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Defensible Methods of Assessing Fish Habitat: Physical Habitat Assessment and Modelling of the Coastal Areas of the Lower Great Lakes
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ABSTRACT

The Fisheries Act prohibits the harmful Alteration, Disruption or Destruction (HADD) of fish habitat unless authorized by the Minister of Fisheries and Oceans. Authorization of a HADD is usually conditional on the implementation of certain compensatory measures to achieve a "no net loss" in the productive capacity of fish habitat. Procedures now exist to quantify the impacts of physical changes on productive capacity. These procedures allow the evaluation of pre- and post-development scenarios, including any compensatory measures. In this report, these procedures are applied to two case studies consisting of the construction of a 150 m long headland at LaSalle Park Marina on Hamilton Harbour, and the construction of marina breakwaters for the Bronte Outer Harbour. The investigations have focused on evaluating the indirectly modified areas, that is, those areas affected by changes to wave and current patterns caused by the presence of the new development. In these areas, impacts are not necessarily immediate and may occur very slowly through time. For exposed Great Lakes conditions, such as exist at Bronte Outer Harbour, important considerations in the evaluation of indirect changes to productive habitat capacity include the potential for fillet beach development (resulting in future areas of lost habitat) and the potential for macrophyte colonization of created marina basins. For more sheltered sites such as LaSalle Park on Hamilton Harbour, techniques to describe wave refraction and diffraction must be applied to determine the extent of the indirect area of impact and the potential changes to macrophyte coverage. A new criterion for the limiting local wave conditions associated with the survival of macrophytes has been proposed and recommendations are provided to refine and substantiate such a criterion.

RÉSUMÉ

La Loi sur les pêches interdit toute activité entraînant la détérioration, la destruction ou la perturbation de l'habitat du poisson, sauf par dérogation avec l'autorisation du ministre des Pêches et des Océans. L'autorisation d'une telle activité est généralement conditionnelle à la mise en oeuvre de certaines mesures compensatoires visant à respecter le principe d' "aucune perte nette" de la capacité de production de l'habitat du poisson. Il existe maintenant des procédures permettant de quantifier les impacts des changements physiques sur cette capacité de production. Ces procédures prévoient l'évaluation de scénarios pré- et post-développement, y compris les mesures compensatoires. Dans le présent rapport, les procédures sont appliquées à deux études de cas, l'une concernant la construction d'une flèche de 150 m de longueur à la marina du parc LaSalle, dans le port de Hamilton, l'autre la construction de brise-lames pour la marina de l'avant-port de Bronte. Les études ont porté sur l'évaluation des zones indirectement modifiées, c'est-à-dire affectées par les changements du régime des vagues et des courants dus à la présence des nouvelles structures. Dans ces zones, les impacts ne sont pas nécessairement immédiats, et peuvent n'apparaître que lentement après un certain temps. Dans une zone battue, comme c'est le cas à l'avant-port de Bronte, les éléments importants à retenir pour évaluer les modifications indirectes de la capacité de production de l'habitat sont notamment le potentiel d'engraissement de la plage (ce qui aboutirait à un perte d'habitat) et le potentiel de colonisation des bassins artificiels de la marina par les macrophytes. Dans les zones plus abritées comme le parc LaSalle, dans le port de Hamilton, il est nécessaire d'appliquer des techniques de description de la réfraction et de la diffraction des vagues pour déterminer l'ampleur de la zone indirectement touchée et les changements éventuels de la couverture de macrophytes. Nous avons proposé un nouveau critère pour mesurer les conditions limitantes du régime local des vagues associées à la survie des macrophytes, et nous formulons des recommandations visant à affiner et à étayer ce critère.

1.0 INTRODUCTION

The Fisheries Act prohibits harmful Alteration, Disruption or Destruction (HADD) of fish habitat. The Act specifies that a HADD can be authorized only at the discretion of the federal minister of the Department of Fisheries and Oceans. Authorization of a HADD is usually conditional on the implementation of certain compensatory measures to achieve a "no net loss" of fish habitat outcome.

Recent advances have been made in quantifying the impacts of physical changes on the productive capacity of fish habitat (see Minns et al, 1995). These procedures can be used to evaluate the productive capacity of fish habitat for the pre- and post-development scenarios (the latter including any compensation measures) to determine, in a defensible manner, whether the "no net loss" objective is satisfied.

The first step in assessing the influence of a project on fish habitat is to determine the physical changes to the environment caused by the project. There are three aspects to the evaluation of the physical changes caused by a project: 1) determination of areas lost (i.e. which are no longer submerged in the post-development scenario); 2) the evaluation of directly modified areas (i.e. where the depth and surficial substrate are changed through the placement of a structure); and 3) the evaluation of changes in indirectly modified areas (i.e. where the project modifies the coastal processes which immediately or eventually result in changes to physical habitat characteristics). A review of the current procedures that are available to assess the physical changes is presented in Baird & Associates (1996).

This report presents the findings of the assessment of physical impacts caused by two projects. These two projects were selected to provide practical examples of the methods for assessing physical impacts. Section 2 provides an overview of the Defensible Methods procedure of Minns et al (1995). The physical impacts of a headland construction project at LaSalle Park Marina located in Hamilton Harbour are evaluated in Section 3. The physical impacts of the Bronte Outer Harbour breakwaters located at the west end of Lake Ontario are investigated in Section 4. Section 5 consists of a review of the available methods for predicting the presence or absence of macrophytes. The findings of this investigation are summarized in Section 6.

2.0 OVERVIEW OF THE DEFENSIBLE METHODS PROCEDURE

2.1 Definitions of Physical Habitat Characteristics

This section provides a brief overview of the definition of different areas of impact and the various fish habitat characteristics that can be affected by coastal projects.

Based on Minns et al. (1995), three areas of change are defined as follows and illustrated in Figure 2.1:

1. areas lost defined as areas below the high water level before the project and above the high water level following the project (A_L),

2. areas directly modified defined as areas below the high water level before and after the project but where the original lake bed is covered by the project, habitat characteristics of depth and surficial substrate are affected in these areas (A_{MD}),

3. areas of indirect impact defined as areas where the original lake bed is not covered by the project but where there may be changes to the key fish habitat characteristics including wave energy, surficial substrate, the condition of submerged macrophytes (including the presence or absence of macrophytes), water depth, water temperature and other water quality parameters (A_{MI}).

For the first category, any habitat is totally eliminated and the community production is reduced from its pre-development level to zero. For the second and third categories, changes to production are evaluated based on changes to the characteristics of the physical habitat.

2.2 Assessment of Impacts - Areas Lost, Directly and Indirectly Modified

Some general comments on the assessment of the three areas of impact are presented in this section. Methods for delineating these areas are introduced. For a detailed discussion of the definition of these areas refer to Baird & Associates (1996).

2.2.1 Areas Lost

The determination of areas lost to habitat is a relatively straightforward exercise. The area lost to fish habitat consists of the area which reverts to "dry land" as a result of the project. An accurate evaluation of the impact of the area lost must be based on an adequate definition of the pre-development depth and substrate conditions within the proposed area lost.

2.2.2 Areas of Direct Impact

The area of direct impact for a coastal structure such as a breakwater is delineated by the wet/dry boundary of the area lost and by the outer edge of the "footprint" of the structure. The "footprint" of the structure is defined the area of lake bed covered by the proposed coastal structure. The evaluation of the impact on fish habitat in the directly modified area requires accurate descriptions of the pre-development depth and substrate conditions as well as the post-development depth and substrate conditions.

2.2.3 Areas of Indirect Impact

Areas of indirect impact of a coastal project in relation to fish habitat are defined as those areas where "significant" changes occur to wave energy, surficial substrate, the condition of submerged macrophytes (including the presence or absence of macrophytes), water depth, water temperature, turbidity and other water quality parameters. The definition of "significant" is continually evolving as the understanding of the relationships between physical fish habitat and community productivity are improved with ongoing research.

Recent work in this area by Minns et al (1995) relates fish community productivity on the Great Lakes to water depth based on 2 m intervals in shallow water and 5 m intervals in depths greater than 5 m. Therefore, "significant" changes in depth relative to fish impact are in the order of 1 m in shallow water and 2.5 m in deeper water at present (i.e. based on Minns et al., 1995).

The definition of "significant" changes in water temperature relate to changes between the optimum temperature range for warm, cool and cold water fish species. Aside from special cases where hot or cold water is introduced from an external source to the ambient water conditions, significant temperature change only occurs where enclosed basins or significant sheltering is created and flushing is restricted. Techniques are available for enhancing flushing, thus reducing any possibility of significant changes to temperature.

Changes to surficial substrate and the local macrophyte conditions are both linked, at least in part, to the changes in wave action and circulation. Coastal development projects which extend into the lake will create areas which are sheltered from some or all directions of wave attack. In addition, the structures may influence circulation patterns (and the related steady current velocities) which are generated by winds and waves or associated with head differences (i.e. river flows). Changes to surficial substrate are also determined by the local shore type and sediment supply characteristics. For example, fine sediments will accumulate in a newly created sheltered area only if there is a local supply of fine sediment.

In the Minns et al (1995) method for quantifying fish habitat impacts, the habitat productivity is related to five categories of surficial substrate including rock, gravel, sand, mud and pelagic based on the Folk (1954) system. In most cases, changes to surficial substrate will only be significant in areas of significant erosion and deposition (and depending on the shore type, even in these areas the changes to surficial sediment may not be significant).

The presence of macrophyte cover is defined by Minns et al. (1995) to be a function of water depth, lake bed slope, water clarity, substrate and wave energy. Owing to the strong dependence of the presence or absence of macrophyte growth (including algae) on the magnitude of wave action (or wave exposure), the changes to macrophyte conditions in exposed coast situations are primarily related to changes in wave action. For example, in areas that become sufficiently sheltered, macrophytes may flourish where they were previously absent (providing that the surficial substrate is appropriate).

In summary, the delineation of the indirect area of impact is a function of the anticipated changes in several fish habitat characteristics including: surficial substrate, the presence or absence of macrophytes, water depth, water temperature and other water quality parameters. The changes to these characteristics are almost always linked in some way to changes in the wave and current conditions created by the presence of the planned coastal structures. Therefore, the primary task in evaluating the area of indirect impact will be defining the changes to wave and current patterns. The focus of this report is an evaluation of indirect impacts for two sites where coastal structures have recently been built.

3.0 LASALLE PARK MARINA - ASSESSMENT OF THE PHYSICAL IMPACTS OF A CONSTRUCTED HEADLAND

The LaSalle Park marina is located in the middle of the northwest shoreline of Hamilton Harbour which is also referred to as Burlington Bay (see Figure 3.1). Prior to 1994, an existing 100 m wide section of lakefill extending between 90 and 130 m into the lake provided the land base for the marina operation. In 1994/5 a headland was constructed from the southwest side of the existing lakefill land base, extending another 150 m into the lake (see Figure 3.2).

Minns et al (1995) used the headland construction at LaSalle Park as a case study to test the proposed "Defensible Methods" approach for evaluating the impact of physical changes on the productive capacity of fish habitat. The impacts were evaluated for areas lost, areas directly modified and areas indirectly modified. This evaluation of the project resulted in the finding that the headland created a net gain to the productive capacity of fish habitat. The primary factor contributing to this result was the prediction of a large area of increased sheltering from wave attack in the lee of the structure (i.e. the indirectly modified area on the north and south sides of the structure) which results in the prediction of a large increase in the area of macrophyte growth.

This section presents a more detailed assessment of the prediction of changes in the indirectly modified area. Four different approaches are taken to assess the increased size of the zone of sheltering. Possible impacts to depth, surficial substrate and the presence or absence of macrophytes are evaluated for the indirectly modified area.

3.1 Site Description and Coastal Processes

The offshore wave conditions were predicted for LaSalle Park from 1973 to 1993 on an hourly basis using a wind wave hindcast model. The input consisted of hourly wind speed and direction from the St. Catharines Airport and overwater fetch distances (i.e. the distance over which winds contribute to the generation of waves reaching the LaSalle site). The fetches ranged from 2 km to 4.5 km. The harbour was assumed to be ice covered from January to March.

A description of the wind conditions is provided in Figures 3.3a and c consisting of a wind rose, wind speed and occurrence by direction and a summary of the wind conditions on a monthly basis. The prevailing winds originate from the southwest. The strongest winds are associated with the southwest and east / northeast sectors, however, the frequency of occurrence for winds over 50 km/h is much greater from the southwest.

The results of the wind wave hindcast are presented in Figures 3.4a and b providing a wave rose and a wave energy rose. These figures clearly illustrate that the dominant wave direction is from the southwest. However, large waves also originate from the east northeast sector, albeit less frequently. From Figure 3.4a, it is evident that the significant wave height (i.e. the average of the highest one third of waves) does not exceed 1.5 m. The largest wave periods are in the range of 4 to 5 s.

