Section 7

7 MARINE WATER QUALITY MODELLING (WAHMO)

7.1 INTRODUCTION

The LAPH studies have included two stages of mathematical modelling of hydraulics and water quality, these being used to investigate the impacts of the alternative port reclamation profiles on tidal flows and water quality in the Study Area, with the objective of safeguarding the navigability and other beneficial uses of the Territorial waters.

The modelling undertaken in the earlier stages of the LAPH study was described in Working Paper No. 21A; *Environmental Assessment of the Selected Options*. This involved the testing of several alternative reclamation profiles (both off Lantau Island and in the south of the Western Harbour) for their effects on hydraulics and water quality, and provided input to the further stages of the Study, which are the primary focus of this report. The results from the earlier investigations were employed in the design of the reclamations to be employed for the Preferred Concept for the Port development, such that detrimental impacts on hydraulics and water quality could be avoided as far as possible.

In the most recent stages of the Study, the Preferred Concept for the Lantau Port development was again subjected to mathematical modelling to define changes to both hydraulics and water quality in the Study Area. The modelling in the later stages of the Study was intended to confirm the acceptability of any impacts on tidal flows and water quality of the Preferred Concept, both in its entirety (i.e. as the "Ultimate" development) and in terms of its various development phases. The following sections assess the results of the latest modelling, outlining the scenarios tested; the assumptions employed; and discussing the results of the investigations.

7.2 THE DEVELOPMENT SCENARIOS MODELLED

In total, five different development scenarios were subjected to modelling in the most recent studies. These were as follows:

Case 1: the Base Case, which approximates present-day conditions in terms of land profiles and pollutant loads, with the exception of the addition of committed reclamations and pollutant loads to the existing situation. It should be noted that the Base Case employed in the modelling of the Preferred Concept differed in certain respects from the Base Case employed in previous stages of the LAPH Study. These differences concerned the pollutant loads assumed in certain locations in the Study Area, and this is discussed further in Section 7.3 below;

Case 2: this scenario constitutes the "Ultimate" development profile for the Lantau Port, as shown in Figure 7.1. It will be noted that this development profile differs somewhat from the corresponding scenario tested in the previous stages of the LAPH Study. Thus, although it is similar in overall shape to the "west-facing island-type" development tested as Scenario 1 in the previous work, Case 2 in the latest testing incorporated a realigned access channel to the main Port area; additional dredging to support large areas of anchorage between Kau Yi Chau and Lamma Island; and a breakwater to the south west of Lamma Island. The major lines of berths in the Port development were assumed to be separated by causeways in Case 2, i.e. it was assumed that water flows between the north-east and the south-west across the Port development could not occur (thus creating a large new embayment in the Discovery Bay area);

Case 3: this development scenario is identical to Case 2 in all respects, save that the two northern-most lines of berths in the area of major Port development were assumed to be separated by a bridge, permitting the flow of water through this area between the north of the Western Harbour and the Discovery Bay/Peng Chau area. The bridge was assumed to be 800m in length, as shown in Figure 7.2. This was included in the modelling to demonstrate the impacts of the maintenance of a degree of flushing in the Discovery Bay area, as concerns exist over the maintenance of water quality in the embayment formed by the Port peninsula;

Case 4: this development scenario involves the Phase I and II reclamations for the Lantau Port, comprising eight berths adjacent to Tsing Chau Tsai in north-eastern Lantau.

Both a dredged access channel from the east and a breakwater protecting the berths from any south-eastern fetch are assumed to exist, as shown in Figure 7.3; and

Case 5: this scenario constitutes the Phase IV development for the Lantau Port, with a causeway assumed to exist between the lines of container berths and extending to Kau Yi Chau, and an offshore breakwater to protect the southern-most lines of container berths (Figure 7.4). Dredged access channels in Case 5 are as for the Ultimate development (Cases 2 and 3 above), but no area of additional dredging is assumed to the south-east of Kau Yi Chau, and no breakwater is assumed in the south of the Western Harbour.

7.3 THE MODELS AND ASSUMPTIONS EMPLOYED

The WAHMO suite of models were employed, and model runs were undertaken by Civil Engineering Department (CED) for the hydraulics and by Environmental Protection Department (EPD) for the water quality aspects, with interpretive tasks being provided by APH. The specific sub-models used were identical to those employed in previous work for the LAPH study. The water quality modelling involves the overlaying of pollutant loads on the hydraulic data provided by CED, and running the two-layered water quality model of the WAHMO suite for 23 tidal cycles under dry season and repeating spring or neap tide conditions. It may be noted here that spring tides are thought from previous studies to give rise to worst case dissolved oxygen levels in the Study Area in most cases.

Model output is provided over a 100m grid in the Study Area, and the data covered here involve profiles of water quality parameters over a tidal cycle (the last 24 hrs of the period modelled), at 17 selected reference sites around the Study Area (Figure 7.6). These data are supported by colour output plots of each parameter over the Study Area as a whole, which visualise the geographical distribution of variations in water quality parameters. It is presumed that the determinants are at equilibrium under this testing schedule. The water quality parameters modelled were dissolved oxygen; BOD_5; organic, ammoniacal and oxidised nitrogen; chlorophyll-a; and *E.coli*.

The Base Case selected for the modelling described here includes committed reclamations in areas such as western Kowloon, north Lantau and north Hong Kong Island, in addition to estimated pollutant loads from existing populations, industry and other sources in the Study Area. It is notable that complete validation of the model is not possible at this time, due to the inclusion of these committed reclamations in the Base Case scenario. Thus, the predictions for water quality in the Base Case testing cannot be expected to exactly mimic existing water quality in the Study Area.

No additional pollutant loads were modelled for the new areas of reclamation included in the port-related scenarios. However, certain pollutant loads were altered in the Base Case (and all other tested scenarios) in the latest studies, by comparison to the earlier LAPH modelling as described in Working Paper No. 21A. These changes are noted below:

- the pollutant loads assumed for the areas of Ma Wan, Peng Chau, Discovery Bay and Yi Pak were increased in the latest studies to take account of committed or likely future developments in these areas such that any possible effects of the port-related reclamations on water quality in the Discovery Bay area might be revealed. The populations assumed for the various areas were 15,000 at Ma Wan (increased from zero in the earlier studies); 8,000 at Peng Chau (increased from 4,000 in the previous work); 25,000 at Discovery Bay (increased from the 8,000 previously tested); and 25,000 at Yi Pak (increased from zero in the earlier modelling). These data were abstracted from the latest version of the *South West New Territories Development Plan*. The population figures are those for Hybrid Option 3 (HO3) i.e. the densest population scenario.

- the discharge points for these outfalls were assumed to be identical to those existing/proposed or, as for Ma Wan an assumed point, i.e. for the Discovery Bay loading the discharge point was through the existing outfall, located to the west of the Tai Pak Tsui peninsula, south of Discovery Bay; the Ma Wan loading was assumed to discharge off the Island's eastern coastline; and for Peng Chau the discharge was located off Tai Lei Island. The Yi Pak development was assumed to discharge to the same point as the existing Discovery Bay discharge point, which is to the south-east of Tai Pak Tsui. The levels of treatment were also assumed to be unchanged from those existing at present, which in each case constitutes screening and degritting only. It will be noted, therefore, that the pollutant loading assumed in the area of Discovery Bay approximates a "worst case", with high population estimates and minimal sewage treatment; and

- the pollutant loads entering Victoria Harbour from the north-west Kowloon area (Mong Kok; Sham Shui Po; Lai Chi Kok; and Kwai Chung) were assumed to be intercepted via the North West Kowloon Interceptor Sewer and discharged to the south-west of Stonecutters Island, as is presently the case. It was anticipated that this would be likely to increase the dispersion of pollutants in the area around Stonecutters Island, leading to improvements in water quality in that region.

On this basis, the modelling essentially compares the water quality predicted once the committed reclamations are in place with that predicted for development scenarios including the various port-related reclamations (but no additional pollutant loads from the latter).

