaomen</td>
<td>6.2</td>
<td>1272</td>
<td>(56,64)</td>
</tr>
<tr>
<td>8</td>
<td>Yamen</td>
<td>6.0</td>
<td>1231</td>
<td>(16,74)</td>
</tr>
</tbody>
</table>
5.4.4 Wind

It has been attempted to include the wind based on recordings from the calibration periods during the wet season. The purpose being partly to drive the offshore current while simultaneously including the wind effects on the calculated current pattern in the area.

The wind has been applied as time variant but simultaneously constant in space due to the high correlation between the measurement stations. Time-series of averaged wind speed and directions over the 10 available stations (see Section 4.5) have been applied to the model during the wet season.

During dry season simulations, a temporally constant wind field has been applied.

5.4.5 Tilting

In the calibration, it has been attempted to include the offshore deep current by introducing a tilting of the boundary in the regional model. In this manner, a unidirectional flow is imposed in the model attaining current speed corresponding to the water level increase. A water level difference of 0.50 m has been introduced between the eastern and western boundaries (±0.25 m at the boundaries) of the regional model. As an effect of the tilting, the water levels in the model are slightly distorted and present an offset with the predicted water levels in the order of 0.20 - 0.25 m. This offset has to be considered and included in the water level results.

The tilting is intended to replace the effect obtained by introducing an artificial wind field to drive the offshore current.
6 SIMULATION RESULTS

6.1 Model verification

The results of the simulations with the local model set-up have been compared to the results achieved during the Pillar Point study. Hereby, verification of the model performance has been obtained.

Two points in the 75 m grid have been selected, east and west of the Lung Kwu Chau Island, and current speed and direction have been compared for the 75 m nested model with results obtained in the 225 m model used during the Pillar Point study. The location of the points are indicated in Figure 6.1.

The results for the dry season simulations of this study are presented as 3D results, whereas previous results were obtained in a 2D simulation. The success criterion for acceptable performance is hence that the 3D results for current speed and direction are centred around the previously obtained 2D results.
Figure 6.1  Position of two points (9,57) and (36,57) for comparison of present study results with previous Pillar Point results.

Comparisons of dry season simulations are shown in Figure 6.2 through Figure 6.7.
Figure 6.2  Comparison between previous calculated water level results and presently calculated results in point (36,57) in the 75 m resolution. 17 days during dry season shown.

Figure 6.3  Comparison between previous calculated water level results and presently calculated results in point (36,57) in the 75 m resolution. 2-day subset during dry season shown.

Figure 6.4  Comparison between previous calculated current speed (depth averaged) and presently calculated speeds in point (36,57) in the 75 m resolution. 17 days during dry season shown.
Figure 6.5  Comparison between previous calculated current speed (depth averaged) and presently calculated speeds in point (36,57) in the 75 m resolution. 2-day subset during dry season shown.

Figure 6.6  Comparison between previous calculated current directions (depth averaged) and presently calculated directions in point (36,57) in the 75 m resolution. 17 days during dry season shown.

Figure 6.7  Comparison between previous calculated current directions (depth averaged) and presently calculated directions in point (36,57) in the 75 m resolution. 2-day subset during dry season shown.
The results for the dry season show that the calculated water levels in the 3D simulations are similar to the previous results. Further it is seen that current direction and magnitude are enclosed in the 2D results previously obtained, which should be expected.

It is concluded that the model describes the hydrodynamic situation satisfactorily.

**Wet season**

Calculated currents are shown in Figure 6.8 and Figure 6.9 for the wet season period at selected times to illustrate the resolution in velocity field around Lung Kwu Chau.

![Figure 6.8](image)

*Figure 6.8 75 m model results for wet season. Embedded 25 m and 8.3 m net.*
In Figure 6.10 through Figure 6.12 the calculated results for current speed, current directions and salinity are shown for the wet season simulations as compared to results calculated under the Pillar Point study. It is observed that good agreement is obtained.

Figure 6.10  Comparison between previous calculated current speed and presently calculated speeds in point (36,57) in the 75 m resolution. Values from layer 1 (bottom) and layer 10 (surface) are shown during 5 days of wet season simulation.
Based on these results for dry and wet season simulations, it is concluded that the model adequately describes the current conditions in the Lung Kwu Chau area.

### 6.2 Influence of the jetty

Based on the hydrodynamic simulations for the dry season period with the 75 m - 25 m - 8.3 m analyses of the influence of the jetty and the effects of the culverts have been performed. The presence of a jetty will block a part of the north-south going water flow in the vicinity of the coast.

In Figure 6.13 and Figure 6.14 snapshots of the current fields without and with the jetty during falling and rising tide are given. In Figure 6.15 difference current plots calculated as jetty scenario minus reference scenario are given. The plots
demonstrate the blocking effect of the jetty. In the difference plots it is observed that a current difference in the order of 0.5-1.0 m/s is present in the area around the jetty periodically during spring tide conditions.