It is noteworthy that both the southwest and the east northeast waves approach the study area shoreline at very oblique angle, and as such, there will be significant wave refraction before the waves actually reach the shore (i.e. where waves realign themselves to approach the shore at a less oblique angle, and in doing so, spread the wave energy along the shore, reducing the approaching wave heights - this is discussed further in Section 3.2).

The bathymetry for the site was shown in Figure 3.2. Water depths drop off to about 20 m approximately 500 m from shore. There is a 150 m wide shelf with depths of less than 2 m along most of the northwest shoreline. In the deeper water the surficial substrate is mud, while closer to the shore is ranges from sand to sandy silt.

The existence of shoreline protection structures along most of the northwest shore would suggest that historically this was an eroding shoreline. Although not confirmed, the shore type is likely to be cohesive.

3.2 Prediction of Changes to Nearshore Wave Conditions

The indirectly modified area created by a coastal structure is defined by the area where the nearshore wave conditions (and/or circulation patterns) have been altered significantly. More discussion on the definition of "significant" is presented in Sections 3.5 and 3.6. Section 3.2.1 provides an introduction to nearshore wave transformation processes and is followed by an assessment of the changes to nearshore wave conditions created by the new LaSalle Park headland structure using a range of different techniques from simple to sophisticated methods. The calculations of wave transformation have been confined to the largest waves from the southwest and the east northeast sectors (i.e. where the largest waves originate from).

3.2.1 Processes of Nearshore Wave Transformation

Waves generated in deep water undergo significant changes in amplitude (height), length and direction as they propagate towards the shoreline, largely due to the influence of the underlying bathymetry. Some of the processes include:

- Shoaling - The changes in wave height and length due to a decrease in water depth.
- Refraction - The bending of a wave crest due to changes in water depth. A shoal may create an area of wave convergence with high concentrations of wave energy.
- Diffraction - The transfer of wave energy from regions of higher energy concentration to areas of lower concentration. Wave diffraction is the predominant consideration when evaluating the wave climate in a sheltered bay or harbour, or at locations where strong changes in nearshore bathymetry result in wave convergence and in concentrations of wave energy.
- Breaking - The dissipation of wave energy due to breaking processes as waves encounter shallow depths. The presence of wave breaking has a strong effect on the movement of sediments and the level of turbulence in the water column.
- Reflection - The reflection of wave energy due to the presence of structures and/or due to rapid changes in bathymetry is often an important consideration with coastal development. Wave reflections can cause a build-up of wave energy in localized areas. The relative importance of wave reflection is a function of the material characteristics of any surface-piercing structures.

The relative impact of each of the above processes on the transformation of waves as they propagate from deep water to the shoreline depends primarily on the nearshore bathymetry and the arrangement of any coastal structures, although bottom friction may have an effect.

3.2.2 Simple Approaches to Wave Refraction, Shoaling and Diffraction

At LaSalle Park, since the nearshore bathymetry may be characterized as having straight, "shore-parallel" contours, the changes in the waves due to refraction and shoaling may be estimated using "Snell's Law", a pocket calculator and tabulated values from the USCOE Shore Protection Manual (1984) or equivalent coastal engineering handbook. The accuracy of this methodology depends largely on the variation of the actual bathymetry from the assumption of straight, parallel contours; such an arrangement is rarely found in nature. The method is also less reliable for cases such as LaSalle Park where the waves approach at a very oblique angle.

With more complex bathymetries, wave ray-tracing techniques based on Snell's Law have been developed which follow the path of the waves as they move toward shore. In this case, a number of wave rays, defining the direction of wave propagation, are drawn manually on a hydrographic chart of the site with changes in wave direction/height being estimated locally at each contour line of the nearshore bathymetry through solution of Snell's Law. The construction of wave rays is described in many coastal engineering text books (e.g. U.S. Army Corps of Engineers Shore Protection Manual, 1984; Dean and Dalrymple, 1984).

For this case study, both Snell's Law and the wave ray tracing approaches have been applied to determine the change in the wave direction between an offshore "deepwater" location and a point at the end of the new headland in 9 m of water. Deepwater is defined as a depth greater than one third to one half the deepwater wavelength (the deepwater wavelength of a 5 s period wave is 39 m). These calculations for southwest and east northeast wave conditions are shown in Figure 3.5 using the Snell's Law approach. A "refraction coefficient", which is determined from the change in wave approach angle between deepwater and a point of interest, describes the energy loss between these two depths (the energy is actually spread along the shoreline). In other words, the nearshore wave height is equal to the offshore wave height multiplied by the refraction coefficient. The findings using Snell's Law and wave ray refraction are summarized and compared in Table 3.1.

Table 3.1 - Results of Refraction Calculations for Snell's Law and Wave Ray Techniques

method	H_s (m)	T (s)	offshore depth (m)	offshore wave direction	nearshore depth (m)	nearshore wave direction	refraction coefficient
Snell's	1.75	5.75	18	SW (225°)	9	193°	0.47
Snell's	1.25	4.75	16	ENE (67.5°)	9	71.5°	0.52
Wave Ray	1.75	5.75	18	SW (225°)	9	202°	0.52
Wave Ray	1.25	4.75	16	ENE (67.5°)	9	76°	0.39

Note: The average azimuth of a normal to the depth contours was taken as 143° for SW approach and 156° for ENE approach for Snell's Law calculations.

The results of Snell's Law and wave ray techniques compare favourably for the SW wave attack, however there is some discrepancy in the comparison of the two approaches for the ENE wave attack. In general, the predicted refraction results in a 40 to 50% reduction in wave heights between deepwater and the 9 m depth contour. Both sets of results may not be accurate owing to the very oblique wave approach angle to the shore. As we shall see from the numerical model results, the amount of wave height reduction due to wave refraction is probably overestimated by these simple techniques (i.e. the refraction coefficients are probably too large).

An initial evaluation of wave diffraction around simple coastal structures may be carried out using diffraction diagrams or templates given in various coastal engineering textbooks (e.g. Shore Protection Manual, 1984). These diagrams indicate, in non-dimensional form, the spread of wave energy behind a single, straight breakwater or through a narrow harbour entrance gap for various wave directions, and are typically based on the solution of the equations governing wave diffraction as developed by Penny and Price (1944). It is assumed that the region of wave diffraction has a constant depth.

The appropriate wave diffraction templates for the angle of wave approach for southwest and east northeast waves at LaSalle Park have been superimposed on the AutoCAD drawing of the pre and post development conditions at the site to determine the area of wave sheltering for these two conditions. The results are presented in Figures 3.6 to 3.9. The contour lines describe the reduction in wave height caused by diffraction alone. The lines also represent the wave direction at any point. The total reduction in the offshore wave height (i.e. through the combined effect of refraction offshore of the structure and diffraction in the lee of the structure) may be calculated by multiplying the values shown in Figures 3.6 to 3.9 by the refraction coefficients which are also noted on the figures. With respect to wave diffraction, for the local angle of wave approach and for the local wave lengths, the wave heights are reduced to less than 30% of their incoming values or less over a distance along the shore equal to the distance of the projection of the landform / structure into the lake. The template approach does not account for wave refraction because it assumes a flat bottom in the diffraction zone. Therefore, the predictions of wave direction will be inaccurate (the waves will bend more towards the shore), and the extent of the sheltering zone may be exaggerated (refraction may result in additional spreading of wave energy into the sheltered zone).

Including the refraction effect between deepwater and the 9 m contour, (i.e. a refraction coefficient of approximately 0.5), the wave heights are reduced to less than 15% of their deepwater values (or 30% of the height in 9 m of water) over a distance along the shore equal to the projection of the structure. This finding is only applicable to the wave approach and wave conditions for this site, the diffraction diagrams or templates provided in the Shore Protection Manual (1984) may be used to determine the degree of sheltering for other sites.

3.2.3 A Commonly Applied Numerical Model Approach

A group of numerical wave models that are widely employed are based on the solution of the mild-slope equation as derived by Berkhoff (1972). There are generally three formulations of such models: the elliptic, the hyperbolic and the parabolic mild slope models.

These models assume that there is a principal direction of wave propagation and the numerical solution begins to deviate when the wave angle relative to the initial wave propagation direction becomes large. Wave breaking processes are considered in most of the available parabolic models. Examples of parabolic models include the REFDIF1 model of Dalrymple and Kirby (1988) and the MIKE21 PMS model of the Danish Hydraulic Institute. Due to the limitations on wave angle, parabolic models must be cautiously applied when evaluating the wave sheltering created by coastal structures. For this investigation the MIKE21 Parabolic Mild Slope (PMS) has been applied.

In order to satisfy the "mild slope" assumption, some of the steep slopes around the pre-development lakefill and the post development headland structure had to be artificially reduced. The implications of these changes are discussed below.

Calculations of combined wave refraction / diffraction are made at all grid points throughout the model grid area. The results are presented in Figures 3.10 to 3.13 for the SW and ENE wave conditions and the pre and post development configurations. These plots show contours of wave height change in addition to vectors showing the local wave direction and wave height magnitude. For both the SW and the ENE waves the wave refraction coefficient between deepwater and the end of the new headland is about 0.80 (i.e. a reduction from the input wave height of 1.2 m to 1.0 m). In these areas the Parabolic Mild Slope (PMS) model probably provides a more accurate representation of the wave transformation processes and therefore, a refraction coefficient of 0.80 may be closer to the actual value than the values of 0.4 to 0.5 found with the simple techniques.

The zone of significant sheltering, where wave heights are reduced to less than 30% of their heights in 9 m of water (i.e. at the end of the new headland structure) over a distance along the shore, is equal to half the distance of the projection of the landform / structure into the lake. For the case of ENE waves, the distance of significant sheltering is no more than 25% of the length of the landform / structure projection into the lake. Therefore, the extent of the sheltered area at the shoreline is between 25 and 50% of the values predicted with the simple template approach. Part of the explanation for the much smaller sheltered area predicted with the PMS model relates to the artificial adjustment of slopes around the steep faces of the lakefill and headland. This is particularly apparent in Figure 3.13 with the ENE waves refracting around the end of the new headland structure. The artificially flattened slopes around the end of the structure result in large and unrealistic refraction which dramatically reduces the width the sheltered zone.

On the other hand, for the parabolic mild slope model diffraction is calculated correctly only when waves are propagating near to the x-direction. Diffraction is underestimated for all other directions. This means that the parabolic mild slope model should not be employed in areas with complex bathymetry, structures, or other situations where large changes in wave direction are expected. At LaSalle, diffraction is an important contributor to wave energy in the lee of the headland and lakefill. Therefore, wave energy in the sheltered area is probably underestimated. This inaccuracy has an opposite, although perhaps not as significant an effect to the refraction inaccuracy described in the previous paragraph. The true extent of sheltering is therefore probably somewhat greater than that predicted with the Parabolic Mild Slope model and less than that predicted with the template method.

3.2.4 State-of-the Art Numerical Model Approach

A third category of wave models are the range of Boussinesq Models which have been developed based on the time-dependent, vertically integrated Boussinesq equations of conservation of fluid mass and momentum. These models represent the state-of-the-art in wave modelling and are the focus of active research and development. Boussinesq models implicitly include the effects of wave refraction, diffraction, reflection and shoaling. Wave breaking has also been implemented in certain models. As many of the models are time dependent, irregular and multi-directional waves can be readily simulated (i.e. very realistic conditions can be reproduced). Boundary conditions must be supplied around the entire modelling region.

A disadvantage of the Boussinesq models is that there is a definite limit on the maximum depth of water that can be incorporated in the model grid. Waves cannot be truly propagated from deep to shallow water. There have been, however, advances in extending the deep water limits of Boussinesq models in recent years (Nwogu, 1993). Also, wave breaking has not yet been incorporated in the solutions used by most Boussinesq models. Therefore, at LaSalle, all depths greater than 9 meters were raised to 9 meters and depths shallower than 2 m were lowered to 2 m for modelling purposes. This represented a significant portion of the offshore area modelled. As a result, refraction occurring in the modified area is not included in the model results. The actual bathymetry and the artificial model bathymetry for the Boussinesq tests can be compared in Figures 3.14 and 3.15.

Examples of Boussinesq models include the Shoal2d model of the National Research Council of Canada and the MIKE21 BW model of the Danish Hydraulic Institute. For this investigation the MIKE21 BW model has been applied. The model has been applied with unidirectional waves (i.e. all waves come from the same direction) and for multidirectional waves (waves come from a 15° spread around the dominant wave approach angle). The latter representation produces more realistic conditions as is evident in the results plots. The results of the Boussinesq model tests for the SW and ENE wave conditions with the pre and post development shoreline configurations are shown in Figures 3.16 to 3.19. There are a pair of figures for each set of results showing a representation of the wave surface (giving an indication of wave direction) and contours of wave height change.