7.4 DATA OUTPUT FOR THE BASE CASE (CASE 1)

Certain differences exist between the data output for the Base Case as tested here (coded Case 1 by EPD), and that for the Baseline scenario tested previously in the earlier LAPH studies. The most obvious changes involve the area of Rambler Channel and the surrounds to Stonecutters Island. Data from the new Base Case show a very considerable improvement in water quality in these areas, with enhanced dissolved oxygen, reduced BOD_5 levels, considerably reduced concentrations of nitrogenous compounds and chlorophyll-a. The extent and degree of these changes are very marked, and reveal the greatly improved dispersion of pollutants which eventuates with the interception of loads from the north-west Kowloon area and their discharge to the south-west of Stonecutters Island, into the main tidal stream in Victoria Harbour.

By contrast, predictions for most water quality parameters in the new Base Case differed little in the eastern Lantau area from those for the Baseline scenario employed in the earlier testing, notwithstanding the inclusion of significantly higher pollutant loads in the Discovery Bay area in the more recent modelling exercise. Only minor changes were observed in levels of *E.coli* and chlorophyll-a, the former increasing slightly in the new Base Case (as would be expected with additional loading in the region of Discovery Bay), but the latter decreasing. These changes in chlorophyll-a predictions between the two Baseline scenarios are counter-intuitive, as it would be expected that the higher nutrient loading to Discovery Bay and its surrounds would be likely to give rise to greater algal productivity in the new Base Case (and hence an increase in chlorophyll-a levels). However, previous testing has noted the sensitivity of the chlorophyll-a predictions to small changes in parameters other than nutrients, and it may be that alterations in factors such as turbidity have affected the chlorophyll-a predictions in this instance.

In any event, it appears from the data output for the new Base Case that the Discovery Bay area could assimilate additional pollutant loads (in the absence of further reclamations) without marked alterations in water quality. This is as expected, and reflects the adequate flushing rates encountered in the north-eastern Lantau area in the absence of the Port peninsula.

7.5 COMPARISONS BETWEEN THE BASE CASE AND CASES 2 TO 5 : DRY SEASON

7.5.1 Introduction

Comparisons between the predictions for the Base Case (Case 1) and those for the various development scenarios (Cases 2 to 5) constitute the principal tool to ascertain the impacts of the proposed port-related developments. Tables 1A to 1G, of Appendix A4, show such comparisons for each water quality parameter in dry seasons under repeating spring tide conditions, and the equivalent data for repeating neap tides are shown in Appendix A4; Tables 2A to 2G.

Very few fundamental differences exist between the predictions for the two different types of tide, and these data are therefore discussed together in the following, which addresses water quality in the various geographical regions in the Study Area.

7.5.2 Victoria Harbour

No significant differences for any parameter were noted between the water quality predictions for reference locations in Victoria Harbour in the Base Case and those at the same locations for any of the Port development scenarios tested.

7.5.3 The North of the Western Harbour

As noted for Victoria Harbour, there were no significant differences between predictions for the Base Case and those for the four development scenarios for any water quality parameter at reference sites 1, 15 or 17 in the north of the Western Harbour. Very minor changes were noted in dissolved oxygen (both tide types) and organic nitrogen (spring tides only) at reference sites 15 and 17 as a consequence of the port reclamations. These are considered to reflect slight changes to the overall estuarine mixing profiles. Their magnitude is so minor, however, that they are considered to be of no significance.

7.5.4 Discovery Bay and Eastern Lantau

The reference sites relevant to these parts of the Study Area are numbered 6 (Discovery Bay), 9 (off Silver Mine Bay), and 10 (to the north-east of the Chi Ma Wan peninsula). By contrast to the data for Victoria Harbour and the north of the Western Harbour, water quality parameters at all of these sites were predicted to be significantly affected by each of the port-related reclamations in dry season simulations.

The changes caused by the port reclamations tended to be more marked as the modelled developments become progressively larger, i.e. from Case 4 (Phase I and II development only), through Case 5 (Phase IV development, with a causeway between the berths), to Case 2 (Ultimate development with a causeway between the berths). The results for Case 3 showed that the addition of a bridge rather than a causeway between the berths in the Ultimate development scenario tends to mitigate the changes in water quality somewhat (as noted for Case 2), although the extent of this varies between the different water quality parameters.

Levels of dissolved oxygen at reference sites 6, 9 and 10 in the area of eastern Lantau Island tended to increase compared to the Base Case for all the modelled reclamations (Appendix A4; Tables 1A and 2A). These increases were predicted for both types of tide; were greater at reference site 6 than at sites 9 or 10; and were most marked in the larger Port developments with causeways, rather than bridges. The changes in dissolved oxygen levels predicted varied from less than 5 to about 15 percentage points. Similar predictions to these were noted in the previous stage of modelling in the LAPH work, and are considered to reflect the entrainment of cleaner waters (with higher dissolved oxygen levels) into Discovery Bay from the south of the Western Harbour, driven by the formation of an embayment in the area. Comparisons of the predictions for Cases 2 and 3 clearly show the impacts of flushing created by the bridge between the berth lines, this causing a decrease in dissolved oxygen in Case 3 compared to Case 2 because of the entrainment of more contaminated water from the north of the Western Harbour.

The BOD_5 levels at the reference locations off eastern Lantau showed parallel improvements to those for dissolved oxygen, reference site 6 again being most affected (Appendix A4; Tables 1B and 2B). The impacts on BOD_5 levels are also considered to reflect the entrainment of cleaner waters from the south into the Discovery Bay embayment created by the port reclamations. It is interesting to note that these improvements in water quality were maintained for all reclamation types, showing that: (i) even the earlier phases of the port reclamation materially affect flushing rates in the Discovery Bay area; and (ii) the effects of the entrainment of cleaner waters from the south are predicted to overcome those from the additional pollutant loads being discharged into the newly-formed embayment.

By contrast, all other water quality parameters were predicted to exhibit deterioration due to the port reclamations, and this is considered to reflect the accumulation of contaminants from the local sources assumed to exist in the embayed area (see Section 7.3 above). By comparison to the Base Case data, levels of organic nitrogen predicted for the other Cases tested increased markedly at reference sites 6 and 9 in spring tides in particular (Appendix A4; Tables 1C and 2C), reference site 10 being less affected. Concentrations of ammoniacal nitrogen followed very similar trends to those of organic nitrogen (Appendix A4; Tables 1D and 2D). Levels of oxidised nitrogen were altered rather less by the port reclamations, however, particularly in neap tide simulations (Appendix A4; Tables 1E and 2E). As noted previously for dissolved oxygen, such changes were apparent even in predictions for the early phases of the port reclamations, although the impacts of these were reduced compared to those of the larger reclamations. The provision of a bridge between the lines of berths reduced the accumulation of nitrogenous contaminants to some degree, although significant increases over the Base Case remained (see data for Case 3 in Appendix A4; Tables 1C to 1E and 2C to 2E).

The predictions for chlorophyll-a concentrations reflected these elevated levels of nutrients in the embayed area created in Discovery Bay, being very considerably elevated in certain development scenarios compared to the Base Case (Appendix A4; Tables 1F and 1G). Predicted concentrations for spring tide conditions of about 2μg/l chlorophyll-a in the Base Case at reference site 6 increased to about 3μg/l in Case 4 (Phase I and II development), and to about 8μg/l in Case 5 (Phase IV development) and Case 2 (Ultimate development with a causeway between the berths). The highest values were not reached, however, in Case 3 (Ultimate development with a bridge between the berths), chlorophyll-a values at reference site 6 being predicted to be about 4μg/l in this instance. This clearly shows the impacts of both the local discharges of contaminants and the flushing introduced by the inclusion of a bridge between the berth lines in the Container Port development. The changes in chlorophyll-a levels predicted for reference sites 9 and 10 were smaller than those predicted for reference site 6, but were nevertheless of significance, with concentrations being approximately doubled in the scenarios exhibiting larger port reclamations. Similar trends were observed in predictions for neap tides, although in this instance the predicted absolute concentrations of chlorophyll-a were even greater, rising to 11μg/l in Cases 2 and 5 at reference site 6.