Figure 6.13  Instantaneous current plots for the reference scenario (upper) and jetty scenario (lower) during a falling tide situation. Contours show current magnitude. Notice that the two grid points containing the culverts in the jetty scenario in the plot appear as water points with small current velocities.
Figure 6.14  Instantaneous current plots for the reference scenario (upper) and jetty scenario (lower) during a rising tide situation. Contours show current magnitude. Notice that the two grid points containing the culverts in the jetty scenario in the plot appear as water points with small current velocities.
Figure 6.15 Difference current plots for falling tide (above) and rising tide (lower) situations. Calculated as jetty scenario current velocities minus reference scenario current velocities. Contours show current magnitude.
6.2.1 Tracer experiment

In order to assess the impact of the proposed jetty on the flushing of the small bay north of the jetty, a numerical tracer experiment is performed. For this purpose the advection-dispersion module of MIKE 3 is applied. Simulations with a conservative tracer are made. The water inside the small bay is given an initial concentration of 100, whereas the remaining water in the model is given an initial value of 0. The model boundary conditions are also specified as 0. In this way, the simulated concentrations inside the small bay at any time can be interpreted as the percentage of the initial bay water still present. Figure 6.16 shows the initial conditions of the tracer.

![Initial tracer field and tracer field after 12 hours of simulation (reference scenario).](image)

The tracer experiment was performed with the reference scenario, with the jetty scenario and furthermore with a scenario including the jetty and the catwalk but excluding the culverts. Figure 6.17 shows a time-series plot of tracer concentrations in Station A (Figure 6.16). This plot shows the relatively small effect of the jetty on the flushing of water in the small bay.
Figure 6.17  Time-series of tracer concentrations in Station A for three different scenarios.

Culverts
The introduction of culverts in two elements in the catwalk enables the flow to pass through the structure during the simulation period. In Figure 6.18 the calculated flow through the culverts in the catwalk is depicted. It is observed that the flow is of limited magnitude, which is to be expected, since the flow is driven by the gradient in the water level from one side of the jetty to the other.

Figure 6.18  Calculated flow discharge through culverts in the catwalk.
### 6.3 Sediment spill modelling

The simulations of spreading of suspended solids from dredging activities are performed using the PA, Particle Dispersion model. The PA model is an add-on module to the hydrodynamic module and simulates spreading, sedimentation and re-suspension of particulate matter based on a pre-calculated flow field. A detailed description of the PA model background is provided in the Methodology Report, Ref. /11/.

In order to enable a detailed 3D description of the hydrodynamics for the sediment spreading, the nested 75 m - 25 m - 8.3 m model grid is applied. All boundary conditions for the 75 m model are obtained from the 225 m model.

The spreading of the suspended sediment released from the dredging works is calculated based on the proposed work procedure and resulting expected spill.

#### 6.3.1 Construction phase scenario

The dredging will be undertaken using one closed grab dredger of small capacity. 5,550 m$^3$ material is assumed to be dredged at the site. Two scenarios are considered:

1. An unmitigated scenario
2. A mitigated scenario, during which silt curtains are applied.

The dredging rate for the unmitigated case is 250 m$^3$/day and a spill of 20kg/m$^3$ removed mud is expected. This amount to an average spill rate at 0.13 kg/s, based on maximum daily rate of dredging (and assuming 11-hour working day). The dredging rate for the mitigated case is 500 m$^3$/day and a spill of rate of 0.065 kg/s is anticipated, based on maximum daily rate of dredging, and assuming 11-hour working day. The implementation of silt curtains around the closed grab dredger will reduce the release of sediment by a factor of 4 (Contaminated Spoil Management Study). Due to a doubling of the dredging rate, the dredging sequence will only last half the period, i.e. 12 days.

The construction phase scenarios are consequently:

- Unmitigated spill release of 0.13 kg/s during 11 hours a day for 22 days
- Mitigated spill release of 0.065 kg/s during 11 hours for 11 days

The simulations are conducted for the dry season period.

The location of the dredging area is shown in Figure 6.19.

The resulting output of the simulation is the calculated time dependent excess concentrations of sediment in suspension and areal coverage of the plume and sedimentation.

The stated Water Quality Objectives, WQO, in the North Western Water Control Zone for suspended solids is to remain below natural ambient level +30% and activities may not cause the accumulation of suspended solids, which may adversely
affect aquatic communities. This criterion corresponds in this context to a surplus concentration of 5.5 mg/l, see later in Section 7.

The sediment is expected to be fine mud. One sample of the seabed has been analysed for grain size distribution, and the resulting distribution curve is shown in Drawing 3. The analysis reveal that more than 50% of the sea bed material has a grain diameter less than 4 micron. And more than 80% of the material has a grain diameter less than 20 micron. To represent the material, the mean grain diameter of the material is set to 8 micron in the simulations to include flocculation effects, and the controlling parameter in the simulation, which is the fall velocity, is set accordingly. The fall velocity has been determined by use of Stokes law.

Figure 6.19 Position of the new jetty and area of dredging.

Table 6.1 Parameters used for spreading simulation.
### 6.3.2 Spreading simulation results

Main results from the simulation of dredging spill are depicted in the following figures. Further results are also presented in Section 7 on environmental impact.

For the unmitigated scenario, Figure 6.20 shows the calculated statistical maximum values of suspended sediment concentrations based on a 24-day simulation period. The concentration level signifies the maximum level attained at any point during the entire period, and does consequently not represent an instantaneous concentration level at any time.

The figure shows that generally the highest levels of concentration in the sediment plume remain relatively close to the island. The corresponding results for the mitigated 11-day dredging scenario is shown in Figure 6.21.

Figure 6.22 and Figure 6.23 show the calculated sedimentation rate during the entire simulation period. The figures also indicate which area is subjected to increased concentration levels from the dredging spill. It is observed that while the area to the north of the island is subjected to increased SS concentration over a larger area, the increase is very marginal.