Owing to the fact that the depths greater than 9 m were artificially set to 9 m to run the Boussinesq model, there is no refraction predicted between deepwater and the 9 m depth off the end of the new headland. From a review of the extent of sheltering for the Boussinesq model results, wave heights are reduced to less than 30% of their heights in 9 m of water (i.e. at the end of the new headland structure) over a distance along the shore equal to the distance of the projection of the landform / structure into the lake. In general terms, these results are very similar to the simple template approach (described in Section 3.2.2) and about twice the extent of sheltering predicted by the Parabolic Mild Slope model.

The Boussinesq model tests, while unable to describe the refraction in depths greater than 9 m for the Hamilton Harbour wave conditions, probably provide the most realistic description of wave transformation in the sheltered zone. For the LaSalle Park bathymetry, the need to set the depths less than 2 m equal to 2 m to avoid wave breaking in the Boussinesq model runs does not distort the actual conditions because of the existence of a shelf with a depth of 2 m next to the shore (compare Figures 3.14 and 3.15).

3.4 Prediction of Changes to Surficial Substrate and Depth

The texture of the surficial substrate may be effected by changes to erosion and deposition patterns caused by the implementation of a coastal engineering project (i.e. in the areas of indirect impact). While numerical model simulation can provide an indication of possible changes to depth as a result of modified erosion and deposition patterns, generally, even the most advanced models are incapable of predicting changes to surficial substrate texture (i.e. as represented by the median grain size of the sediment). Nevertheless, there are some analytical approaches which can be taken in an attempt to define the changes to surficial substrate texture associated with predicted erosion and deposition; these are applied in this section to the LaSalle Park case study.

To determine the change to the surficial substrate (i.e. from pre- to post-development conditions), it is essential to have developed a good description of the pre-development surficial substrate conditions, particularly in areas where erosion and deposition is anticipated. The pre-development conditions have been described for LaSalle Park by Rukavina and Versteeg (1995). Figure 3.20 presents this information according to the Folk (1954) system.

The site conditions feature a relatively complex pattern of a range of sediment types from sand through to mud. There is a general trend for the sediment to become coarser moving in a shoreward direction. There appears to be a concentration of slightly coarser sediment around the created marina land base. This could be the result of deposition related to the interruption, deflection and trapping of sediment being transported along the northwest shoreline.

A process-based numerical model referred to as COSMOS was used to predict the potential alongshore sediment transport rate for two locations on either side of the marina (see Figure 3.21 for the location of the profile calculations). This type of process-based model predicts alongshore and cross-shore transport based on a detailed consideration of the many processes which contribute to the transport of sediment including: wave transformation, orbital velocities, steady currents (longshore and undertow), and sediment transport. A description of the model is provided in Nairn and Southgate (1993). The advantage of process-based models over the more traditional "bulk" models is that the distribution of alongshore sediment transport is predicted across the profile.

Aside from the profile shape and a representative grain size (assumed to be 0.1 mm for the fine sediments in the vicinity of LaSalle Park marina), the primary input consists of a description of the incoming waves and the water levels. The average annual alongshore transport is determined based on the input of a statistical description of the wave climate for an average year (this description accounts for the fact that the harbour is ice covered for three months of the year). The results of these calculations are presented in Figures 3.22 to 3.27. These figures show the distribution of alongshore transport for the northerly and southerly directed components at the two test profiles. The total average annual alongshore transport is also noted on the figures (i.e. integrated across the profile).

The estimate of northerly directed sediment transport (created by the southwest waves) on the south side of the harbour provides an indication of the potential rate of deposition in the lee of the structure (i.e. as sediment is deposited in the zone of sheltering it is trapped at this location). The predicted 385 m^3/year of northerly directed transport is relatively low compared to estimates for exposed shoreline conditions on the Great Lakes owing to the low energy nature of the wave climate on Hamilton Harbour. The southerly directed average annual alongshore transport rate is predicted to be 295 m^3/year for the profile on the north side of the marina. These estimates derived from the process-based model are the "potential" rates of sediment transport and are only realized if the sediment supply is adequate. The main source of sediment supply along this shoreline would have been through erosion of the shoreline itself. Considering the ubiquitous nature of shoreline protection along the northwest shore of Hamilton Harbour, it is unlikely that the full potential transport has been realized, the "actual" transport is probably significantly less than the potential value. In order to determine the actual transport rate, a detailed sediment budget would have to be performed to determine the annual rate of sediment supply to the shoreline (based on the shoreline recession rate and the type of sediment that was eroded).

In lieu of a detailed sediment budget, any evidence of historic deposition can be assessed through a review of the existing contours. The marina land base has probably existed since the early 1900's, and if sediment was accumulating at a rate as high as 385 m^3/year, some form of deposit should be visible from the pattern of the depth contours. Beach deposits do not exist because the sediment is too fine to sustain steep beach slopes close to the shore. A review of the existing contours in the vicinity of the marina reveals that compared to the general trend of contours along the shoreline, the 6 m contour has been pushed offshore south of the marina - this may delineate a zone of deposition (see Figure 3.14). However, the maximum possible change in depth over this century has probably been no greater than 1 or 2 m between the 4 and 8 m contours.

A 150 m wide, 2 m deep shelf exists along most of the northwest shoreline. This feature is probably a result of erosion of the shoreline and not deposition. A shoreline recession rate of 10 to 20 cm/year (which is typical of these conditions) would explain the existence of the 150 m wide shelf considering that the present lake level has existed for about 10,000 years. In other words, for depths less than 2 m the lake bed is susceptible to erosion.

Based on the finding that there has been only very limited deposition over the last century as a result of the presence of the LaSalle Park Marina landform, and considering the sediment supply has been virtually eliminated in recent times through the protection of most of the shoreline from erosion, it is unlikely that the new headland structure will result in any significant deposition (or erosion). Therefore, no changes to nearshore depths are anticipated in response to the construction of the new headland. Also, it is unlikely that there will be any discernible changes in the texture of the surficial substrate (because of the limited potential for any redistribution of sediment). There is a possibility that the sediment may become slightly finer in the lee of the structure, but this is not quantifiable with the available techniques for describing sediment transport.

3.5 Prediction of Changes to Macrophyte Coverage

The presence of submerged macrophyte cover is defined by Minns et al (1995) to be a function of surficial substrate, water clarity, water depth, wave energy and lake bed slope. The algorithm used by Minns et al (1995) to determine whether the submerged macrophyte cover is greater than 50% (present) or less than 50% (absent) is given below:

If substrate is sand or finer and,
If depth is less than twice the Secchi depth and,
If effective fetch is less than 2 kilometres and,
If maximum slope is less than 15 percent,
Then vegetation is present (i.e. cover greater than 50%),
Else, vegetation is absent (i.e. cover less than 50%).

As noted in Section 3.1, the fetches associated with wave attack at LaSalle Park are in the range of 2 to 4.5 km. The above algorithm would therefore suggest that macrophytes would not be able to exist on the exposed shoreline and that sheltering may be very important in creating areas where macrophytes would thrive (i.e. with cover greater than 50%).

Surveys were completed in 1994 and 1995 to define the pre-development and post-development macrophyte coverage. The new headland was completed in the fall and winter of 1994/5. The surveys consist of estimates of macrophyte coverage along the 1.5 m contour and at several shore perpendicular transects. The results of the 1.5 m contour surveys are shown in Figures 3.24 and 3.25. A comparison of the survey results with the location of the 2 m contour reveals that there is almost complete macrophyte coverage inside the 2 m contour all along the shoreline in the vicinity of LaSalle Park Marina. In other words, the coverage of macrophytes appears to be limited only by the depth and not the exposure to waves. Macrophytes exist in both sheltered and unsheltered sections of shoreline. The 2 m depth limit for macrophyte growth corresponds well to twice the Secchi depth for Hamilton Harbour (personal communication, Minns).

Therefore, on first consideration, it would appear that the 2 km fetch limit may not be applicable at this location. However, the analysis of the offshore and nearshore wave climate found that the predominant directions of wave attack for this shoreline are from the southwest and the east northeast (refer to Sections 3.1 and 3.2). Both the SW and the ENE waves approach the shoreline at a very oblique angle to the shore and undergo significant refraction. This refraction reduces the wave heights to the extent that the wave heights are equivalent to wave height generated over a fetch of less than 2 km (i.e. where the waves are generated over a fetch measured perpendicular to the shoreline). The implications of wave refraction on the 2 km fetch threshold are discussed in more detail in Section 5.

Based on these findings, it may be concluded that the creation of the new headland will not influence the coverage of macrophytes. The increased sheltering will not increase the coverage of macrophytes because the sheltering influences an area where macrophytes already exist.

3.6 Summary

The area lost and the area directly modified resulting from the construction of the new headland at LaSalle Park Marina were assessed by Minns et al (1995). This section has re-evaluated the changes in the indirectly modified areas which consist of those areas where the wave heights have been altered by the increased sheltering in the lee of the new headland structure.

3.6.1 Wave Action and the Extent of the Indirectly Modified Area

The extent of the zone of sheltering was determined for the dominant southwest and east northeast wave attack. Techniques ranging from simple methods to state-of-the-art numerical modelling were applied to describe the refraction and diffraction which modify the waves as they propagate into shallow water and eventually encounter the new headland structure. Peak offshore waves feature heights of about 1.5 m and wave periods of 4 to 5 s. Wave refraction reduces the wave heights by 30 to 60% by the time they reach the area of the new headland structure. As a result of wave diffraction, a zone of sheltering (defined as the area where waves are reduced to 30% or less of their refracted values at the 9 m contour) was found to extend along the shore for a distance equal to between one and one half of the length of projection of the structure / landform into the lake. It must be noted that these findings are site specific and related to the local wave and bathymetry conditions. These findings contrast the Minns et al (1995) findings that the zone of sheltering extends along the shore for a distance equal to 4 times the length of the obstruction.

These investigations also found that none of the available methods were ideal for describing the wave transformation. The simple analytical approach may overestimate the degree of wave refraction owing to the oblique wave attack, however, the simple wave diffraction template approach provided a reasonable estimate of the extent of wave sheltering. The Parabolic Mild Slope numerical model probably provides a reasonable description of wave refraction but underestimates the extent of the sheltering zone as a result of the artificial adjustment to the steep slopes around the headland and marina structures (i.e. that was required to meet the mild slope constraint). The state-of-the-art Boussinesq numerical model provides the most realistic prediction of wave refraction and diffraction in the zone where it is applicable which is limited to depths between 2 and 9 m for the waves at this site. Baird & Associates (1996) provide a comprehensive review of many of the available techniques for determining the wave climate and assessing wave transformation.

3.6.2 Impacts to Depth and Substrate

The potential for the new headland structure to modify the wave and current patterns to the extent where changes to the nearshore depths are experienced was evaluated through the application of numerical models of sediment transport, consideration of historical changes and a brief consideration of the sediment budget. There are no available analytical or numerical techniques to predict accurately the changes to the nearshore depths for these types of site conditions (see Baird & Associates, 1996 for a detailed discussion of available methods). A combination of numerical model and geomorphic tools must be applied to evaluate these types of changes.

It was determined that the new headland structure at LaSalle Park would not result in any significant changes in the erosion or deposition patterns. Generally, the "morphodynamics" (i.e. the dynamics of erosion and deposition) of the site are benign owing to the low energy wave conditions, the resulting low sediment transport rates and the lack of a significant source of sediment supply.

The tools available to assess the changes to the texture of the surficial substrate are even less adequate than those available to predict changes to erosion and deposition patterns. This is particularly true for conditions where the erosion and deposition patterns are not expected to change significantly, such as LaSalle Park Marina. It is likely that the changes to the surficial substrate will be minimal at LaSalle Park.

3.6.3 Impacts to Macrophyte Coverage

The impacts to macrophyte changes were assessed through the application of the algorithm to determine the presence or absence of macrophytes (from Minns et al, 1995) and through a review of pre-development and post-development macrophyte surveys.

It was found that macrophyte coverage was close to 100% for all areas with depths of less than 2 m regardless of the wave exposure. In other words, the wave heights were low enough for macrophytes to survive all along the exposed shore. Therefore, wave sheltering does not have a significant influence on macrophyte coverage at this site and the construction of the new headland will not have any significant indirect impacts on the area of macrophyte coverage.

The fetch lengths for generating wave attack along the exposed northwest shore of Hamilton Harbour exceed the 2 km limit for defining the presence of macrophytes (i.e. they are in the range of 2 to 4.5 km). However, it is postulated that the degree of wave refraction at this site accounts for this discrepancy. Refinements to the algorithm for the prediction of the presence or absence of macrophytes will be presented in Section 5.