These predictions for chlorophyll-a in the Study Area are of concern, and clearly indicate that the higher pollutant loads assumed in this stage of testing threaten to overcome the assimilative capacity of the waters of Discovery Bay and its surrounds, particularly where larger port reclamations are assumed and these contain a causeway rather than a bridge. These changes are intuitively understandable, in that the larger reclamations create a deeper embayment in the Discovery Bay area and reduce overall flushing, thus exacerbating the impacts of locally-discharged nutrients. If concentrations of chlorophyll-a approximating those modelled were to be attained in the embayed area, the overall water quality would be expected to deteriorate markedly. Thus, levels of chlorophyll-a varying between 8 and 11μg/l are indicative of an unstable system, with episodic algal blooming (as found until recently in Tolo Harbour, for example). It would be expected that such rates of primary productivity would lead to fish kills due to the development of hypoxia in the local waters, and to a variety of other undesirable changes in water quality as a whole.

Levels of *E.coli* were also predicted to increase in the Discovery Bay area as a result of the port reclamations (Appendix A4; Tables 1G and 2G). Such changes were similar in extent and magnitude for both types of tidal simulations, and reflect the trapping of sewage-derived microbial agents in the embayment formed by the port reclamation. The predicted increases ranged in most instances from 5-fold to 10-fold, tidally-averaged absolute values varying from about 100 *E.coli* per 100ml at reference site 6 in the Base Case, to 500 *E.coli* per 100ml at the same site in the earlier phases of the Port development, and to about 1,000 *E.coli* per 100ml at reference site 6 in the larger Port developments. Such concentrations of microbial agents can be considered to threaten the use of these waters for bathing, with obvious implications for the Discovery Bay development.

7.5.5 The South of the Western Harbour

Predicted changes to water quality at reference sites in the south of the Western Harbour (sites numbered 4, 5, 11, 12 and 16) were more minor than those observed in the Discovery Bay area, but nevertheless merit discussion here.

Compared to the Base Case predictions, levels of dissolved oxygen found in the modelling of the larger port reclamations tended to decrease at reference site 11 in neap tide simulations, and similar changes were observed for reference site 16 in spring tide modelling (Appendix A4; Tables 1A and 2A). In all instances where significant changes occur, these approximated a decrease in predicted dissolved oxygen levels of about 5 percentage points. By contrast, no significant changes were observed between dissolved oxygen predictions for the Base Case and those for the various port-related reclamations for reference sites 4, 5 or 12, which are located further to the south of the Study Area.

Such changes were also observed in certain of the earlier LAPH studies, and these are believed to be due to a delay in estuarine mixing caused by the larger port reclamations. Thus, the presence of the port reclamation off north-eastern Lantau Island hinders estuarine mixing in the north of the Western Harbour, and effectively extends the area of mixing of the coastally-derived waters and the offshore oceanic waters. As noted also in previous

LAPH work, this effect is greatest in development scenarios which incorporate a breakwater in the south of the Western Harbour (Cases 2 and 3 in the present studies), as coastal waters tend to "pool" somewhat to the north of the breakwater, where mixing takes place. This is the only obvious impact on water quality of the breakwater situated to the south west of Lamma Island.

This delay in estuarine mixing also affected the other parameters modelled, as the coastal waters exhibit high levels of BOD_5, nutrients and *E.coli* compared to the offshore oceanic waters. By comparison to the Base Case, concentrations of each of these contaminants tended to increase somewhat at reference sites 11 and 16, and these changes were greatest in Cases 2 and 3, which incorporate large reclamations off north-eastern Lantau together with a breakwater in the south of the Western Harbour.

The actual magnitudes of these changes at reference sites 11 and 16 are, however, quite small. Thus, for example, concentrations of BOD_5 were predicted to increase in spring tide conditions by about 10-15% for Cases 2 and 3 over those modelled for the Base Case. It may also be noted that levels of oxidised and ammoniacal nitrogen species tended to be more affected than concentrations of organic nitrogen, and that there was no evidence for an increase in chlorophyll-a concentrations in the southern waters of the Territory. The latter point is important, in that concerns exist over the incidence of algal blooms ("red tides") in the southern waters of Hong Kong, which are of importance for recreation. The modelling results showed no evidence of a significant threat to these waters in terms of algal blooming due to the slight changes in estuarine mixing which are expected to eventuate from the reclamation supporting the Preferred Concept.

The absence of any changes to water quality at reference sites 4, 5 and 12 indicates that the port-related reclamations exert impacts on water quality which are restricted to the region to the north of the breakwater off Lamma Island. This is as expected from the previous LAPH studies, and indicates that estuarine mixing is delayed only slightly in the Study Area by the port-related reclamations. The mixing patterns to the south of the southern breakwater in Cases 2 and 3 are thus indistinguishable from those in the Base Case.

7.5.6 South of Hong Kong Island

The only significant predicted changes to water quality in the area to the south of Hong Kong Island involve small alterations in the predicted levels of *E.coli*; all other parameters were effectively unchanged by the port-related reclamations. The changes in *E.coli* were predicted for both neap and spring tide conditions and were quantitatively similar for Cases 2, 3 and 5 (alterations in Case 4 being insignificant). These affected only reference site 3, which is located off Picnic Bay on Lamma Island; reference site 8 off Repulse Bay was unaffected.

The changes involved approximate an increase in *E.coli* levels by approximately 5-fold or less. It is considered that these changes in the area of the East Lamma Channel reflect the increased importance of this channel (in scenarios involving more extensive port reclamations) for carrying coastal waters to the offshore areas. This is essentially a further example of the extension to estuarine mixing created by the construction of large reclamations to the north of the Western Harbour. Such changes are not considered likely to be of major significance in terms of the attainment and maintenance of Water Quality Objectives in the Study Area. In particular, the *E.coli* levels were not predicted to change in the area of the southern beaches on Hong Kong Island, where bathing is popular. It should also be noted that the modelling predicted no significant changes to chlorophyll-a levels in the waters to the south of Hong Kong Island.

7.6 COMPARISONS BETWEEN THE BASE CASE AND CASES 2 TO 5: WET SEASON

7.6.1 Introduction

Comparisons between the predictions for the various development scenarios and those for Base Case under wet season conditions are shown in Appendix A4; Tables 3A to 3G for spring tide simulations, and in Appendix A4; Tables 4A to 4G for neap tide conditions. As noted for dry seasons, there are few substantive differences between the results for each type of tide, and the effects of the various developments on water quality will be covered by geographical area in the following sections.

7.6.2 Victoria Harbour

As noted above for dry season modelling data, the predictions for wet season conditions revealed no substantive changes in water quality in the Victoria

Harbour area (reference sites 2,7,13, and 14) for any parameter under either type of tide. It may be concluded that the reclamations to support the Preferred Concept for the Port have no significant impacts on the water quality in the Victoria Harbour.

7.6.3 The North of the Western Harbour

The reference sites relevant to this part of the Study Area are those coded 1, 15 and 17. Wet season modelling revealed no significant impacts of the various Port developments at reference sites 1 or 17, for any parameter or for either tidal simulation. However, certain small changes in water quality were observed at reference site 15 for some of the Port developments, these being of significant magnitude only under repeating neap tide conditions.

Reference site 15 is located between southern Tsing Yi Island and Green Island, to the east of the planned Port peninsula and in the middle of the tidal stream between northern Lantau and Victoria Harbour. The modelled discharge from the North West Kowloon Interceptor Sewer, entering the receiving waters to the south-west of Stonecutters Island, is located about 2km to the east of reference site 15.

The effects of the port-related reclamations on water quality at reference site 15 under spring tide conditions were insignificant in terms of their magnitude (see Appendix A4; Tables 3A to 3G), and will not be addressed further here except to note that in most instances, a slight improvement in water quality was predicted to occur by comparison to the Base Case simulations. In neap tide conditions, this trend was generally stronger, and certain of the Port developments modelled materially affected the predicted water quality (Appendix A4; Tables 4A to 4G). The modelled effects were more marked for the Port developments of greater extent, i.e. for Case 2 (the Ultimate Port development with a causeway linking the berths) and Case 5 (the Phase IV Port development, also with a causeway between the lines of berths). Dissolved Oxygen levels showed minor and generally insignificant increases at reference site 15 (sometimes extending to reference site 17), but the of BOD_5 levels were more materially affected, being decreased in Cases 2, 3 and 5 by comparison to the Base Case. Minor improvements in water quality were also observed with respect to species of nitrogen and for chlorophyll-a, the Port developments tending to lead to reductions in both nutrients and chlorophyll-a levels at reference site 15 compared to Base Case simulations. By contrast, no significant changes were noted for predictions of *E.coli* levels between the Base Case simulations and the other cases modelled.