In comparison, Figure 6.24 and Figure 6.25 show that, as expected, the main part of the sedimentation remains close to the island and is located south of the dredging area. And while the northern area is subjected to sedimentation over a larger area, the area just to the south of the location of dredging is subjected to increased levels of sedimentation relative to the area north of the location of dredging.

The total net sedimentation after the simulation period is depicted in Figure 6.26 and Figure 6.27. The figures show that a thin plume propagates to the southern model domain, but since the resulting sedimentation is very low, so is the concentration.

<table>
<thead>
<tr>
<th>Mean grain size diameter (micron)</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall velocity (mm/s)</td>
<td>0.04</td>
</tr>
<tr>
<td>Shields parameter</td>
<td>0.045</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>2.65</td>
</tr>
</tbody>
</table>


Figure 6.20 Unmitigated scenario: Calculated statistical maximum values of concentration based on a 24-day simulation period. The concentration level signifies the maximum level attained at any point during the entire period, and does not represent an instantaneous concentration level at any time.
Figure 6.21  Mitigated scenario: Calculated statistical maximum values of concentration based on a 12-day simulation period. The concentration level signifies the maximum level attained at any point during the entire period, and does not represent an instantaneous concentration level at any time.
Figure 6.22  Unmitigated scenario: Calculated average sedimentation rate in kg/m²/day during the entire simulation period.
Figure 6.23 Mitigated scenario: Calculated average sedimentation rate in kg/m²/day during the entire simulation period.
Figure 6.24  Unmitigated scenario: Calculated average sedimentation rate in kg/m^2/day during the entire simulation period along eastern coastline of Lung Kwu Chau.
Figure 6.25 Mitigated scenario: Calculated average sedimentation rate in kg/m²/day during the entire simulation period along eastern coastline of Lung Kwu Chau.
Figure 6.26 Unmitigated scenario: Total net sedimentation in kg/m$^2$ resulting from entire dredging sequence during a period of 24 days.
Figure 6.27  Mitigated scenario: Total net sedimentation in kg/m² resulting from entire dredging sequence during a period of 12 days.
7 ENVIRONMENTAL IMPACT ASSESSMENT

7.1 Water Quality

The main impact of the project on the water quality around Lung Kwu Chau is anticipated to be an increased turbidity during dredging of the seabed caused by the release and dispersal of sediments. On this background, the following assessment will focus on the potential impacts of the sediment dispersal on sensitive species and habitats.

7.2 Background Conditions

The water around Lung Kwu Chau is generally rather turbid (unclear). A high turbidity is very common in river estuaries due to river discharges of suspended sediment. The results of the monitoring of suspended solids at four stations in the Sha Chau and Lung Kwu Chau Marine Park during 1997-2000 are summarised in Table 7.1. The monitoring shows depth-averaged mean concentrations of suspended solids of 11.5 – 13.4 mg/l. The measured concentrations ranged from 2 to 113 mg/l and even the station with lowest maximum was 35 mg/l.

Table 7.1 Concentrations of depth-averaged suspended solids for monitoring stations in Sha Chau and Lung Kwu Chau Marine Park.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Monitoring Station</th>
<th>Overall average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS (mg/l)</td>
<td>N Lung Kwu Chau</td>
<td>N Sha Chau</td>
</tr>
<tr>
<td>Mean</td>
<td>13.0</td>
<td>11.5</td>
</tr>
<tr>
<td>Range</td>
<td>3.0 – 113.0</td>
<td>2.0 – 36.0</td>
</tr>
<tr>
<td>90th percentile</td>
<td>20.4</td>
<td>16.0</td>
</tr>
<tr>
<td>(ambient level)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30% increase of ambient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>level</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The water quality objectives for marine waters in the North Western Water Control Zone in Hong Kong, concerning the concentration of suspended solids, are the following: "Waste discharge not to raise the natural ambient level by more than 30%, nor cause the accumulation of suspended solids which may adversely affect aquatic communities."

In the assessment below, the ambient level of the concentration of suspended solids is defined as the 90th percentile of the observations in 1997-2000. These values range from 16.0 to 20.4 mg/l at the four stations with an average of 18.23 mg/l (Table 7.1). A 30% increase of the ambient level is thus defined as an increase of 5.5 mg/l.

### 7.3 Release and Dispersal of Sediments

The major activities involved during the construction stage of the project are dredging for approach channel and foundation of the jetty and catwalk, filling rubble foundations, setting precast concrete blocks, placing bermstones, general concrete work and demolition of existing jetty. Of these activities, only the dredging is believed to cause significant release of sediments.

The expected amounts of sediment spill during dredging and the patterns of dispersal and the resulting increase in concentration of suspended solids are assessed in Section 6.3 by means of model calculations. Two scenarios have been described. One scenario deals with unmitigated dredging and the other considers dredging with the case that the sediment dispersal is mitigated by means of silt curtains and shortening of the dredging period. The assumptions of the model calculations are described above.