3.6.4 Summary of Impacts

In summary, the construction of the new headland extending offshore from the existing LaSalle Park Marina land base will not have a significant indirect influence on the physical characteristics of fish habitat compared to the pre-development conditions. The direct impacts and the areas lost as a result of the construction of the new headland have been evaluated by Minns et al (1995).

This investigation was completed as a test case study of the Minns et al (1995) approach and was not exhaustive in nature. For example, the possible changes to circulation patterns caused by the construction of the new headland have not been considered. Therefore, the findings should be viewed as an example of the techniques available to assess physical changes to fish habitat and not as the definitive assessment of the new headland structure at LaSalle Park Marina.

4.0 BRONTE OUTER HARBOUR - ASSESSMENT OF THE PHYSICAL IMPACTS OF HARBOUR BREAKWATERS

The second case study consists of the assessment of physical impacts on fish habitat of the Bronte Outer Harbour breakwaters. These breakwaters were constructed in the early 1990's to form an enclosed marina basin (see Figure 4.1). The assessment was completed for the conditions that existed prior to the infilling of part of the basin in 1994/5 to create the park land base.

This section presents the results of the assessment of all aspects of impact including: areas lost, areas directly modified and areas indirectly modified.

4.1 Site Description and Coastal Processes

Bronte Harbour is located towards the west end of Lake Ontario between Oakville and Burlington. This section of Lake Ontario shoreline is an erodible rocky shore consisting of the Queenston shale formation and perhaps the Dundas limestone/siltstone formation further offshore. Historically the average annual shoreline recession rate was in the range of 0.15 to 0.25 m/year. However, most of the shoreline between Oakville and Burlington is now protected by a variety of concrete and armour stone shore protection structures.

As part of this investigation, the offshore wave conditions were predicted for Bronte Outer Harbour from 1958 to 1993 on an hourly basis using a wind wave hindcast model. The input consisted of hourly wind speed and direction from the Toronto Islands Airport (adjusted to represent overwater winds) and overwater fetch distances (i.e. the distance over which winds contribute to the generation of waves reaching the Bronte site). The fetches range from 10 km to the south / southwest to more than 200 km to the east. The shoreline was assumed to be exposed to waves for the full year as the majority of Lake Ontario usually does not freeze over.

A description of the wind conditions is provided in Figure 4.2 consisting of a wind rose. The prevailing winds originate from the west to southwest sector. The strongest winds are associated with the west / southwest and east sectors.

The results of the wind wave hindcast are presented in Figures 4.3a and b providing a wave rose and a wave energy rose. These figures clearly illustrate that the dominant wave direction is from the east, owing to the long fetch in the east direction. Easterly wave attack occurs for 15% of the year. Offshore wave heights exceed 3 m for 0.2% of the year with corresponding wave period in the 9 to 11 s range. The largest wave heights from the south and southwest are in the range of 1 to 2 m and occur over 0.4% of the year.

Due to the orientation of the shoreline at this location, the easterly waves undergo only limited refraction before reaching the shore (i.e. the general shoreline trend in the area is close to northwest-southeast).

The bathymetry for the site was shown in Figure 4.1. The slope of the nearshore profile is relatively constant at 1/100 from the shoreline to beyond the 50 m depth contour.

4.2 Evaluation of Areas Lost and Direct Impacts

The areas lost and the direct impacts are associated with the two breakwater arms (see Figure 4.4). The shorter west arm consisted of an extension of the pre-existing harbour entrance jetty.

The areas lost are defined as those areas that were converted from lake bed to dry land as defined by a water level of 74.2 m IGLD which coincides with chart datum. The estimated total area lost is about 31,000 m^2. As noted earlier, this calculation does not include the recent marina basin infilling to create the park land base. Also, as suggested by Baird & Associates (1996) there would be advantages to determining the area lost above a higher water level and treating the wet/dry zone as a separate directly modified area. If this approach were taken, the proponent would be discouraged from creating steep slopes above the water line. Therefore, the area lost presented above overestimates the true loss of habitat (i.e. for most of the time the water levels are higher than the chart datum level, some of the calculated area lost will be submerged).

The area of direct impact consists of the horizontal projection of the area of the breakwater between the water line defined by a water level of 74.2 m IGLD and the toe of the breakwater structure. This area was subdivided into several areas based on similar initial and modified depths. The total size of the directly modified area was found to be about 17,000 m^2.

4.3 Prediction of Changes to Nearshore Wave Conditions

The pre- and post-development nearshore wave conditions were determined using simple analytical techniques and through the application of a commonly applied numerical model. The results of these investigations are presented in the following sections.

4.3.1 Simple Approaches to Wave Refraction, Shoaling and Diffraction

Since the nearshore depth contours are close to being shore parallel, it is reasonable to apply Snell's Law to determine the wave refraction between deepwater (where the offshore waves were hindcast) and the 4 m depth contour at the toe of the main breakwater arm. The results, which are presented in Table 4.1, indicate that only limited refraction occurs as the waves approach the shore. Wave refraction will only result in a 5% decrease in wave heights between deepwater and the 4 m contour.

Table 4.1 - Results of Refraction Calculations for Snell's Law

method	H_s (m)	T (s)	offshore depth (m)	offshore wave direction	nearshore depth (m)	nearshore wave direction	refraction coefficient
Snell's	5.5	11	100	E (90°)	4	113°	0.95
Snell's	2	6	100	S (180°)	4	163°	0.88

A nearshore contour orientation of about 45° (or southwest to northeast) was used in the above analysis. The offshore and predicted nearshore wave directions are shown in Figure 4.5. From this figure it is evident that there will be almost no sheltering outside the marina basin from the easterly and southerly wave attack. Therefore, there is no need to perform a diffraction analysis for this site.

4.3.2 A Commonly Applied Numerical Model Approach

The Danish Hydraulic Institute Parabolic Mild Slope numerical model was applied to determine the nearshore wave heights through the modelled grid area based on the effects of combined wave refraction and diffraction. The contours of the model grid area are shown in Figure 4.6 and 4.7 for the east and south wave attack model runs respectively. The results of the wave transformation analysis for the pre- and post-development conditions are presented for the easterly and southerly wave attack in Figures 4.8 to 4.11. These figures show contours of wave height and vectors of wave direction for the largest waves from the two dominant directions. As found with the application of the simple Snell's Law approach, the easterly wave attack results in no sheltering and the southerly wave attack results in only very limited sheltering. These findings are clearly shown in Figures 4.12 and 4.13 which present the percent reduction in wave heights for the post-development situation compared to the pre-development situation for the easterly and southerly wave attack respectively. The very minor sheltering on the northeast side of the structure created during southerly wave attack is not significant because this area is frequently attacked by the high energy easterly waves. These figures also clearly demonstrate that the enclosed marina basin is effectively sheltered from all wave action.

4.4 Prediction of Indirect Changes to Depth and Surficial Substrate

Since this shoreline consists of slowly eroding bedrock, the construction of the breakwaters will not result in any significant depth changes through erosion. The only possible depth changes, which could result in both areas lost and areas directly modified, may result from the development of a fillet beach along the section of shoreline adjacent to the location where the main breakwater arm meets the shore on the north side of the facility.

Using the statistical summary of the wave data as input, along with the existing profile shape, the COSMOS model was applied to determine the stable orientation of a beach at this location. This iterative analysis consists of running the numerical model until the shoreline orientation with a net average annual alongshore transport rate of zero is determined. This orientation will represent the eventual "equilibrium" orientation of the shoreline. For the Bronte Harbour site, the calculated stable fillet orientation is shown in Figure 4.14. The next question that must be answered concerns the potential size of the fillet beach deposit, the beach shown in Figure 4.14 represents the ultimate size of the deposit with a volume of 64,000 m^3. Whether this size of beach will ever exist at this location depends on the local sediment transport and sediment supply rates. Once again, using the COSMOS model, and assuming a grain size of fine gravel, the potential transport rate from north to south for a location immediately north of the fillet beach was found to be about 8,000 m^3/year. If the supply of sediment along this shore was sufficient to achieve the potential transport rate, the fillet beach would reach its full size as shown in Figure 4.14 within only 8 years. However, in reality the sediment supply along this section of shoreline has been dramatically reduced by several factors listed below:

- almost all of the shoreline is protected from erosion, eliminating the primary source of sediment supply;
- during the implementation of the shoreline protection much of the nearshore sediment would have been covered and thus eliminated from the sediment budget;
- in the early part of this century the practices of stone hooking (mining loose rock from the lake bed) and beach mining may have dramatically reduced the available sediment for transport along the lake bed;
- the various artificial structures located to the northeast of Bronte which protrude into the lake and intercept the sediment moving along the shore.

Historically, any beaches in this area consisted primarily of "shingle" which are flat rounded stones derived from the erosion of Queenston shale and Dundas limestone/siltstone formations that make up the lake bed and the shoreline in this area. As noted above, much of the supply has been eliminated and only the supply from erosion of the lake bed remains. No attempts have been made to perform a detailed sediment budget for this section of shoreline. The Bronte Outer Harbour breakwaters have been in place for at least three years now and only a very minor shingle beach deposit has accumulated, perhaps with a volume of less than 150 m^3. Therefore, from this limited information, it may be postulated that the fillet beach shown in Figure 4.14 may not develop for a very long period of time (i.e. greater than 1000 years based on the rough estimate of accumulation in the last 3 years). Such a time frame is well beyond the expected life of the structure.

The fillet beach will be composed of shingle which, in places, may eventually directly modify the existing surficial substrate of exposed bedrock. When, or if, the fillet beach develops to the size shown in Figure 4.14, an additional 30,000 m^2 of lake bed would revert to "area lost". This area is almost equivalent to the area lost through the construction of the marina breakwaters.

The only other area which may experience a change in surficial substrate conditions is the area within the enclosed basin of the marina. We have assumed that the existing surficial substrate is exposed bedrock based on observations of lake bed conditions both east and west of this site. Due to the very low wave activity within the marina basin, fine sediments will be able to settle out and remain stable on the lake bed of the basin. While this has the potential to occur, the limiting factor is whether, and at what rate this material might be supplied to the basin. This depends on the point and non-point loadings to the basin and on the potential interaction between the Bronte Creek outflow and the waters of the basin. At any rate, there is potential for this area to change from exposed bedrock to a thin layer of fine sediment.

4.5 Prediction of Changes to Macrophyte Coverage

As noted in Baird & Associates (1996), only under very specific circumstances will macrophytes be able to survive along the exterior shoreline of a coastal structure along exposed Great Lakes shores. These circumstances do not exist at Bronte Harbour. This issue is discussed in greater detail in Section 5 of this report.

The Baird & Associates (1996) report also found, based on a review of macrophyte colonization of created marina basins in the jurisdiction of the Metro Toronto Region Conservation Authority, that macrophyte growth could be established within marina basins. This was only true for areas where the shoreline and lake bed did not consist of eroding fine sediments (e.g. such as the erodible bedrock shoreline and lake bed conditions that exist at Bronte Harbour). Therefore, providing that fine sediment does accumulate within the marina basin, the sheltered basin may eventually be able to support macrophyte growth. The only local process which may hinder the establishment of macrophytes in the basin is the possible influence of the Bronte Creek outflow on the water quality within the basin.

4.6 Summary

For the Bronte Outer Harbour project, consisting of two breakwaters constructed along an exposed Great Lakes shoreline with an erodible bedrock shore type, the only possible indirect impacts are related to the changes associated with the growth of a fillet beach and the changes within the sheltered basin. The growth of the fillet beach is likely to be very slow at this location. However, the shingle beach accumulation could eventually result in an area lost almost equivalent to the area lost through the construction of the breakwaters.

Within the enclosed basin, the surficial substrate could change from exposed bedrock to fine sediment providing there is a sufficient supply of fine sediment. If this change in surficial sediment conditions occurs, and providing that the light penetration is adequate, macrophytes could colonize the basin. Light penetration is a function of basin depth and water clarity. Usually, for erodible bedrock shorelines, sufficient light is able to reach the bed to support macrophyte growth. However, at this location, the Bronte Creek outflow may have an adverse effect on the water clarity within the basin. It should also be noted that the thermal characteristics of the water within the basin will differ from the pre-development exposed coast conditions.

5.0 PRELIMINARY INVESTIGATION OF THE LINK BETWEEN PHYSICAL PROCESSES AND MACROPHYTE GROWTH

This section provides a preliminary discussion of the link between physical processes and the potential for macrophyte growth based on the findings of this investigation and that of Baird & Associates (1996). Changes to the presence or absence of macrophyte growth between pre- and post-development scenarios in many cases could be the most important indirect impact. Also, where the area of macrophyte growth expands for the post-development scenario, this may partly or completely offset the areas of habitat lost resulting from the construction of a coastal project.