These small changes in water quality are considered to reflect alterations in estuarine mixing created by the construction of the Port developments, these becoming more marked as the assumed developments grow in size. Estuarine mixing in the Study Area as a whole is delayed somewhat by the construction of the Port developments (see Section 7.5.5 above), and flushing rates are affected in certain parts of the Study Area. The magnitudes of the changes observed for the various water quality parameters are not great, however, and the improvements to water quality as a whole in this area can be considered to be of marginal nature only.

7.6.4 Discovery Bay and Eastern Lantau

As noted previously for dry season modelling, predictions of water quality in wet seasons in Discovery Bay (reference site 6) and eastern Lantau Island (reference sites 9 and 10) revealed significant impacts from the port-related reclamations, these generally becoming more marked as the modelled developments grow in size. The changes caused by the Port developments were generally similar in wet season simulations to those predicted for the dry season conditions, although some differences were noted.

The port reclamations tended to give rise to increased concentrations of dissolved oxygen in neap tides at reference site 6 in Discovery Bay compared to the Base Case (Appendix A4; Table 4A). In spring tides, by contrast, a small (and generally insignificant) decrease in dissolved oxygen resulted (Appendix A4; Table 3A). In most instances, it would be expected that such changes in dissolved oxygen would also be reflected by predictions for BOD_5 levels, as the latter would be anticipated to drive dissolved oxygen values in the receiving waters of the Study Area. However, no such linkage between dissolved oxygen and BOD_5 levels was observed in the wet season modelling. Thus in spring tide simulations, the small decreases in dissolved oxygen were accompanied by minor improvements in BOD_5 levels (Appendix A4; Table 3B). The converse trends in each instance occurred for neap tide predictions, improvements in dissolved oxygen being accompanied by minor increases in BOD_5 levels (Appendix A4; Table 4B). It is considered that the dissolved oxygen predictions in this part of the Study Area were responsive principally to the modelled changes in chlorophyll-a levels (see below), rather than to predicted BOD_5 levels. This is supported by the fact that the predicted dissolved oxygen concentrations were frequently at or above 100%, indicating supersaturation of oxygen due to algal photosynthesis.

The Port developments were also predicted to create changes by comparison to the Base Case in the speciation of nitrogen in the areas of Discovery Bay and eastern Lantau (Appendix A4; Tables 3C to 3E and 4C to 4E). Spring tide simulations for the wet season suggested an increase in organic nitrogen concentrations in particular, coupled to decreases in the levels of oxidised nitrogen (but with no significant changes in ammoniacal nitrogen concentrations). These effects were more marked at reference site 6 in Discovery Bay than for reference site 9 or 10, and also tended to be of greater magnitude for the more extensive port reclamations. Neap tide simulations also revealed increases in the predicted levels of organic nitrogen compared to the Base Case, but no changes in the concentrations of either ammoniacal nitrogen or oxidised nitrogen were predicted.

Such alterations in the levels of nutrients in Discovery Bay and eastern Lantau waters gave rise to marked changes in the predicted chlorophyll-a values at these locations (Appendix A4; Tables 3F and 4F). As noted in the dry season simulations, wet season modelling suggested that the construction of the port reclamations would cause chlorophyll-a levels to increase markedly in Discovery Bay compared to the Base Case predictions, these changes being observed for both spring and neap tides. The magnitudes of these increases were considerable: for example, concentrations of chlorophyll-a of about 11μg/l at Discovery Bay in spring tides in the Base Case were predicted to increase to approximately 13μg/l for Case 4 (Phase I and II development only); to about 16μg/l for Case 3 (Ultimate development with a bridge connecting the berths); and to approximately 18μg/l for cases 2 and 5 (Ultimate or Phase IV developments with a causeway connecting the berths). While less marked changes in chlorophyll-a levels were observed at reference sites 9 and 10, these were nonetheless significant, and reflect the decreased flushing of the embayed waters off eastern Lantau, created by the construction of the port reclamations.

The comment made in Section 7.5.4 above may be reiterated here: these predictions suggest the creation of unstable conditions in the Discovery Bay and eastern Lantau waters due to the reduced level of flushing and the accumulation of nutrients in this area, which are predicted to give rise to substantial increases in algal growth. The provision of a bridge between the berth lines in the proposed Container Port gives rise to only a slight alleviation of the predicted deterioration in water quality.If the modelled values were even to approximate reality, it would be expected that this proliferation of algae would materially affect levels of dissolved oxygen in the area (see Section 7.6.2 above), giving rise to hypoxic conditions and probably to fish kills. Water Quality Objectives (WQOs) would be likely to be infringed.

Predictions for *E.coli* levels in Discovery Bay and eastern Lantau waters in the wet season modelling are again similar to those for the dry season (Appendix A4; Tables 3G and 4G). Levels of *E.coli* were predicted to increase substantially (by between 5-fold and 10-fold in most instances) by comparison to the Base Case, the changes observed being greater for the more extensive port reclamations, but extending to both reference sites 6 and 9. As noted in Section 7.5.4 above, such changes threaten the beneficial use of such waters for bathing, with obvious consequences for Discovery Bay.

7.6.5 The South of the Western Harbour

While certain significant changes to water quality in the south of the Western Harbour were predicted to eventuate under wet season conditions due to the construction of the port reclamations, these were relatively minor compared to those modelled in Discovery Bay and eastern Lantau.

Concentrations of dissolved oxygen were predicted to decrease compared to the Base Case at reference sites 11 and 16, but increase slightly at reference site 5 (Appendix A4; Tables 3A and 4A). These changes are similar to those predicted for dry season conditions, and are considered to reflect the delay in estuarine mixing discussed previously, with 'pooling' of contaminated waters to the north of the southern breakwater in Cases 2 and 3 exacerbating this effect.

Predicted changes to BOD_5, nutrient concentrations and *E.coli* levels in the south of the Western Harbour were generally minor, although some small changes in the speciation of nitrogen were noted, and the levels of *E.coli* were predicted to increase at reference sites 11 and 16 in particular. These changes in water quality again reflect the delay in mixing between the coastal waters and the oceanic receiving waters, contaminants from the land-based sources reaching further offshore prior to their dilution and dispersion. Interestingly, the changes in nutrient levels were predicted to give rise to small increases in chlorophyll-a levels at reference sites in the south of the Western Harbour (Appendix A4; Tables 3F and 4F). Such changes were minor and are not likely to threaten the WQOs, but extended under certain tidal simulations to the sites in the extreme south of the Study Area (reference site 5). This again reveals the sensitivity of the chlorophyll-a predictions from the WAHMO modelling to small changes in other parameters.

7.6.6 South of Hong Kong Island

The only changes predicted to occur to water quality in the south of Hong Kong Island consequent to the construction to the port reclamations involve reference site 3 off eastern Lamma Island. At this location, dissolved oxygen values were predicted to decrease slightly compared to the Base Case in neap tide simulations, and *E.coli* levels were predicted to increase somewhat in spring tide modelling. As noted in Section 7.5.6 above, these changes are believed to be due to the greater importance of the East Lamma Channel in the dispersion of contaminants from Victoria Harbour and its surrounds, when the port reclamations are in place. No other changes of significance were predicted, and neither of these impacts is considered likely to lead to infringements of the WQOs. Notably, no changes in nutrient values or chlorophyll-a concentrations are predicted for this part of the Study Area, under either dry or wet season conditions.