Figure 7.1 and Figure 7.2 show examples of the calculated instantaneous concentration of suspended sediment from unmitigated dredging during southgoing and northgoing current, respectively. During dredging, sediment plumes being generally less than 200 m wide will go along the coast of Lung Kwu Chau. Calculated statistical maximum concentrations above 50 mg/l and 20 mg/l, respectively, will be experienced up to 100 and 250 m away from the working area in case of northgoing current and at shorter distances during southgoing current (Figure 7.5). The maximum surplus concentration is predicted to be higher than 5.5 mg/l in the nearby bays and just outside these in areas extending up to 400 m from the coast. However, in the main part of these areas, SS concentrations of higher than 5.5mg/l would occur less than 10% of the time during the 24-day simulation period (Figure 7.7).

Figure 7.3 and Figure 7.4 show the calculated instantaneous concentration of suspended sediment from mitigated dredging during northgoing and southgoing current, respectively. During mitigated dredging, the sediment plumes will be very narrow (20-60 m) and even in the plume, the concentrations of suspended matter will, in general, be only slightly elevated (1-4 mg/l).

Maximum concentrations above 20 mg/l and 10 mg/l, respectively, will be experienced up to 200 m and 400 m away from the working area in case of northgoing current and at shorter distances during southgoing current. The maximum surplus SS concentration is predicted to be higher than 5.5 mg/l in an area along the eastern coast being approximately 400m long. However, in the major part of this area, the surplus SS concentrations would occur less than 1% of the time.
during the 12-day dredging period (Figure 7.8). Even very close to the working area, elevations in SS concentrations of higher than 5.5mg/l would occur less than 10% of the time (less than 1 day).

From the considerations above, even if no mitigation measures are applied, the impact of dredging on the concentration of suspended solids will occur only on a very local scale and through a rather short time. Furthermore, the sediment load outside the working area and very close to this will be well below natural maximum concentrations measured in the area during 1997 – 2000. If the impacts of dredging are mitigated by using silt curtains and by shortening the dredging period, the impacts on water quality will be of an even more local and transient nature.
Figure 7.1  Calculated instantaneous concentration of suspended solids released from unmitigated dredging for the proposed jetty at Lung Kwu Chau during northgoing current.
Figure 7.2  Calculated instantaneous concentration of suspended solids released from unmitigated dredging for the proposed jetty at Lung Kwu Chau during southgoing current.
Figure 7.3  Calculated instantaneous concentration of suspended solids released from mitigated dredging for the proposed jetty at Lung Kwu Chau during north-going current.
Figure 7.4  Calculated instantaneous concentration of suspended solids released from mitigated dredging for the proposed jetty at Lung Kwu Chau during southgoing current.
Figure 7.5  Calculated statistical maximum concentration of suspended solids released from unmitigated dredging for the proposed jetty at Lung Kwu Chau.
Figure 7.6  Calculated statistical maximum concentration of suspended solids released from mitigated dredging for the proposed jetty at Lung Kwu Chau.
Figure 7.7 Areas in which SS concentrations higher than 5.5 mg/l occur a certain percentage of the time during the 24-day simulation period of unmitigated dredging for the proposed Jetty at Lung Kwu Chau.
Figure 7.8 Areas in which SS concentrations higher than 5.5 mg/l occur a certain percentage of the time during the 12-day simulation period of mitigated dredging for the proposed Jetty at Lung Kwu Chau.
7.4 **Chinese White Dolphin**

The construction of the jetty will take place in the Sha Chau and Lung Kwu Chau Marine Park, which were established mainly to protect the population of Chinese White Dolphin in Hong Kong Waters.

Chinese White Dolphin is the local name of the species more broadly known as Indo-Pacific Humpback Dolphin, *Sousa chinensis*. The species are distributed throughout shallow coastal waters of the Indian and the western Pacific Oceans, from South Africa in the west to the northern Australia and southern China in the east (Ref. /4/).

The Dolphins that inhabit Hong Kong waters belong to a population centred around the mouth of Pearl River. The dolphins are distributed in the eastern Pearl River Estuary, from the western waters of Hong Kong to at least the Zhuhai and Macau areas. The dolphins are protected in Hong Kong by the Wild Animals Protection ordinance, Cap. 170 (Ref. /4/).

Within Hong Kong waters, dolphins occur only regularly to the north and west of Lantau Island. There are seasonal changes in the distribution patterns of dolphins in the north Lantau area. In winter and spring, dolphins are mostly seen west of Brothers’ Islands, while in summer and autumn they are more continuously distributed in the entire North Lantau area (Refs. /5/ and /7/). This means that dolphins explore the areas around Lung Kwu Chau throughout the year.

The abundance of dolphins in Hong Kong waters are observed to range from 88 dolphins in spring to 145 in the summer. The best available estimate of the total population in the Pearl River Estuary is 1028 dolphins (Ref. /4/).

The highest abundance and widest distribution of the dolphins in Hong Kong waters are associated with the season of the largest freshwater discharge from Pearl River. The dolphins feed almost entirely on fish. It is believed that a high abundance of fish associated with the mixing zone of fresh water and seawater is a main factor determining the seasonal variations in dolphin abundance and distribution (Refs. /4/ and /5/).

In its entire area of distribution, the Indo-Pacific Humpback Dolphin is mainly found in shallow coastal areas and it generally has a preference of estuarine waters. The species in general are therefore naturally adapted to a turbid environment. Turbidity is believed to be of minor importance for the species itself, as the dolphins generally rely more on echolocation than on vision for navigation and location of prey items. This also holds through for the dolphins in the Sha Chau and Lung Kwu Chau Marine Park and in the whole North Lantau area. These dolphins are in fact most abundant in the seasons associated with highest natural concentrations of suspended solids.