5.1 Background

As noted in Section 3, Minns et al (1995) provide the following algorithm to determine whether the submerged macrophyte cover is greater than 50% (present) or less than 50% (absent):

If substrate is sand or finer and,
If depth is less than twice the Secchi depth and,
If effective fetch is less than 2 kilometres and,
If maximum slope is less than 15 percent,
Then vegetation is present (i.e. cover greater than 50%),
Else, vegetation is absent (i.e. cover less than 50%).

The first two criteria relate to direct descriptions of the surficial substrate and water clarity conditions and the fourth criteria is also explicit with regard to the lake bed slope. However, the third criterion of effective fetch is a less direct measure of local wave and current conditions. The focus of this section will be on the possible improvements to this criterion. Recommendations will be provided to advance the understanding of this important aspect of the algorithm on the presence/absence of macrophyte coverage.

5.2 The Findings of the LaSalle Park Case Study and Other Investigations

One of the important findings of the LaSalle Park Marina case study described in Section 3 of this report concerned the presence of almost 100% macrophyte coverage in areas exposed to effective fetches of greater than 2 km. It was explained that the dominant wave attack approaches the site with oblique angles that result in significant wave refraction. This wave refraction acts to reduce the incoming wave energy to the extent where the nearshore wave heights are comparable to those that would be expected for waves generated directly offshore of the site (i.e. and not at an oblique angle) with effective fetches of less than 2 km. Therefore, for effective fetches in the range of 2 to 6 km, the influence of wave refraction will be an important modifying influence on the 2 km fetch criterion.

In addition, "effective fetch" is by no means a straightforward or accurate approach for assessing the process of wave diffraction in sheltered areas. The estimates of sheltered area based on an application of the effective fetch in Minns et al (1995) found that the sheltered area extended for a distance along the shore equal to <u>four</u> times the length that the obstruction extends into the lake (refer to Figure 4.5 of Minns et al, 1995). Both the analytical and numerical techniques used in this investigation found that the sheltered area extended for a distance along the shore of only <u>one half</u> to <u>one</u> times the length that the obstruction extends into the lake.

Calculations of the nearshore wave conditions for the LaSalle Park Marina and Bronte Outer Harbour case studies were performed with nearshore wave transformation numerical models. These models provide estimates of wave height, period and direction at every point within the model grid area. This information is often available from investigations to support design development. Therefore, it would be advantageous to establish a more physically based criterion related to local wave (and current) conditions. This possibility is explored in more detail in Section 5.3.

A review of the presence and absence of macrophytes around the headland and breakwater structures along the exposed and sheltered shorelines under the jurisdiction of the Metro Toronto and Region Conservation Authority was completed by Baird & Associates (1996). The only example of significant macrophyte growth in an embayment created by a headland structure on the exposed shoreline of the Toronto Waterfront is the west side of Humber Bay West. This large lakefill project extends approximately 600 m from shore and the west embayment has an opening approximately 200 m in width. Macrophytes generally do not appear to be able to survive in small embayments or semi-sheltered areas created by large shore perpendicular structures. Created embayments are more apt to provide improved conditions for the growth of *cladophera* and other types of algae particularly where the sediment supply is such that rapid accumulation or frequent shifting of sediment is not occurring. In general, the growth of algae is much more widespread than macrophyte growth, possibly for the following reasons:

- it is more streamlined and therefore able to resist the higher near bed velocities associated with exposed shoreline wave conditions;
- it can grow on rock substrates, whereas larger macrophytes usually require a fine sediment deposit;
- it recolonizes much more quickly after removal by energetic wave conditions.

A review of the macrophyte coverage at Crysler Park Marina on the St. Lawrence River located just east of Morrisburg by Baird & Associates (1995) found that there was a 50 m wide band along the shoreline which was not colonized by macrophytes. It was apparent that this zone coincided with the zone of breaking waves (i.e. the surfzone).

Hodnett and King (1987) present the results of macrophyte surveys on seven Irish lakes with fetch lengths in the range of 1 to 15 km. Their data also documents areas and conditions of vegetation washout. The authors propose a method to predict the survival of macrophytes based on the bottom shear stress which is a function of the square of the near bed orbital velocity. In another Irish study, O'Neill (1990), investigates the possibility that wind-induced steady currents, in addition to wave orbital velocities, may contribute to vegetation washout.

Denny (1995) presents a comprehensive investigation of the survivorship of various organisms that inhabit the rocky shores of the U.S. west coast. Using descriptions of the resistance of the various organisms to dislodgement, the probability of exceedence for near bed flow velocity, and the lift and drag characteristics of the different organisms, a description of the probability of survivorship was developed. A similar investigation could be undertaken to define the survivorship of submerged macrophytes (and algae) on Great Lakes shores.

In lieu of a comprehensive physically based description of the absence or presence of macrophytes (e.g. following the approach of Denny, 1995), an empirical approach could be taken which relates the distribution of macrophytes (for nearby pre-development areas or associated with nearby structures) to descriptions of appropriate wave height (or orbital velocity) and/or steady current flow velocities. As noted above, the appropriate descriptor for the wave and current conditions will depend on the manner in which survivorship of an individual species is determined (i.e. related to disturbance of the lake bed at any time of year or to the exceedence of a velocity threshold during part or all of the growing season). Changes to the physical parameters describing the wave and current conditions could be used to forecast changes to the absence or presence of macrophytes.

5.3 Possible Improvements to the 2 km Effective Fetch Limiting Factor

The primary data set on macrophyte coverage available for this investigation consisted of the 1994 and 1995 surveys in the vicinity of LaSalle Park. Unfortunately, as noted earlier the absence or presence of macrophytes along the northwest shore of Hamilton Harbour appears to be a function of depth (or water clarity) alone, wave energy was not a factor as it was everywhere less than the threshold value.

Without access to both detailed nearshore wave data and macrophyte surveys for other sites, an attempt to advance the understanding of the criterion for survivorship of macrophytes was based on an analysis of the 2 km fetch criterion. A criterion was required to provide an improved description of the local flow conditions near the lake bed. This criterion would provide an indication of the maximum intensity of flow near the bed that the macrophytes would be able to withstand before being damaged or uprooted.

Maximum wind speeds for the spring and summer months corresponding to the growing season for macrophytes (i.e. June to September) were found to be no greater than 50 km/hr (refer to Figure 3.3c for the St. Catharines Airport wind data). The overland wind speed measurements do not need to be converted to overwater values (i.e. an increase by 20 to 40%) for fetches less than about 20 km (i.e. wind blowing off the land takes more than 20 km to alter the land wind profile to a marine wind profile - see Richards et al, 1966). Figure 5.2 provides estimates of wave height and period for different wind speeds based on the Shore Protection Manual (1984) technique. The 2 km fetch with a wind speed of 50 km/hr results in the generation of a 0.45 m wave height with a 2.5 s period. For wind speeds and greater than 50 km/hr and for fetches greater than 2 km the wave heights in particular appear to grow more rapidly than for conditions below these limits.

Figure 5.3 presents estimates of near bed wave orbital velocities as a function of depth based on linear theory for different combinations of fetch length and wind speeds. Close inspection of this figure reveals an even greater divergence of conditions for fetch lengths less or greater than 2 km, particularly for the higher wind speeds. For fetch lengths equal or less than 2 km and wind speeds of less than 50 km/hr orbital velocities remain at or below 0.6 m/s. Figures 5.4a and b show orbital velocity and the square of orbital velocity as a function of fetch length for various wind speeds at a depth of 1 m. The shear stress at the lake bed is a function of the square of orbital velocity. The bed shear stress is used to describe the stability of sediments on the bottom and may also be effective in describing the survival of macrophytes, as noted by Hodnett and King (1987).

It appears that the 2 km fetch criterion corresponds to an orbital velocity threshold of approximately 0.6 m/s. Therefore, a 0.6 m/s limit on orbital velocity may be applied to determine whether macrophytes can survive at any given location in addition to the sediment texture, water clarity and bed slope criteria. In other words, where information is available, the orbital velocity criterion may replace the 2 km fetch limit as the wave condition criterion. It should be noted that at some sites, steady current velocities (such as wind and wave induced currents or river flows) may also be important in addition to orbital velocity in defining the hydrodynamic criterion.

5.4 Recommendations for Future Investigations

In order to complete defensible assessments of the influence of developments on fish habitat, it will be important to develop and test a local wave/current condition criterion, such as wave orbital velocity, to help define the presence or absence of macrophytes. In Section 5.3, a preliminary estimate of such a criterion was made based on the 2 km fetch criterion and several assumptions. However, the 0.6 m/s orbital velocity limit has not been directly tested against actual field data.

From the findings of the LaSalle Park case study it was evident that some data sets on the presence or absence of macrophytes may not be suitable for testing a criterion such as the wave orbital velocity limit. At LaSalle Park, it appeared that the effective fetch limit (or a wave orbital velocity criterion) had no influence on the presence or absence of macrophytes. Therefore, prior to undertaking detailed analyses on the presence or absence of macrophytes, data sets should be screened to evaluate in a preliminary manner whether the pattern of macrophytes has any relation to the local variations in wave conditions. A proposed outline for a future investigation to develop a wave/current condition threshold is provided below.

1. Assemble preliminary information on all available data sets on the coverage of macrophytes for the Great Lakes (or other lakes with similar conditions). In addition to the distribution of macrophyte

coverage, this information should include details on surficial substrate, bathymetry (to provide depths and bed slope) and some indication of local water clarity (or Secchi depth).

2. Undertake a preliminary screening of the data to select those data sets which reveal a strong link between wave conditions and the presence or absence of macrophytes. For Great Lakes sites, it is likely that these data sets will be associated with partially sheltered embayments or locations along the St. Lawrence River.
3. For the selected sites, determine the required level of sophistication for wave refraction and diffraction analyses. Where possible, focus efforts on those sites where simple refraction and diffraction techniques may be applied to describe the nearshore wave transformation.
4. At each site, develop maps of wave conditions (local wave height and period) for areas where there is a transition between the absence and presence of macrophytes. Determine whether the boundary between areas with and without macrophytes can be described by a criterion such as orbital velocity. Consider the possible influence of steady current velocities in addition to orbital velocities.

Once a definition of a local wave/current condition criterion (such as an orbital velocity limit) was established and verified, it would be possible to develop a table to describe where, and to what extent, changes to macrophyte coverage might be expected. This table would be based on wave exposure (i.e. fetch lengths) and the orientation of the shoreline and new structures to dominant wave attack. Such a table would provide a tool for the preliminary assessment of indirect impacts to macrophyte coverage.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The case studies on the assessment of impacts to fish habitat at LaSalle Park Marina and the Bronte Outer Harbour provided some valuable lessons on the application of the Defensible Methods procedure presented by Minns et al (1995).

6.1 Direct Impacts - Areas Lost and Areas Modified Directly

The direct impacts, which consist of areas lost and areas directly modified, are straightforward to determine with design or as-built drawings of the structures. One important and less straightforward consideration is the potential implication of the development of a fillet beach on the area lost. For Bronte Outer Harbour, it was shown that if the sediment supply was sufficient, there was potential for the development of a fillet beach which would result in future areas lost that would be equivalent to the area lost by the construction of the breakwaters. However, at Bronte there is probably insufficient supply of sediment to allow the fillet beach to reach its potential size within the expected lifetime of the structure (i.e. in the order of 100 years). Therefore, it is important to develop estimates of potential sediment transport rates and the regional sediment budget in order to assess the potential for the development of a fillet beach and possible future areas lost to fish habitat.

6.2 Indirect Impacts - Waves, Erosion/Deposition and Surficial Substrate

The area in which indirect impacts are sustained is associated with the area where there are significant changes to wave and current patterns as a result of a development project.

Therefore, the first step in assessing the area of indirect impact is the development of a description of the local wave climate consisting of a description of local wave conditions over a 10 to 30 year period. This is performed with a numerical wind wave hindcast model or through the use of existing wave climate data bases (refer to Baird & Associates, 1996 for sources). Summaries of the wave climate information prepared for LaSalle Park Marina and Bronte Outer Harbour as part of this investigation showed that there were one or two directions of dominant wave attack at each site (e.g. SW and ENE at LaSalle and E and S at Bronte). Most sites will feature one or two dominant wave directions based on the direction of prevailing winds (SW for the Great Lakes) or the direction of the longest fetch for a given site. Identification of these dominant wave directions which feature the largest waves that approach a site is important in order to focus the analysis of nearshore wave transformation and impacts of new structures.