7.7 SUMMARY OF THE MODELLING DATA

The most important changes to water quality predicted by the modelling may be summarised as follows:

- the construction of the major Port facilities off north-eastern Lantau creates an embayment in the Discovery Bay area, and the assumption of increased pollutant loads in this area reveals that the assimilative capacity of the waters of this embayment is limited. While levels of dissolved oxygen and BOD_5 were predicted to improve in the embayment (due in most instances to the entrainment of cleaner waters from the south), discharged sewage-derived pollutants were predicted to accumulate in the embayed waters. The resulting higher levels of nutrients (and in some instances, alterations in the chemical speciation of nitrogen) were predicted to cause considerable increases in primary productivity, with high concentrations of chlorophyll-a eventuating. These effects were evident in both types of seasonal simulations and in each tide modelled. In addition, *E.coli* levels increased by 5-fold to 10-fold in certain scenarios, and this change may threaten the bathing water quality off the beach at Discovery Bay;

- smaller changes to water quality were predicted in the south of the Western Harbour, these mostly being restricted to reference sites 11 and 16 to the north of the breakwater off Lamma Island. These changes compared to Base Case predictions are indicative of delayed mixing of the coastal waters with offshore oceanic water masses, and are more pronounced when a breakwater is assumed to exist to the south west of Lamma Island. Small decreases are predicted in the concentrations of dissolved oxygen in the area, accompanied by small increases in the levels of BOD_5 and nutrients. No significant changes in chlorophyll-a concentrations were predicted in dry season conditions, and only small increases in such concentrations were found in the wet season modelling. These changes are not considered likely to threaten the overall water quality in the south of the Western Harbour, or the attainment and maintenance of WQOs in this area;

- the extended estuarine mixing also affected *E.coli* levels in the area of the East Lamma Channel under certain circumstances. *E.coli* levels were predicted to increase by about 5-fold or less by comparison to the Base Case, in instances where the larger port-related reclamations were modelled. These impacts did not, however, extend to the popular bathing beaches in the south of Hong Kong Island and are not considered significant in terms of the attainment and maintenance of WQOs;

- changes to water quality in the north of the Western Harbour were insignificant in the dry season modelling, and were restricted to reference site 15 in neap tides, where minor improvements in water quality were noted. These are believed to result from changes to estuarine mixing profiles and flushing rates in this area; and

- no significant affects on water quality were predicted from the construction of the port-related reclamations in Victoria Harbour.

7.8 FURTHER MODELLING: MITIGATION OF IMPACTS AT DISCOVERY BAY

The predicted effects of the various port reclamations on water quality in Discovery Bay were considered to be of sufficient concern that mitigation should be sought. As noted in Section 7.7 above, the principal concerns surround the predicted increases in chlorophyll-a concentrations and in the levels of *E.coli*, which are driven essentially by the discharge of nutrients and microbial agents in sewage. While the provision of further flushing through construction of a second bridge between the two southern-most lines of container berths was considered as a possible option for mitigation, this was not preferred, as it was considered most unlikely that the additional minor increase in flushing afforded by this option would give rise to acceptable water quality in the Discovery Bay area.

Mitigation of the undesirable effects on water quality in the Discovery Bay and eastern Lantau areas thus involves either the further treatment of the assumed sewage-derived loads entering the local receiving waters, or the removal of loads by the diversion of sewage from Discovery Bay and the proposed Yi Pak development to the Siu Ho Wan sewage treatment works (STW) on northern Lantau.

Further modelling was considered to be necessary to investigate the extent of mitigation available through these changes. Thus, EPD were requested to undertake further runs of the water quality models, making the following changes:

- alterations of the pollutant loads entering eastern Lantau receiving waters from the assumed developments at Discovery Bay, Yi Pak and Peng Chau. In these runs, the discharge points assumed for the three pollutant loads remained as previously tested, but the loads themselves were reduced to simulate the provision of secondary sewage treatment for all sources; and

- alteration of the magnitude of the pollutant load entering from the assumed Peng Chau development to reflect the provision of secondary treatment, as above, but with no change in location of the outfall. This was coupled to removal of the pollutant loads from the proposed developments at Discovery Bay and Yi Pak, which were assumed to be discharged at the Siu Ho Wan STW at northern Lantau. It should be noted here that, due to time constraints, it was not possible for EPD to adjust the assumed loads entering from the Siu Ho Wan treatment works (which requires rerunning the model covering northern Lantau waters, to provide altered boundary conditions for the models covering the LAPH Study Area). Thus, in effect, the loads from the proposed Discovery Bay and Yi Pak developments have been deleted altogether in this testing, rather than moved to Siu Ho Wan.

This modelling was undertaken using wet season conditions (which had provided the results of greatest concern in the previous work) and for both spring and neap tides. All other parameters remained as in the previous testing discussed above. The results of this modelling are shown in Appendix A4; Tables 5A to 5G (spring tides) and 6A to 6G (neap tides). While data were made available for all the various phases of the port development (i.e. for Cases 2 to 5 inclusive, as discussed above), these Tables are restricted to the Ultimate Port development for the purposes of clarity and simplicity. The results for the other phases of the Port development are qualitatively similar to those shown in the Tables presented here, but the effects of mitigation are more apparent in data for the Ultimate development scenarios, as these affected water quality to a greater extent than did earlier phases of the Port development.

Thus, Tables 5A to 5G and 6A to 6G, of Appendix A4, show the impacts of mitigation for the Ultimate development scenario with a causeway linking the container berths (Case 2) and with a bridge between these berths (Case 3). As noted previously, all interpretation relies on changes between the Base Case and the various development and pollutant loading scenarios. Data from the modelling of Cases 2 and 3 under the original pollutant loading scenario are also provided in Appendix A4; Tables 5A to 5G and 6A to 6G, to assist in the interpretation.

The model predictions reveal that the changes in pollutant loading affected water quality predictions mainly in the local area of Discovery Bay and eastern Lantau (as would be expected, given the proportions of the total loads to the Study Area represented by these contaminant sources). Thus, levels of dissolved oxygen in the Study Area as a whole were affected in only a minor fashion in either spring tides (Appendix A4; Table 5A) or neap tides (Appendix A4; Table 6A). Significant changes were evident mainly in the Discovery Bay-eastern Lantau areas and extended to a limited degree to the south of the Western Harbour. In spring tides, the reduction in loading decreased the levels of dissolved oxygen in Discovery Bay (reference site 6) and at reference site 9 in eastern Lantau, which at first sight is counter-intuitive. However, these decreases reflect the changes in chlorophyll-a values and in supersaturation of oxygen due to algal blooming, as noted below.

BOD_5 levels were materially affected by the alterations in pollutant loads only at reference sites 6 (Discovery Bay), 9 and 10 (eastern lantau Island). In all cases, levels of BOD_5 improved at these sites, consistent with the decrease in local pollutant loading (see Appendix A4; Tables 5B and 6B). There was little difference between the two alternative pollutant loading scenarios, although the improvements were rather more marked in neap tide conditions when the Discovery Bay and Yi Pak loads were assumed to be removed, rather than subjected to secondary treatment.

Concentrations of the various chemical species of nitrogen were also affected significantly by the changes in pollutant loading, as expected (Appendix A4; Tables 5C to 5E and 6C to 6E). Once again, these changes were restricted mainly to the Discovery Bay and eastern Lantau area, although a few minor improvements were also predicted in the south of the Western Harbour. The considerable increases in concentrations or organic nitrogen in Discovery Bay and eastern Lantau which were predicted under the original loading scenarios (see Sections 7.5 and 7.6 above) were abolished by the further treatment and/or removal of the local pollutant loads, and similar improvements in the concentrations of ammoniacal nitrogen and oxidised nitrogen were also predicted as a result of the assumed alterations in sewage treatment. Again, no major differences were evident between the two alternative treatment scenarios.

These changes in the concentrations of nitrogenous species gave rise to very significant alterations to the predicted levels of chlorophyll-a in the Discovery Bay and eastern Lantau waters (Appendix A4; Tables 5F and 6F). The considerable increase in chlorophyll-a levels noted under the original pollutant loading scenarios (Sections 7.5 and 7.6 above) were markedly reduced or abolished, and in several instances, the new pollutant loading gave rise to predicted improvements even over the Base Case. The latter is thought to reflect the partial entrapment of cleaner waters to the west of the proposed port reclamation,with entrainment of waters of a more oceanic character from the south of the Western Harbour predominating over the entry of contaminated water from the north of the Western Harbour. Chlorophyll-a levels in Discovery Bay and eastern Lantau were improved to a greater extent by the removal of the Discovery and Yi Pak sewage loads than by their treatment and local discharge, as would be anticipated.

Similar improvements were noted with respect to *E.coli* levels predicted under the altered pollutant loading scenarios, and these extended in some instances to the waters of the south of the Western Harbour (Appendix A4; Tables 5G and 6G). In Discovery Bay, levels of *E.coli* were predicted to improve by comparison to the Base Case, and this is thought to be due to the entrainment of cleaner waters from the south of the Western Harbour, as noted above for chlorophyll-a predictions.