Considering the limited magnitude and the local nature of the impact from the dredging operations on turbidity as well as the large area in which the dolphins are distributed, the dolphins will hardly experience the turbidity regime during the construction to deviate substantially for the natural conditions. However, it cannot be totally excluded that transient and local displacements will occur due to changes.
in fish distribution caused by fish avoidance of the sediment plumes from the dredging.

The dolphins in Hong Kong Waters are believed to be under great pressure, and concern about the future existence of the species in Hong Kong have been expressed (see e.g. Ref. /6/). The potential threats to the dolphins include habitat loss caused by extensive coastal development and reclamation, intense boat traffic causing disturbance and collisions, incidental entanglement in fishing gear, overfishing of prey species and pollution with e.g. organochlorides such as PCB’s and DDT.

Compared to these general threats the limited impact of the jetty construction on the water quality around Lung Kwu Chau must be regarded as negligible, even considering the general pressure on the dolphin population.

7.5 Impact on Benthic Organisms and Artificial Reefs

Potential impacts of the release of suspended sediments on benthic organisms include, in general, shading of macroalgae (seaweeds), seagrass and stony corals, which all depend on light for growth and survival. Furthermore, large concentrations of suspended solids may smother the feeding organs or in other ways impair the feeding of organisms that filter microscopic food from the water column (filter feeders, e.g. bivalves). Furthermore, sedimentation of spilled sediments may potentially cover and smother benthic fauna and vegetation and the settling and establishment of the young stages of benthic fauna (larvae) and macroalgae (spores) on the seabed may be impaired.

However, in the present case it is important to note that all benthic species living in the Lung Kwu Chau area must be adapted to an environment, which is generally turbid and where very high concentrations of suspended solids occur occasionally. Therefore, no benthic communities that are really sensitive to increased turbidity such as coral reefs have developed in the area. As the turbidity during dredging is not expected to deviate substantially from the natural conditions, no impact of increased turbidity on benthic communities is expected outside the working area and very close to this.

Along the main part of the eastern coast of Lung Kwu Chau, the sedimentation due to unmitigated dredging will be below 50 g/m\(^2\)/day or approximately 1200 g/m\(^2\) through the whole construction period, assuming 24 days of dredging. This corresponds to a sediment layer of 1-2 mm. The maximum sedimentation rates in small areas near the jetty are expected to be up to 150 g/m\(^2\)/day or 3600 g/m\(^2\) through the whole construction period, corresponding to a sediment layer of 3-4 mm. In most of the impacted area, the sedimentation induced by mitigated dredging will be below 100 g/m\(^2\) through the whole period, corresponding to a sediment layer of 0.1 mm. Only in very small areas, the total sedimentation will exceed 500 g/m\(^2\) corresponding to a layer of approximately 0.5 mm. The impact of dredging-induced sedimentation on Gorgonian soft corals, that have been observed on a shipwreck off the coast approximately 200-300 m north of the working area, is therefore predicted to be minimal. As the natural seabed in the bay areas consists mainly of soft sediments (sand and mud), even the local impact of sedimentation on benthic organisms are expected to be limited and temporal of nature.
An artificial reef has been established in the Marine Park about 2 km south of Lung Kwu Chau. A biological community will develop or have already developed on this artificial reef. No description of the biological colonisation of the artificial reef has been available for the present assessment. However, the community is likely to be made up of sessile animal species like soft corals, sponges, barnacles, bivalves, squirts (tunicates), bryozoans and an associated mobile fauna of crustaceans, sea stars, brittlestars and fish. Some seaweed species may also colonise the artificial reef, if the light conditions allow for this. However, as was the case for the fauna in the area in general, only species adapted to a rather high turbidity will colonise the artificial reef. Furthermore, the model calculations show that the artificial reef will be virtually unaffected by sediment from the dredging operations (Figure 7.9 and Figure 7.10). Therefore, no impact of the jetty construction on the marine life on the artificial reef is expected. The same conclusion is judged to be valid for the occurrences of Gorgonian soft corals that have been observed at some locations near Tree Island and Sha Chau.

### 7.6 Other Impacts on Water Quality

Other potential impacts of the project on the water quality include the release of inorganic nutrients from the dredged sediments, giving rise to an increased growth of phytoplankton. Similar organic and inorganic oxygen consuming substances may be released leading to local decreases in water oxygen content. However, due to the limited sediment release and the short duration of the work, these impacts are expected to be negligible and the water quality objectives concerning these parameters (Table 7.2) are expected not to be violated.