The next step in the assessment of the area of indirect impact is an analysis of nearshore wave transformation. Waves which approach the shore at an angle undergo refraction which results in changes to wave height and direction. Where the nearshore bathymetry is fairly regular (i.e. with relatively straight and shore parallel contours), and where waves do not approach the shore too obliquely, simple analytical wave refraction techniques such as Snell's Law provide for an accurate description of the wave refraction process. While this was the case for Bronte Harbour, the dominant SW and ENE waves approached the LaSalle Park shoreline at a very oblique angle, and the Snell's Law predictions were less than ideal. A commonly applied numerical modelling technique (of the family of Parabolic Mild Slope solution models) was also applied to describe the nearshore wave transformation. This type of model represents an effective approach for assessing wave refraction for more complex bathymetry, however, for most versions of this type of model, is limited wave approach directions which are not too oblique to the shore. The state-of-the-art numerical models based on the solution of the Boussinesq equations are more reliable for situations of complex bathymetry and oblique wave attack, however, they also have constraints on the range of depths to which that they can be applied (i.e. they are generally restricted to applications in intermediate water depths at present). More detail on the assessment of the available approaches to wave transformation is provided by Baird & Associates (1996).

The most important process in determining the extent of an area of wave sheltering is wave diffraction (i.e. the process where wave energy spreads laterally into a sheltered area). The simple template overlay approach was found to be relatively effective for defining the extent of the sheltered area at LaSalle Park. The assumption that the sheltered area is relatively flat (i.e. no wave refraction effects), as required by the template approach, was valid at LaSalle Park. The Parabolic Mild Slope numerical model was found to significantly underestimate the zone of sheltering at LaSalle Park because of the requirement to maintain mild slopes throughout the model domain (i.e. as a result the slopes of the headland structure had to be significantly flattened for the model to run). The Boussinesq model provides an accurate description of the combined refraction/diffraction process in areas where the models are applicable (i.e. outside the breaking zone, in general). At Bronte Harbour, the refracted waves almost approach the shore "straight on" and there was little or no zone of sheltering, particularly for the dominant east waves.

For partly different reasons, very little change to the nearshore depths as a result of changes to erosion/deposition processes were predicted for the LaSalle Park and Bronte Harbour case studies. At LaSalle Park, the low wave energy environment and the limited sediment supply were the reasons for the prediction that there would be no appreciable indirect changes to depths as a result of the construction of the new headland. As a result, it is likely that the changes to the texture of the surficial sediment will not be significant. At Bronte Harbour, no significant changes in depths are expected because the lake bed consists of erodible bedrock and because the sediment supply rate is probably very low. Issues regarding the potential development of a fillet beach were discussed in Section 6.1. There is potential for the surficial substrate of the enclosed basin to change from exposed bedrock to fine sediment, providing there is a source of fine sediment. It would be very difficult to accurately predict the rate of sedimentation within the basin and this would be best evaluated through a post construction monitoring program.

6.3 Indirect Impacts - Changes to Macrophyte Coverage

The result of the original application of the Defensible Method approach to the LaSalle Park Marina case study by Minns et al (1995) was strongly influenced by the predicted large increase in macrophyte coverage between the pre- and post-development conditions. Essentially, the predicted increase in macrophyte growth was found to more than compensate for areas lost and directly modified by the construction of the new headland. In direct contrast, with the benefit of access to pre-and post-development macrophyte surveys, our investigation has shown that the new structure will have little or no impact on the macrophyte coverage at LaSalle Park. The discrepancy between the Minns et al (1995) and the current assessment of changes to macrophyte coverage at this site resulted from the inadequacy of the 2 km effective fetch criterion for assessing the presence or absence of macrophytes (this issue is discussed further in the next paragraph). For Bronte Park, the enclosed basin has the potential to be colonized by macrophytes providing that fine sediments are deposited over the existing bedrock substrate conditions. If macrophytes do colonize the basin, this would have a significant influence on the overall assessment of change to productive capacity of fish habitat for this project.

These case studies have underlined the potential importance of changes to the patterns of macrophyte coverage between pre- and post-development scenarios. The weakest aspect of the algorithm presented by Minns et al (1995) to predict the absence or presence of macrophytes is the wave condition criterion. The surficial substrate, water clarity and bed slope criteria consisted of direct measurements of local conditions. In contrast, the 2 km effective fetch criterion is not a direct or accurate measure of wave conditions at any given location. This inadequacy was clearly demonstrated in the LaSalle Park Marina case study, where the new headland appeared to reduce effective fetches from greater than to less than 2 km for a large area (resulting in the prediction of a large increase in macrophyte growth). This inaccurate prediction resulted from an inability for the 2 km fetch criterion to properly consider the important nearshore wave transformation processes of wave refraction and diffraction that determine local wave conditions (i.e. as a result of waves propagating into shallow water and spreading energy into sheltered areas).

Based on a review of the implications of the 2 km fetch criterion, a more local criterion consisting of a 0.6 m/s near bed wave orbital velocity was derived. Local orbital velocity is a function of local wave height, period and water depth. Therefore, this new criterion requires a consideration of refraction and diffraction processes to define the local wave conditions. Recommendations were presented in Section 5.4 consisting of a study outline to substantiate and refine a local wave/current condition criterion for the algorithm to define the presence or absence of macrophytes.

7.0 ACKNOWLEDGEMENTS

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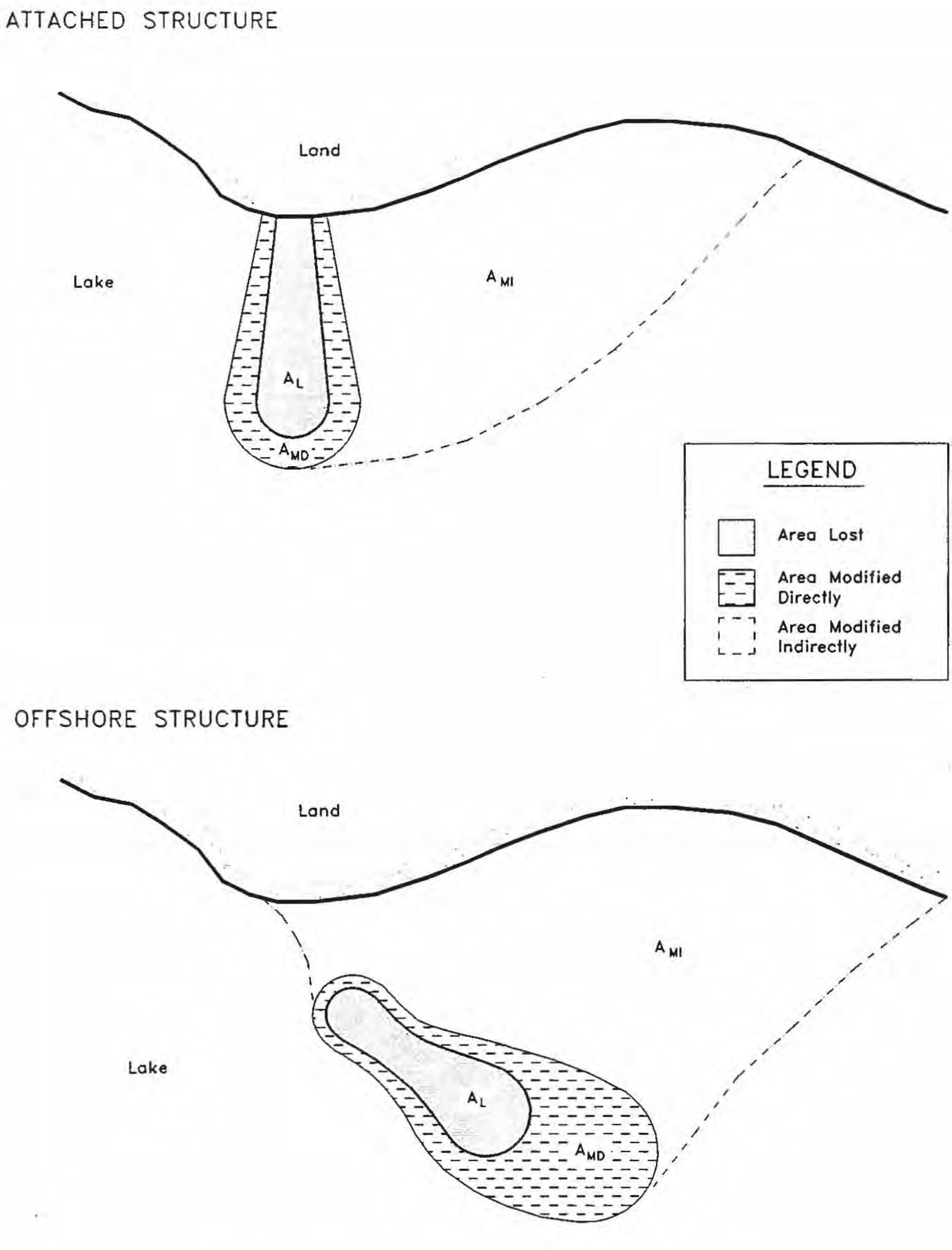


Figure 2.1 Plan View of Attached and Offshore Structures

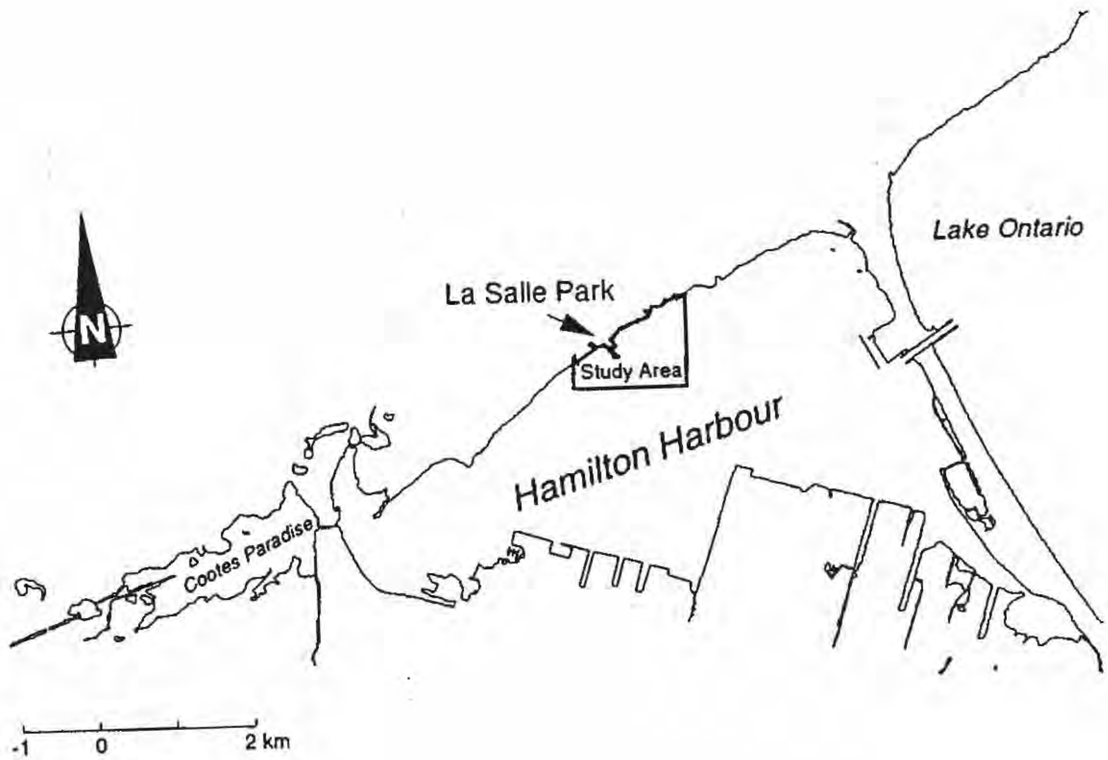


Figure 3.1 LaSalle Park Marina - Site Location
(after Mins et al., 1995)

Figure 3.2 Lasalle Park Marina – Pre and Post Development Conditions
Map Scale – 1:4,000