It may be concluded that these additional model runs have demonstrated that the water quality of Discovery Bay and eastern Lantau can be adequately protected through the introduction of additional sewage treatment for the three major local sources of contaminants (the developments assumed at Discovery Bay, Yi Pak, and Peng Chau). Few marked differences exist between the predictions for water quality parameters in these areas with secondary treatment of local effluents and their continued disposal to the local waters, or with the removal of the Discovery Bay and Yi Pak loads. Both solutions are therefore considered to be robust, and both appear to provide a solution to the predicted deterioration in water quality noted in Section 7.5 and 7.6 above.

The modelling has emphasised the low assimilative capacity of the embayed waters of Discovery Bay subsequent to the construction of the Port reclamation. This implies that all practicable measures should be considered to minimise pollutant loading (from whatever source) to these waters, and that the flushing of these waters should be encouraged wherever possible.

7.9 CONCLUSIONS

The original WAHMO modelling undertaken in this final phase of the LAPH studies was designed to test the robustness of the solution for the Port development in terms of its impacts on water quality. Of particular concern was the quality of the waters in Discovery Bay and eastern Lantau, thought from previous studies to be at risk due to the embayment created by the proposed Port development.

The modelling has essentially confirmed the conclusions of earlier studies with respect to the impacts of the proposed Port development on water quality in the Study Area as a whole. Thus, the proposed development is predicted to exert only minor effects on water quality in Victoria Harbour or the Western Harbour. Such minor changes as are believed to be due to the extended estuarine mixing which results from the construction of the major reclamation off north-eastern Lantau Island. Further minor alterations to water quality also result in the south west of Lamma Island. However, all such alterations are minor and create little cause for concern in terms of the attainment and maintenance of WQOs.

By contrast, the latest phase of the modelling has indicated clearly that water quality in Discovery Bay and eastern Lantau Island is at significant risk from the proposed Port development. The assumption of higher local pollutant loading from proposed residential developments at Discovery Bay, Yi Pak and Peng Chau gave rise to marked changes in the predicted water quality in the embayed area to the west of the proposed port reclamation of north-eastern Lantau Island. The predicted changes in the concentrations of chlorophyll-a and in *E.coli* levels are considered to be unacceptable if WQOs are to be attained and maintained in these waters. With the original pollutant loading scenario, it was anticipated that water quality would deteriorate markedly in Discovery Bay in particular, giving rise to algal blooms and hypoxia and threatening the use of these waters for recreational pursuits (including primary contact recreation at least).

These changes were considered to be of sufficient concern that mitigation should be sought. Additional modelling studies were therefore undertaken, assuming the introduction of secondary treatment of the sewage effluents arising from Discovery Bay, Yi Pak and Peng Chau developments, or the relocation of the effluent discharges from Discovery Bay and Yi Pak to the proposed sewage treatment facility off northern Lantau Island at Siu Ho Wan. Both of these measures were predicted to give rise to very considerable improvements in water quality, in certain instances extending to improvements even over the Base Case (which approximates existing conditions). There is no evidence from these data of any significant deterioration in water quality compared to the existing conditions.

It is concluded that the WAHMO modelling of the proposed port reclamations predicts no unacceptable impacts to water quality, provided that the pollutant loads arising from the local developments in north-eastern Lantau Island (Discovery Bay, Yi Pak and Peng Chau) are subject to either additional treatment to secondary standard (or better), or to relocation so that they discharge outside the embayed area created by the port reclamation. Of these two options, the relocation of the Discovery Bay and Yi Pak discharges and the treatment of the Peng Chau discharge is preferred and recommended and this would reduce duplication of facilities.

There is little difference predicted by the WAHMO modelling between the water quality eventuating in the Discovery Bay and eastern Lantau areas when either a causeway or a bridge is assumed in the body of the port reclamation. However, it is important to note that there are a number of pollutant loads which are not included in the WAHMO water quality modelling.

The discharge of these pollutants represents a potentially significant loading into the embayed area and will arise during both the construction and operation of the Container Port. The unmodelled loads include surface run-off, arising from a number of sources including the reclamation areas, the TCT Mega Borrow area and the Port itself, spillages of oil/grease and the possible release of toxic materials from damaged/leaking containers. The provision of a bridge structure rather than a solid causeway, between Phases II and III, would improve the flushing characteristics of the embayed area and so the time for dispersion/dilution of these loads would be reduced. It is also important to note that once the Strategic Sewage Disposal Strategy (SSDS) has been implemented the quality of the water to the east of the Port will improve considerably, and the apparent benefit of a causeway acting as a barrier will be reduced.

It is considered that all practicable measures should be adopted to minimise pollutant loadings (from whatever source) to the embayed waters and that flushing should be encouraged wherever possible. Thus it is recommended that the bridge structure between Phase II and Phase III should be incorporated/retained in the final design of the Container Port. It is also recommended that investigations on the hydraulic characteristics of the bridged opening are carried out to optimise its flushing ability.