The presence of the proposed jetty and catwalk may cause some degree of interference with the existing water circulation pattern, which again may lead to changes of the water quality. However, simulation results reveal that no major interception of water current is to be expected. Thus, the permanent impact of the project on the water quality around Lung Kwu Chau is anticipated to be small and to occur only on a very local scale.
Figure 7.9 Location of the artificial reef and the calculated statistical maximum concentrations of suspended sediments from unmitigated dredging for the jetty at Lung Kwu Chau.
Figure 7.10 Location of the artificial reef and the calculated sedimentation rates during unmitigated dredging for the jetty at Lung Kwu Chau.
### Table 7.2: Summary Statistics (mean and range) of Water Quality of Sha Chau and Lung Kwu Chau Marine Park in 1997 – 2000.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Monitoring Station</th>
<th>WPCO WQOs (in marine waters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N Lung Kwu Chau</td>
<td>N Sha Chau</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>24.0</td>
<td>24.1</td>
</tr>
<tr>
<td></td>
<td>(10.0 – 30.3)</td>
<td>(10.0 – 30.0)</td>
</tr>
<tr>
<td>Salinity (ppt)</td>
<td>26.5</td>
<td>26.4</td>
</tr>
<tr>
<td></td>
<td>(3.0 – 36.9)</td>
<td>(3.0 – 36.2)</td>
</tr>
<tr>
<td>DO (mg L⁻¹)</td>
<td>Surface</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.4 – 8.5)</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.9 – 8.6)</td>
</tr>
<tr>
<td>pH value</td>
<td>8.1</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>(7.6 – 8.4)</td>
<td>(7.6 – 8.4)</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>15.6</td>
<td>9.67</td>
</tr>
<tr>
<td></td>
<td>(1.0 – 146.0)</td>
<td>(0.5 – 42.1)</td>
</tr>
<tr>
<td>SS (mg L⁻¹)</td>
<td>13.0</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td>(3.0 – 113.0)</td>
<td>(2.0 – 36.0)</td>
</tr>
<tr>
<td>BOD₅ (mg L⁻¹)</td>
<td>0.80</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>(0.01 – 2.27)</td>
<td>(0.05 – 1.99)</td>
</tr>
<tr>
<td>Ammoniacal Nitrogen (mg L⁻¹)</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>(0.02 – 0.64)</td>
<td>(0.01 – 0.76)</td>
</tr>
<tr>
<td>Total Inorganic Nitrogen (mg L⁻¹) **</td>
<td>1.56</td>
<td>1.61</td>
</tr>
<tr>
<td></td>
<td>(0.03 – 8.29)</td>
<td>(0.04 – 8.87)</td>
</tr>
<tr>
<td>Total Phosphorus (mg L⁻¹)</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>(&lt;0.02 – 0.31)</td>
<td>(&lt;0.02 – 0.62)</td>
</tr>
<tr>
<td>Chlorophyll-a (μg L⁻¹)</td>
<td>2.94</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>(0.21 – 16.3)</td>
<td>(0.5 – 22.4)</td>
</tr>
<tr>
<td>Unionized Ammonia (mg L⁻¹)</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>(0.01 – 0.09)</td>
<td>(0.00 – 0.09)</td>
</tr>
<tr>
<td>E.coli (colonies/100ml)**</td>
<td>90.2</td>
<td>63.5</td>
</tr>
<tr>
<td></td>
<td>(0.0 – &gt;200)</td>
<td>(0.0 – &gt;200)</td>
</tr>
</tbody>
</table>

Notes:
1. The presented data are depth-averaged data, except when specified otherwise.
8 MORPHOLOGICAL IMPACT ASSESSMENT

This section describes the methodology and data used in the assessment of the impact that construction of the projected jetty at Lung Kwu Chau may have on beach morphology, together with the results obtained and the conclusions reached.

8.1 Description of Problem

There is some concern that construction of the projected jetty at Lung Kwu Chau may have a negative impact on the morphology of the beach located immediately to the north of the rocky headland where the jetty will be constructed. The position of the jetty and the beach are indicated on Figure 8.1 below.

![Aerial photograph of Lung Kwu Chau, where the position of the projected jetty and the beach subject of the present assessment have been indicated](image)

Figure 8.1 shows that the beach is a small pocket beach that extends between two rocky headlands, which keep the beach in place. Figure 8.2 and Figure 8.3 show a view from the sea of the beach and of the existing jetty.
Construction of the planned jetty could impact on the beach morphology if the shadow zone that the new jetty will generate on its lee side encompasses the beach. Accumulation of sediment in the lee side of shore-normal structures such as groins and jetties due to the current that flows towards the area protected from the incident waves by the structure is a well-known mechanism in coastal engineering practice.
The morphological impact assessment that is described in further detail in the following sections of this note has been based on this concept.

### 8.2 Study Methodology

The east coast of Lung Kwu Chau is well protected from waves from westerly directions due to its location close to Hong Kong peninsula and Lantau Island, see Figure 8.4.

![Figure 8.4](image)

Waves reaching the eastern coast of Lung Kwu Chau are therefore locally generated by winds blowing from easterly directions and possibly also from north and south.

Based on the above discussion and on the approach described in Section 8.1, the morphological impact assessment has consisted of the following tasks:

1. Establishment of yearly-averaged wind-wave climate off Lung Kwu Chau

2. Detailed analysis of wave conditions in the vicinity of the project site, both for the present situation and after construction of the jetty and dredging of the approach channel

3. Assessment of impact on beach morphology based on the comparison of the results obtained from the propagation of selected wave cases for the existing conditions and after construction of the jetty
Tasks 1 and 2 are described in further detail in the following sub-sections, while the analysis of results and assessment of impact on beach morphology are discussed in Section 3 of the present note.

8.2.1 Yearly mean wind-wave climate off the eastern coast of Lung Kwu Chau

DHI's nearshore wind-wave model MIKE 21 NSW was used to generate the yearly mean wind-wave climate off the eastern coast of the island.