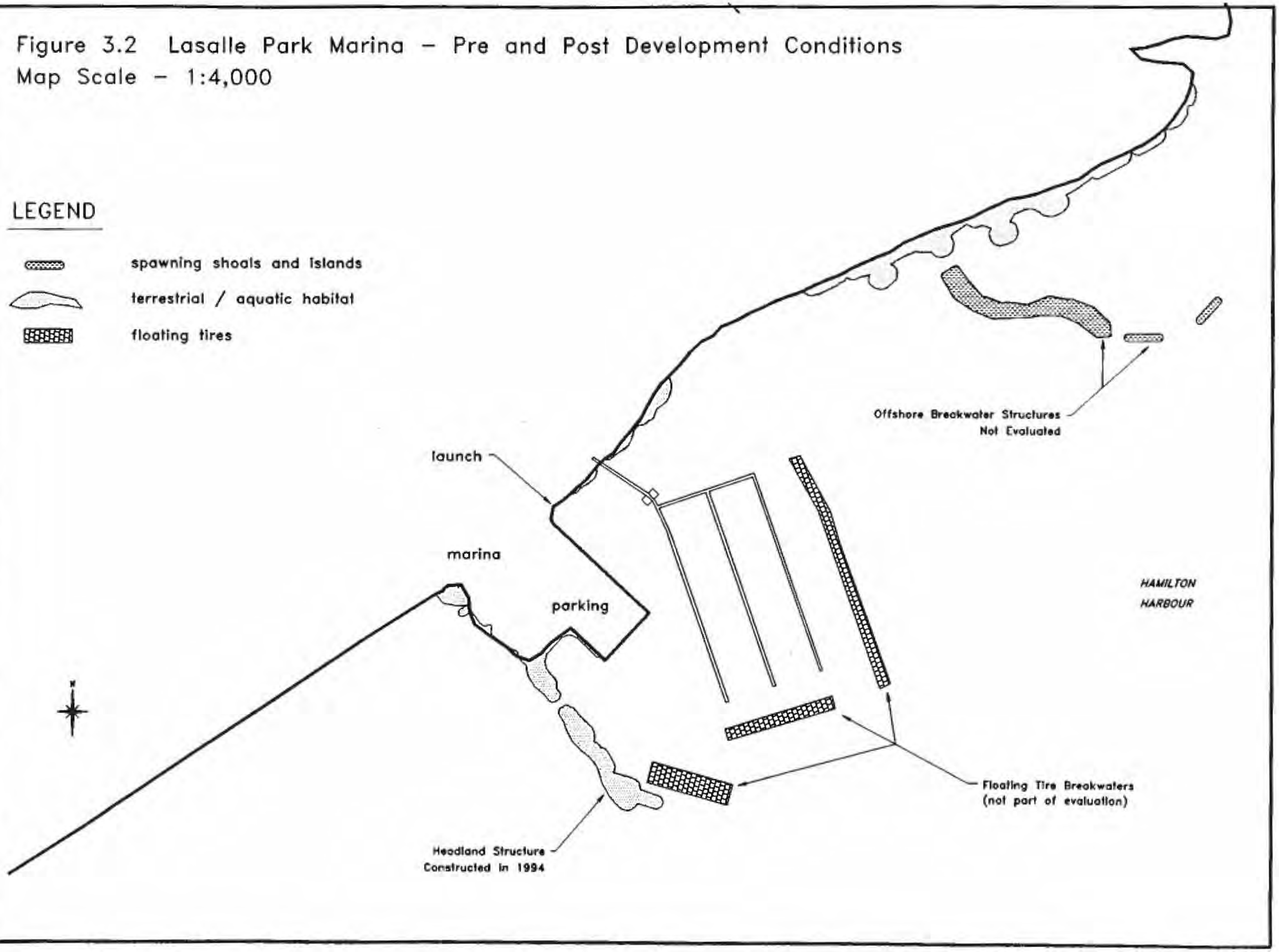
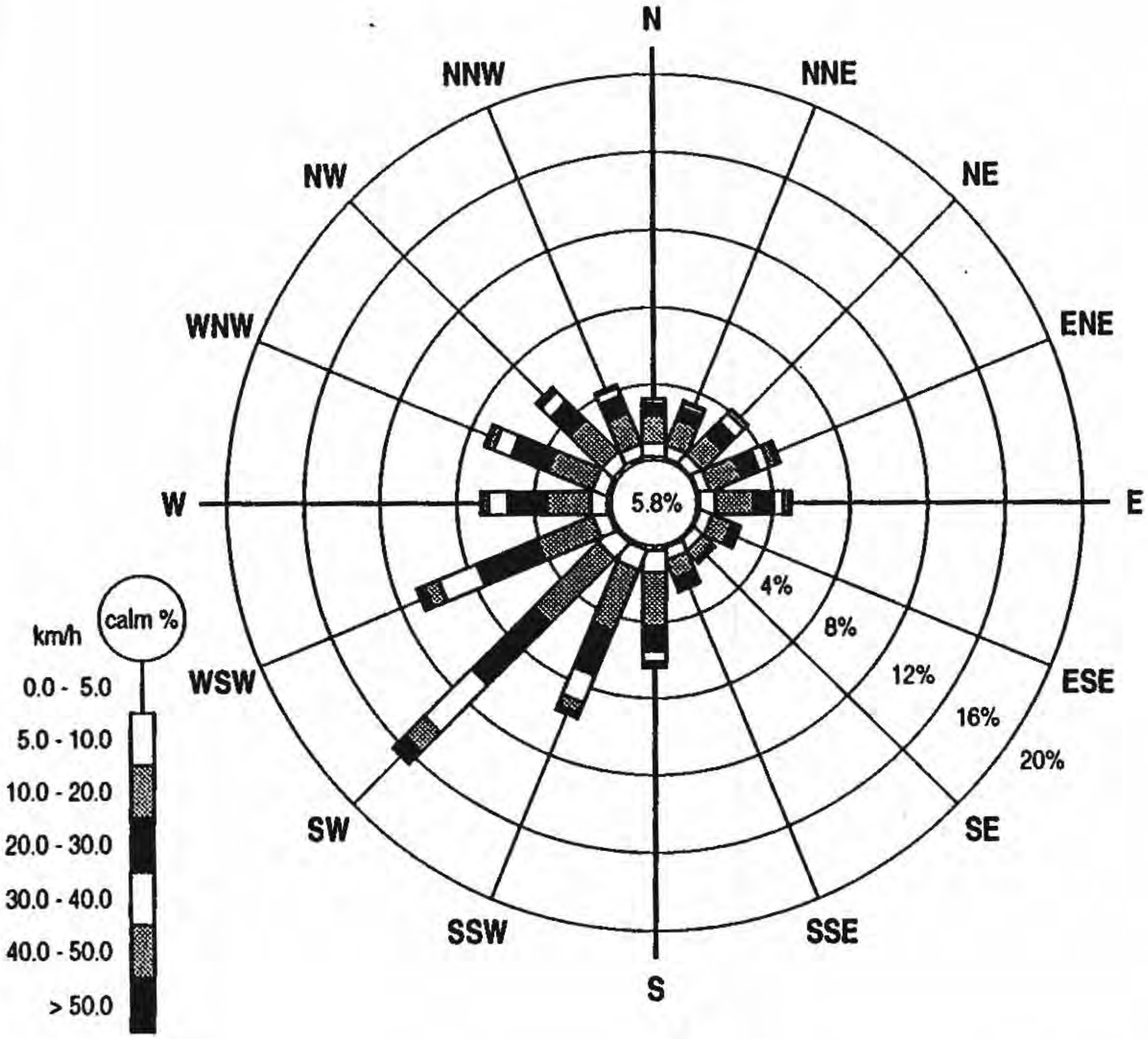


Figure 3.3a Wind Rose

Wind Station: ST. CATHARINES A.



Cumulative Distribution (%)

	0.0	5.0	10.0	20.0	30.0	40.0	50.0 km/h
NNE	0.2	0.8	2.3	3.0	3.2	3.3	3.3
NE	0.1	0.7	2.2	3.2	3.8	4.1	4.1
ENE	0.1	0.7	2.5	3.5	4.1	4.5	4.7
E	0.1	1.0	3.0	4.0	4.5	4.8	4.9
ESE	0.1	0.8	1.9	2.3	2.4	2.4	
SE	0.1	0.7	1.4	1.6	1.6	1.6	
SSE	0.1	0.8	1.8	2.2	2.4	2.5	2.5
S	0.2	1.4	4.2	5.5	6.1	6.3	6.4
SSW	0.2	1.3	4.7	7.3	8.8	9.4	9.7
SW	0.2	1.2	6.0	10.6	14.1	15.6	16.4
WSW	0.2	1.0	4.1	7.5	9.6	10.5	10.9
W	0.2	1.0	3.3	5.4	6.4	6.7	6.8
WNW	0.2	1.0	3.5	5.5	6.5	6.9	7.0
NW	0.2	1.0	3.3	4.8	5.4	5.7	5.8
NNW	0.2	0.9	2.6	3.7	4.1	4.2	4.3
N	0.2	0.9	2.4	3.0	3.2	3.3	3.3

Baird

Figure 3.3b Wind Occurrence Frequency by Direction

Wind Station: ST. CATHARINES A.

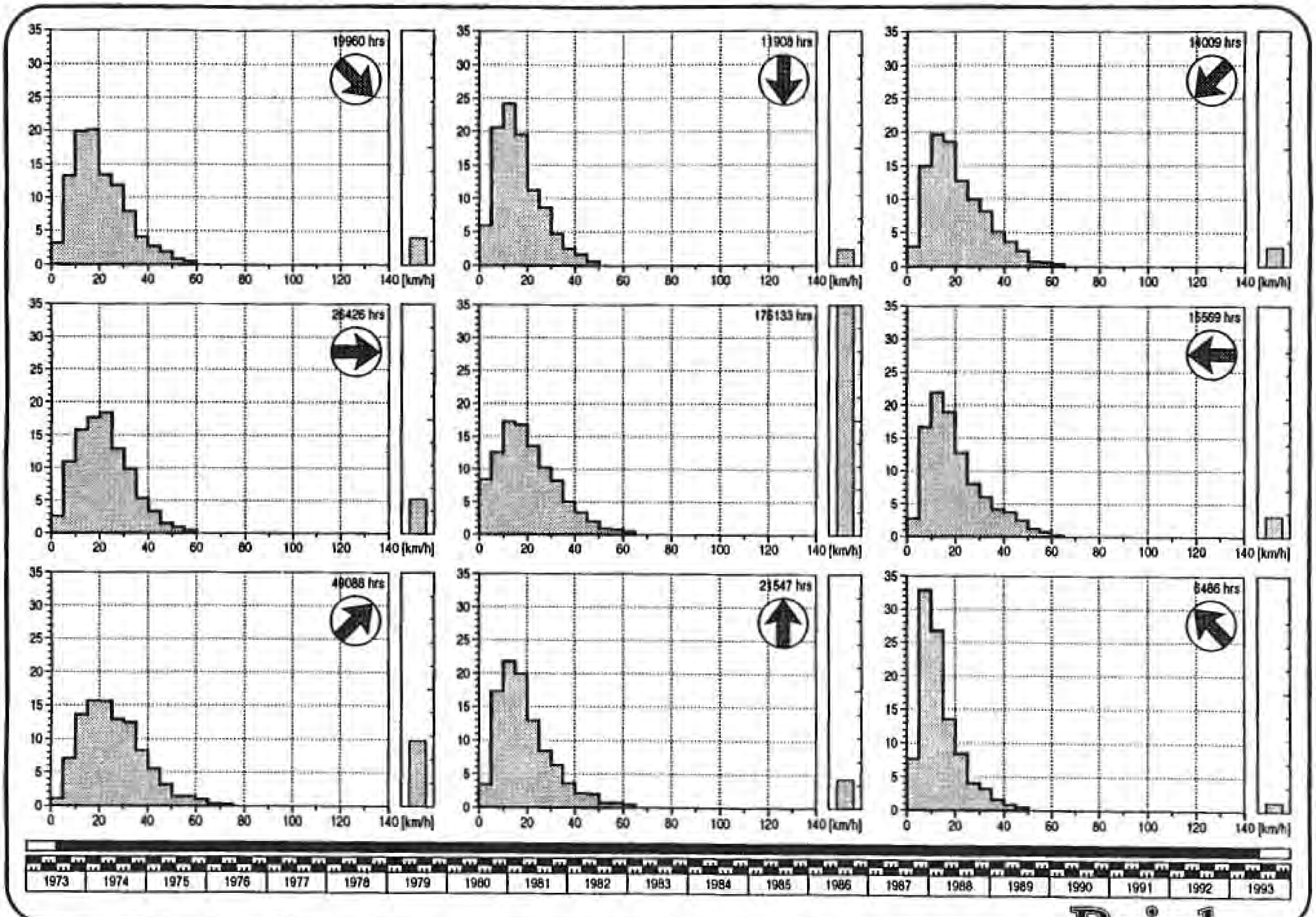


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Figure 3.3c Wind Occurrence Frequency by Month

Wind Station: ST. CATHARINES A.