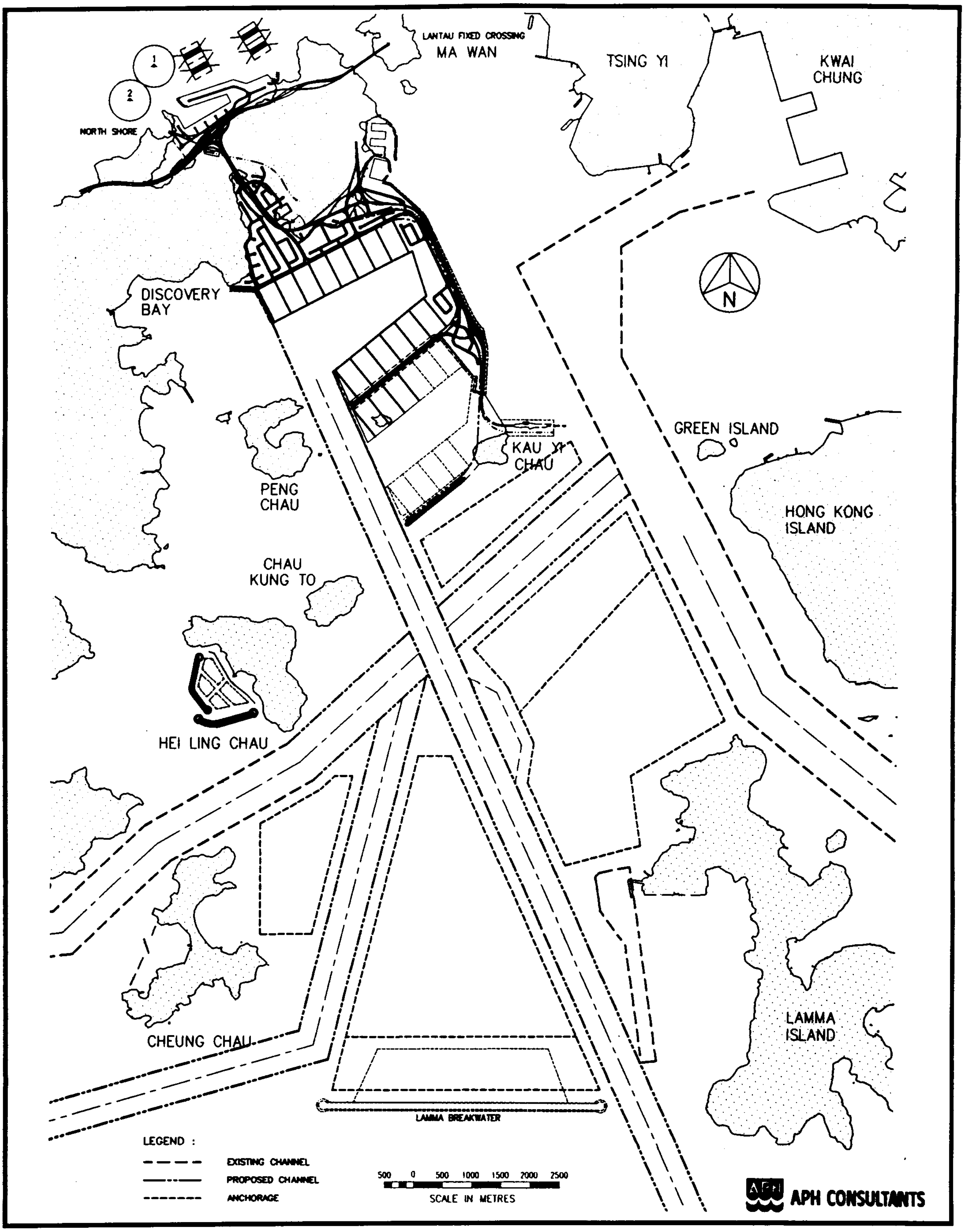

FIGURE 7.1

WAHMO MODELLING – CASE 2 ULTIMATE PHASE CAUSEWAY CONNECTION

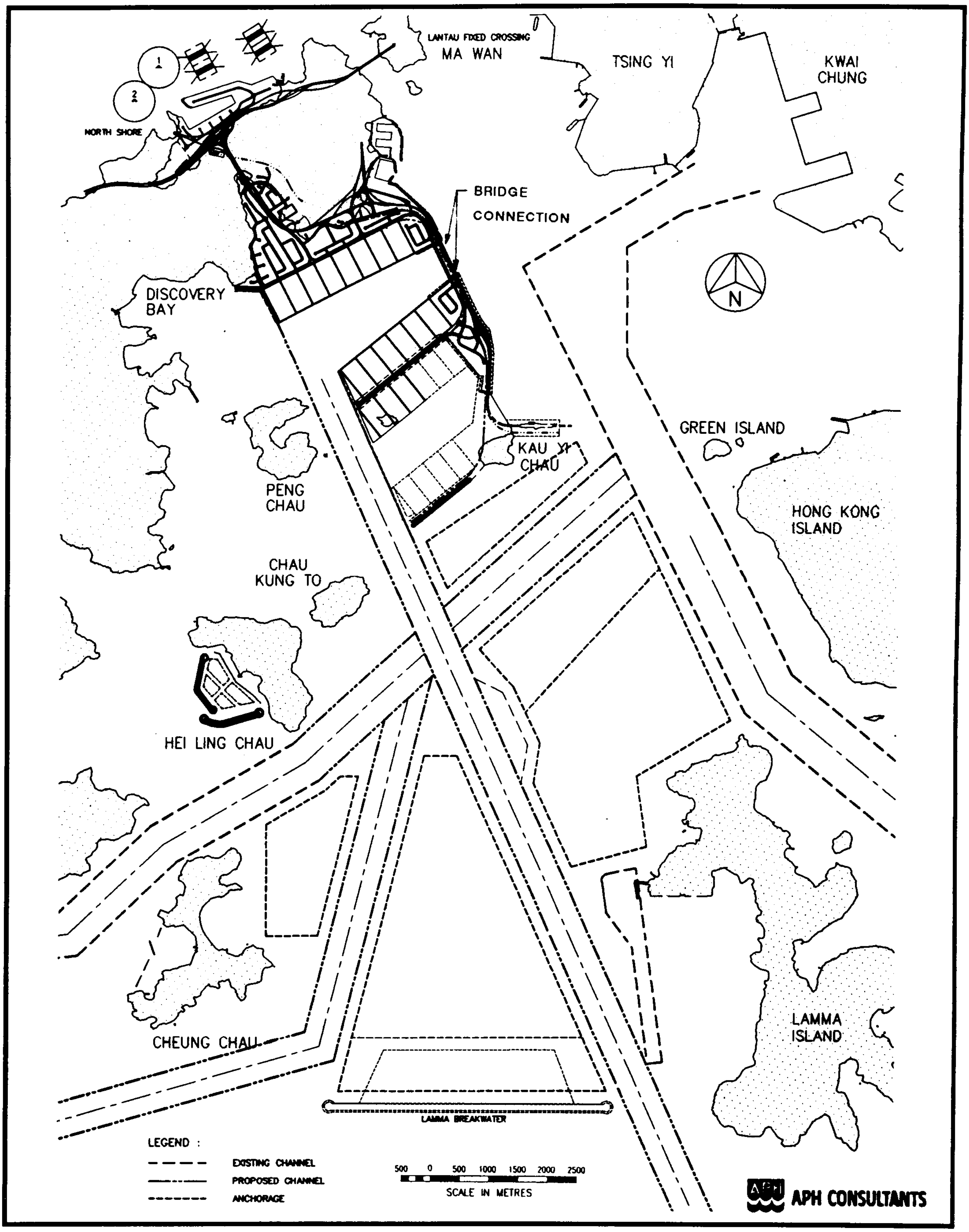

FIGURE 7.2

WAHMO MODELLING – CASE 3 ULTIMATE PHASE BRIDGE CONNECTION

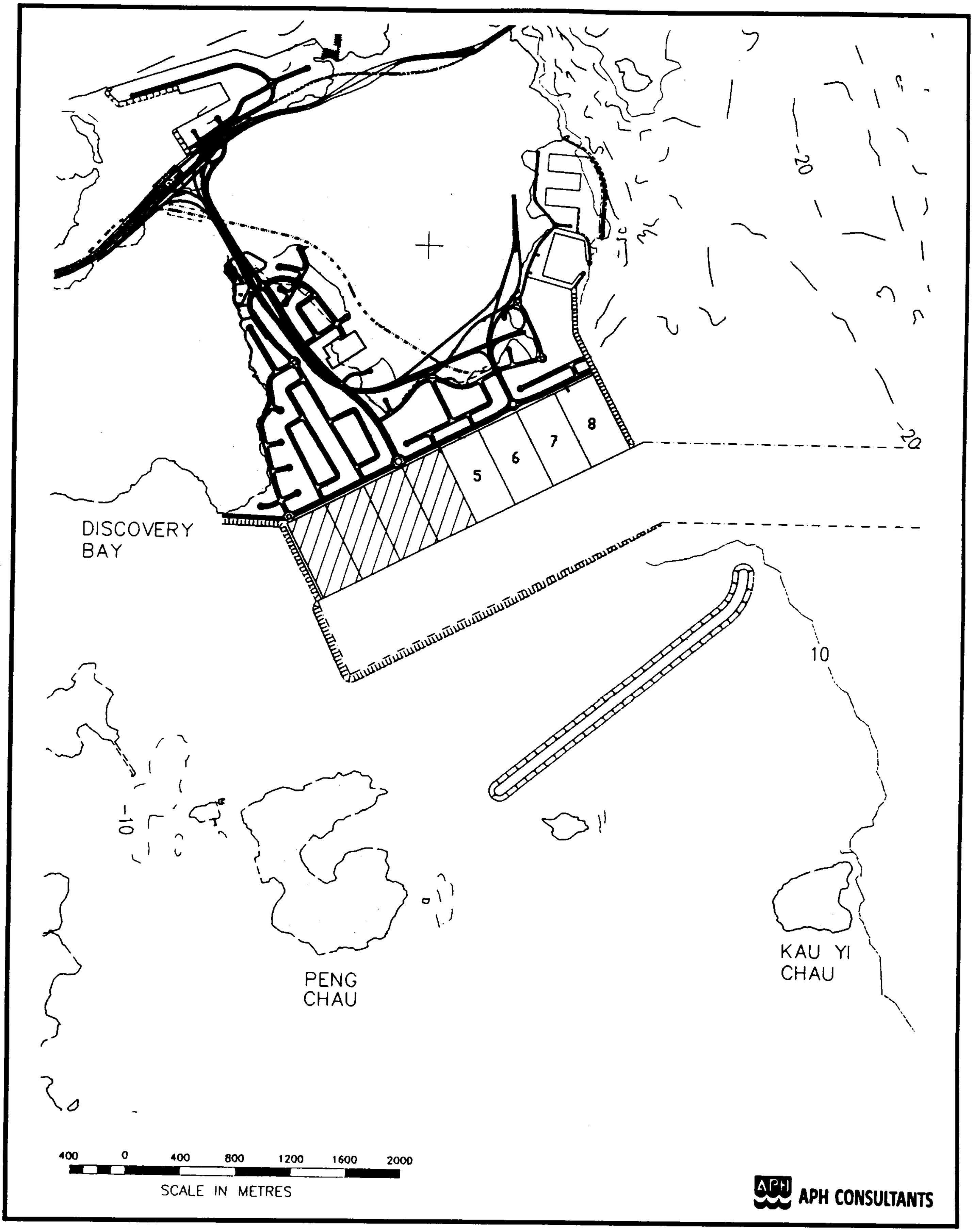