MIKE 21 NSW is a spectral wind-wave model, which describes the propagation, growth and decay of short-period waves in nearshore areas. The model includes the effects of refraction and shoaling due to varying depth, wave generation due to wind and energy dissipation due to bottom friction and wave breaking. The effects of current on these phenomena are included. For additional details regarding MIKE 21 NSW, cf. Ref. /8/ and the User Guide for the model.

Wind statistics derived from 12 years of wind records at Lau Fau Shan automatic weather station, Ref. /9/, were used as input for the generation of wind-waves using the MIKE 21 NSW model. Wind data are presented in tabular form, as percentage frequency of occurrence of hourly wind direction and speed, at 30° intervals for wind direction and for wind speed classes 0-3.2 m/s, 3.3-8.2 m/s, 8.3-14.2 m/s and >14.2 m/s. Very few data fall in the last wind speed class, thus indicating that wind conditions in the area are relatively mild.

The wind rose corresponding to the data used in the present study is shown in Figure 8.5 below.

![Wind rose for Lau Fau Shan (1986-1997)](image)

Figure 8.5 Wind rose for Lau Fau Shan (1986-1997)

The figure shows that prevailing winds in the area are from the NE-SE sector.

Model bathymetries were generated using information about the variation of water depths in the area available from digital sea charts. Due to MIKE 21 NSW requirement regarding the maximum allowable angle between wind (wave) direction
and the x-axis of the model bathymetry (which points towards land), a number of bathymetries were generated to accommodate all winds between north and south, i.e. wind directions between 0° and 180°. The bathymetry used to generate wind-waves corresponding to wind from east is shown as an example in Figure 8.6. Note that north is pointing downwards in this figure.

![Figure 8.6 MIKE 21 NSW model bathymetry](image)
As Figure 8.6 shows, the water depths in the area around Lung Kwu Chau range between 4 m and 8 m. A shallow area around continental Hong Kong, with depths less than 4 m can also be seen. A deep channel (Urmston Road) separates Lung Kwu Chau from the mainland.

The wave rose corresponding to the yearly mean wind-wave climate generated using MIKE 21 NSW off Lung Kwu Chau is shown in Figure 8.7.

![Wave rose for wind-waves off the eastern coast of Lung Kwu Chau generated by MIKE 21 NSW](image)

Analysis of Figure 8.7 leads to the following conclusions:

- Almost 50% of the time, the significant wave height $H_{m0}$ is less than 0.05 m
- Waves off the eastern coast of the island have a significant wave height predominantly between 0.05 m and 0.30 m
- No waves approach the island from directions 30° and 60°. This is due to the presence of the deep channel (Urmston Road) which refracts (turns) the waves from these directions towards north. This is the reason why waves from north seen to be over-represented in Figure 8.7 when it is compared to the wind rose in Figure 8.5.
- Highest waves approach the island from north and east. For waves from north, this is due to a combination of the relatively long fetches and strong winds associated with directions 0°, 30° and 60°. For waves from east, the high waves are due to the strong winds from this direction and the large water depths that exist between Lung Kwu Chau and the mainland.
- The wave rose shown in Figure 8.7 is in qualitatively good agreement with the alignment of the beach being investigated, cf. Figure 8.1. A stable beach will
tend to assume an orientation that faces the prevailing waves, in such a way that its alignment corresponds to zero net yearly transport. As Figure 8.1 shows, the beach is aligned in such a way that its normal is slightly turned southward with respect to due east, which agrees well with the wave rose shown in Figure 8.7. Note that the beach is protected from waves from north by the rocky headland and promontory on its northern side.

8.2.2 Detailed analysis of wave conditions in the vicinity of the project site

Five wave conditions (combination of significant wave height $H_{m0}$, peak period $T_p$ and mean direction of wave propagation MWD) were selected from the nearshore yearly mean wind-wave statistics generated with MIKE 21 NSW, cf. Figure 8.7. Since construction of the projected jetty will not modify the wave conditions along the beach for waves propagating from north, this direction was not taken into account in the analysis.

The wave conditions as applied along the offshore boundary of the model bathymetry (see Figure 8.8 for details) are listed in Table 8.1 below.

<table>
<thead>
<tr>
<th>Wave case #</th>
<th>$H_{m0}$ (m)</th>
<th>$T_p$ (s)</th>
<th>MWD ($^\circ$ N)</th>
<th>Type of spectrum</th>
<th>$n$ (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45</td>
<td>2.6</td>
<td>100</td>
<td>JONSWAP</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>0.60</td>
<td>2.9</td>
<td>120</td>
<td>JONSWAP</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>0.60</td>
<td>2.9</td>
<td>150</td>
<td>JONSWAP</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>0.60</td>
<td>2.9</td>
<td>170</td>
<td>JONSWAP</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>0.25</td>
<td>2.3</td>
<td>120</td>
<td>JONSWAP</td>
<td>5</td>
</tr>
</tbody>
</table>

If the wave heights in Table 8.1 are compared to the wave rose in Figure 8.7, it can be seen that rather large values have been used in the detailed analysis of wave conditions in the vicinity of the jetty. This was done on purpose, in order for the analysis to be conservative and therefore on the safe side.

DHI’s wave model MIKE 21 PMS was used for the analysis. MIKE 21 PMS is based on a parabolic approximation to the elliptic mild-slope equation governing the refraction, shoaling, diffraction and reflection of linear water waves propagating on gently sloping bathymetry. For additional information about the theoretical background of the model, cf. Ref. /10/ or the User Guide for MIKE 21 PMS.

MIKE 21 PMS can be applied to any water depth on a gently sloping bathymetry, and it is capable of reproducing phenomena, such as shoaling, refraction, dissipation due to bed friction and wave breaking, forward scattering and diffraction. This last feature is of special importance for the present study, in which diffraction of the waves due to the presence of the jetty and the associated currents that are generated may have a negative impact on the morphology of the pocket beach.
An additional feature of MIKE 21 PMS is the ability to simulate directional and frequency spreading of the propagating waves by use of linear superposition. This feature was used in the simulations by prescribing irregular, directional waves at the offshore boundary of the model bathymetry, cf. Table 8.1. A relatively low value of the directional spreading index $n$ was used, keeping in mind that the waves are wind-generated. $n$ is the exponent in the directional distribution of wave energy given by $\cos^n|\theta - \theta_m|$, where $\theta_m = \text{MWD}$ is the mean direction of wave propagation.

In order to assess the impact that construction of the jetty will have for the wave conditions along the pocket beach, two model bathymetries were generated. The first one corresponds to the existing conditions (i.e. no jetty) while the second bathymetry includes the projected jetty and dredging of an approach channel to $-2.5$ m CD. The two bathymetries are shown in Figure 8.8. It must be noted that the bathymetries have been rotated due to modelling requirements already discussed in Section 8.2.1.
8.3 **Results and Conclusions**

The results obtained from the propagation of wave cases #1 to #5 in Table 8.1 using MIKE 21 PMS on the two bathymetries shown in Figure 8.8 are presented in Figure 8.9 to Figure 8.13 below. Results obtained for the existing conditions are shown to the left of each figure, whereas results including the projected jetty are shown to the right.

Results are presented in the form of contours of significant wave height $H_{m0}$ and vectors indicating the direction of wave propagation, with the length of the vectors scaled according to the local wave height. The lowest level of the colour scale (dark blue) corresponds to $H_{m0} < 0.05$ m. The scale has uniform increments of 0.10 m in significant wave height, meaning that red areas correspond to $0.35 < H_{m0} < 0.45$ m and yellow areas to $H_{m0} > 0.55$ m.

Note that only a part of the area covered by the models has been shown in Figure 8.9 to Figure 8.13 inclusive, in order to focus attention on the analysis of the results along the pocket beach being investigated.

*Figure 8.9* Wave fields corresponding to $H_{m0} = 0.45$ m, $T_p = 2.6s$ and MWD = 100° N calculated with MIKE 21 PMS. Existing situation (left) and with jetty and dredging included (right)
Figure 8.10  Wave fields corresponding to $H_m0 = 0.60$ m, $T_p = 2.9$s and $MWD = 120^\circ$ N calculated with MIKE 21 PMS. Existing situation (left) and with jetty and dredging included (right)

Figure 8.11  Wave fields corresponding to $H_m0 = 0.60$ m, $T_p = 2.9$s and $MWD = 150^\circ$ N calculated with MIKE 21 PMS. Existing situation (left) and with jetty and dredging included (right)
Analysis of Figure 8.9 to Figure 8.13 leads to the following conclusions:

- For waves lower than $H_{m0} = 0.50$ m and propagating from 100° N and 120° N (corresponding to cases #1 and #5 in Table 8.1), construction of the jetty and dredging of the approach channel to −2.5 m CD will not change the wave conditions along the beach compared to the present situation. This is shown by Figure 8.9 to Figure 8.13, and means that for the wave conditions prevailing in the area (cf. Figure 8.7), construction of the jetty will not have any negative impacts on the morphology of the beach.

- For higher waves approaching the beach from 120° N (corresponding to case #2 in Table 8.1), construction of the jetty and dredging of the approach channel will
only change the wave conditions along the beach marginally, as shown in Figure 8.10. Thus, it is deemed that construction of the projected jetty will not have any negative impacts on the morphology of the beach for these wave conditions.

- It may appear as if the differences between the wave fields calculated with and without the jetty for wave cases #3 and #4 in Table 8.1 are more important than for the other three cases, see Figure 8.11 and Figure 8.12. However, it is important to keep in mind that waves are small event for the present condition, due to the sheltering effect of the headland to the south of the beach. Another aspect to consider is that the waves for cases #3 and #4 have limited occurrence during the year, 0.12% and 0.16%, respectively, as shown by the wave rose in Figure 8.7. Based on these two facts, it is concluded that construction of the jetty and dredging of the access channel will not have negative impacts on the beach morphology, even for the case of relatively high waves from directions 150° N and 170° N.
9 REFERENCES


/7/ Parsons, E. C. M. 1998. The behaviour of Hong Kong's resident cetaceans: the Indo-Pacific hump-backed dolphin and the finless porpoise. Journal of Environmental


/9/ Hong Kong Observatory, Climatology of Lau Fau Shan 1986-1997 – Technical Note No. 95, by M.C. Ng & W.M. Chan, April 1999.


/11/ Fax message from Maunsell containing: 'Site Plan, Improvement works to Lung Kwu Chau Jetty, Drw. No. P20278-1B'.
Drawing 1  Typical current field (m/s) calculated in 675 m during neap period, outgoing flow during dry season.
Drawing 2  Typical current flow (m/s) calculated in 675 m grid during neap tide, incoming flow during dry season.
Drawing 3  Grain size distribution curve.