FIGURE 7.3

WAHMO MODELLING – CASE 4
PHASE II DEVELOPMENT

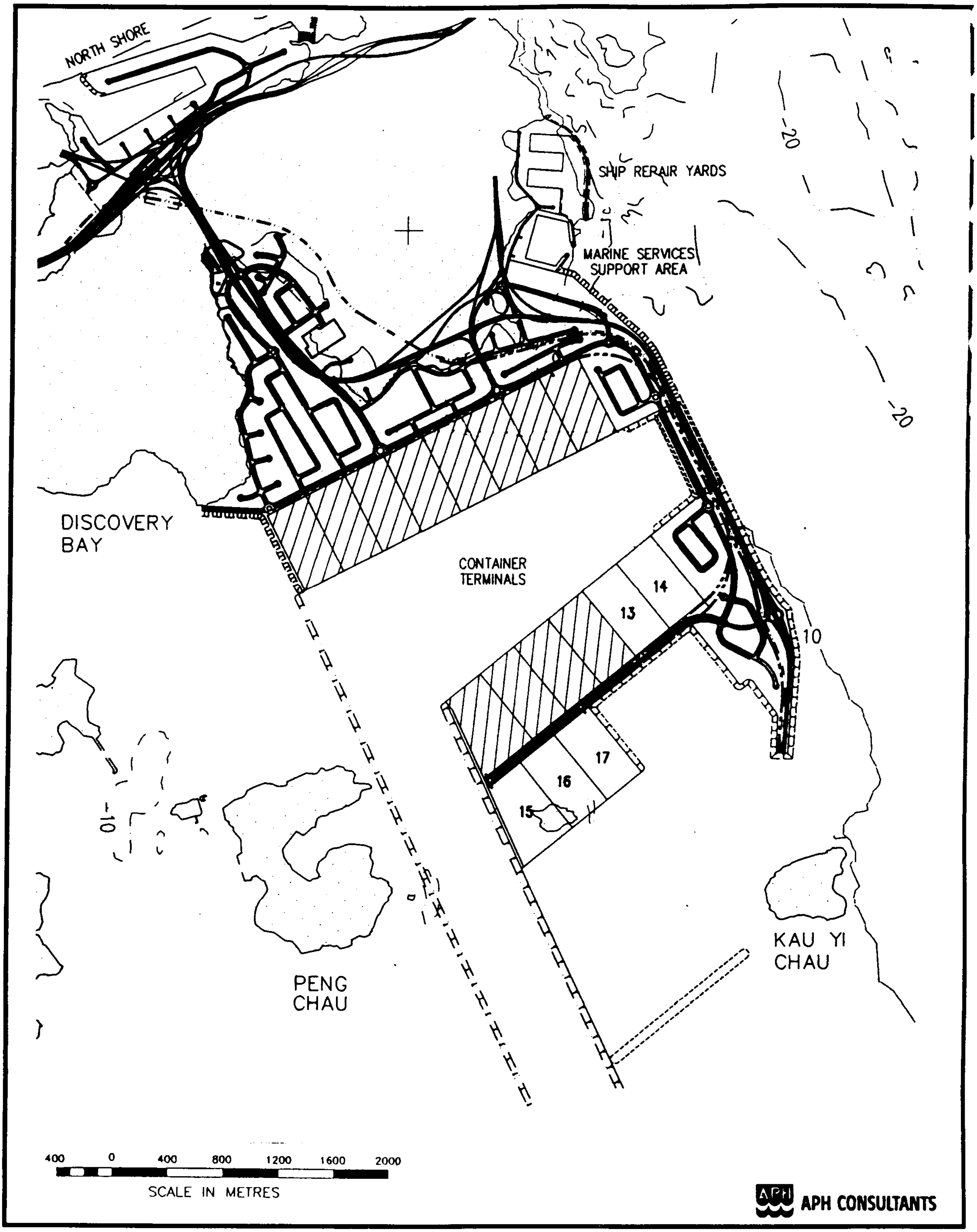

FIGURE 7.4

WAHMO MODELLING – CASE 5
PHASE IV DEVELOPMENT

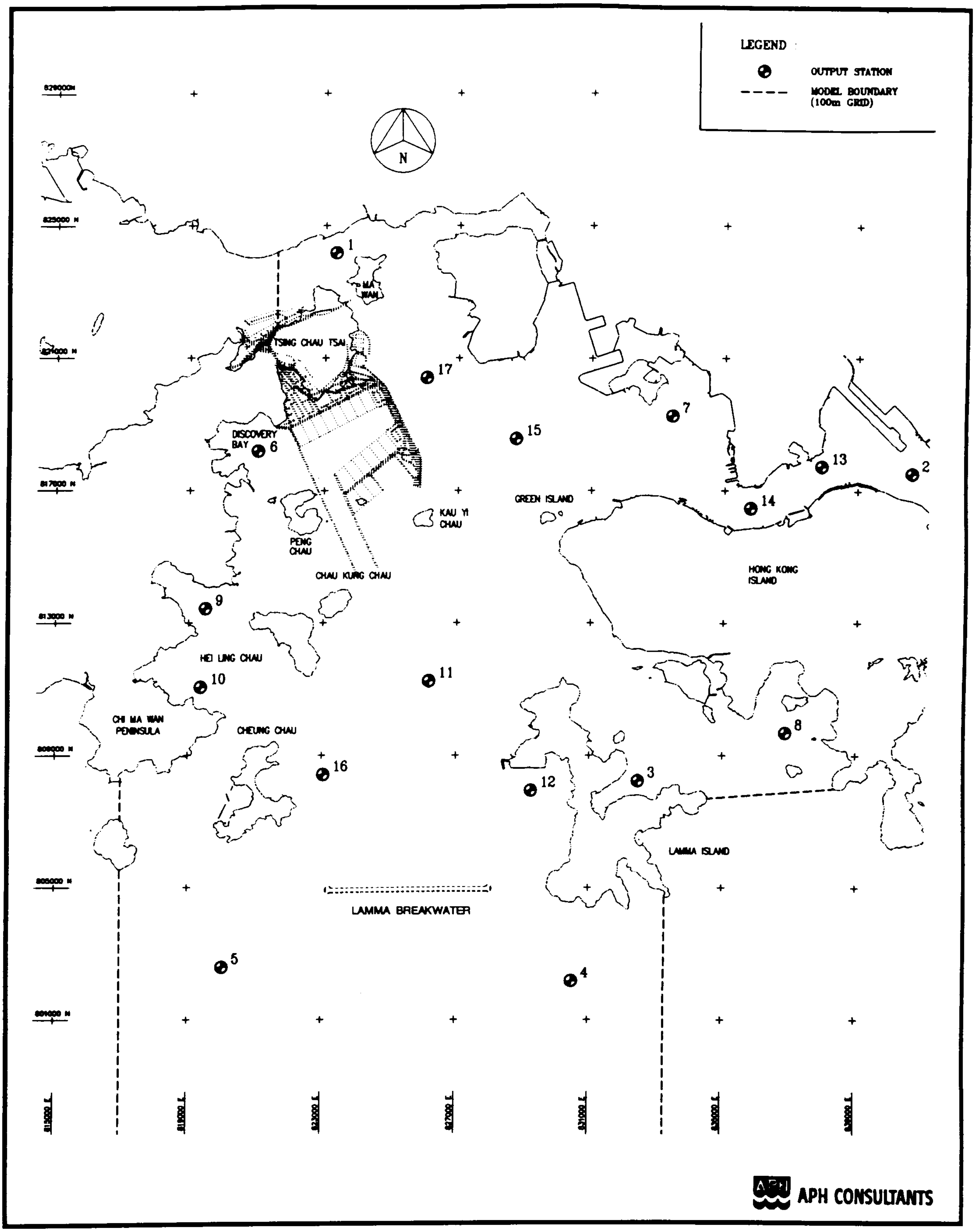

FIGURE 7.5

OUTPUT STATIONS FOR WAHMO WATER QUALITY MODEL