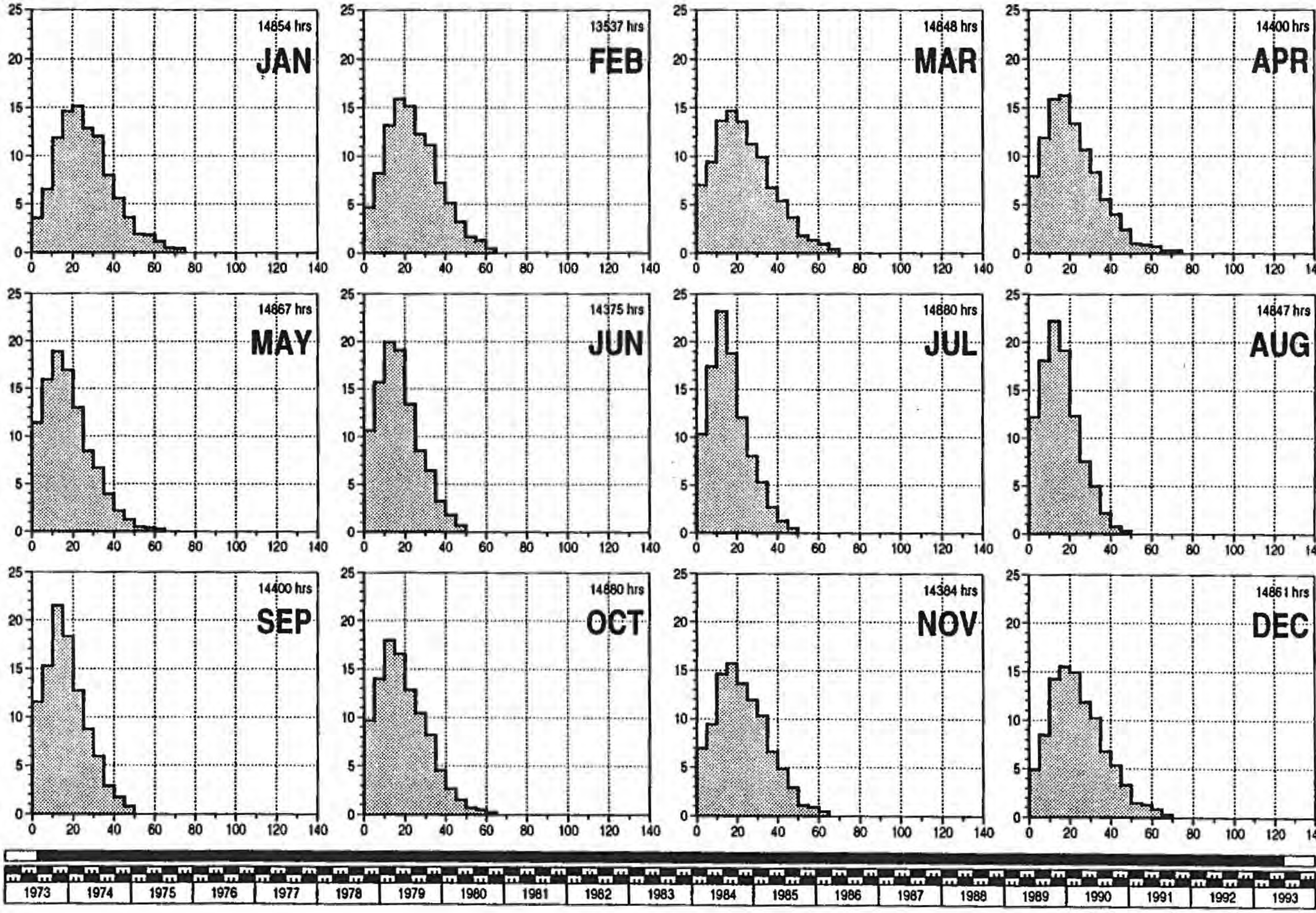

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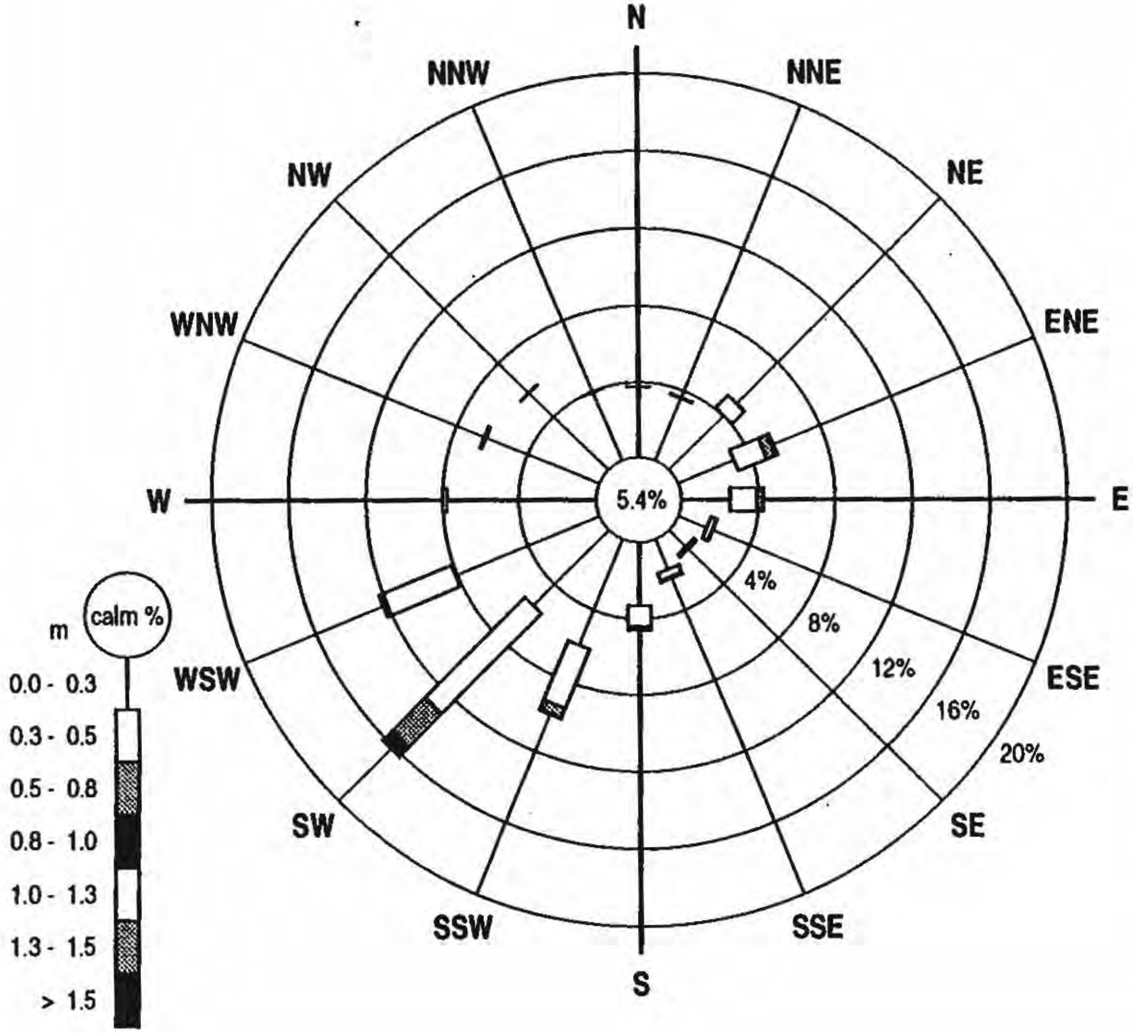
Figure 3.4a Wave Rose

Wave Station: La Salle Park



Cumulative Distribution (%)

	0.0	0.3	0.5	0.8	1.0	1.3	1.5	m
NNE	3.6	3.6						
NE	4.0	4.9	5.0					
ENE	3.1	4.7	5.3	5.3				
E	2.5	3.9	4.2	4.3				
ESE	1.6	1.9	1.9					
SE	1.2	1.4	1.4					
SSE	1.7	2.1	2.2	2.2				
S	3.3	4.4	4.6	4.6				
SSW	6.0	9.3	9.9	9.9				
SW	5.5	13.0	15.4	16.0	16.1			
WSW	8.1	12.0	12.2					
W	7.8	8.0						
WNW	6.3	6.4						
NW	5.8	5.8						
NNW	3.9							
N	3.7	3.8						

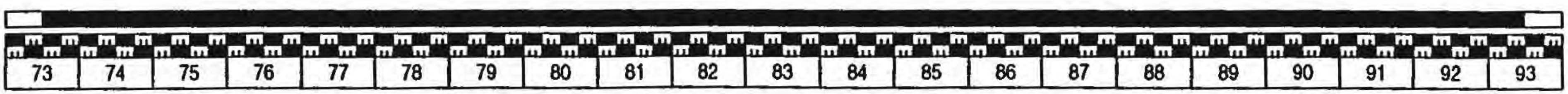


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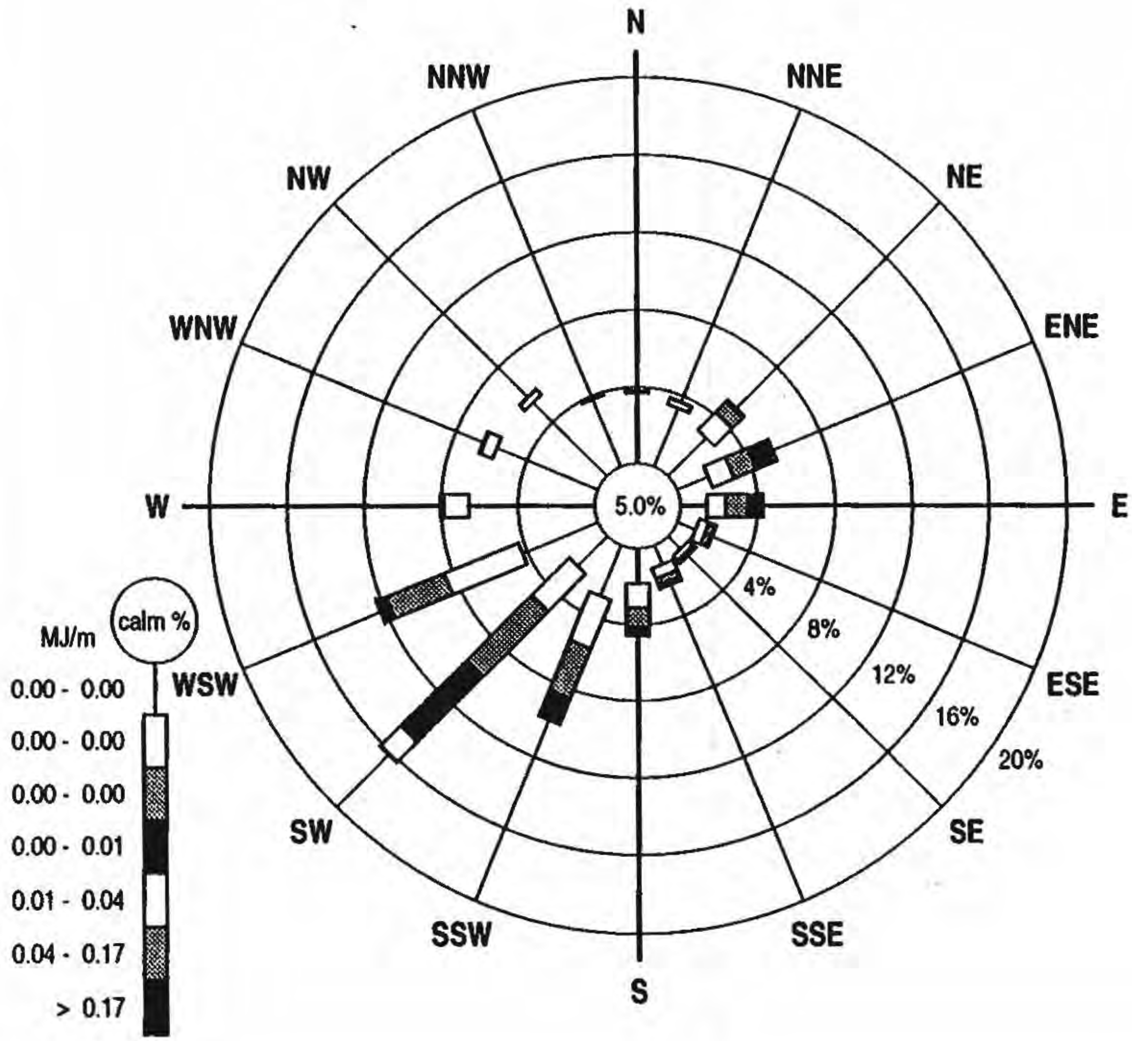
Figure 3.4b Wave Energy Rose

Wave Station: La Salle Park



Cumulative Distribution (%)

MJ/m	0.00	0.00	0.00	0.00	0.01	0.04	0.17
NNE	3.3	3.6	3.7				
NE	2.8	4.1	4.9	5.0			
ENE	1.7	3.0	4.2	5.1	5.4		
E	1.4	2.3	3.5	4.2	4.3		
ESE	1.0	1.5	1.8	1.9			
SE	0.9	1.2	1.4	1.4			
SSE	1.1	1.6	2.0	2.2	2.2		
S	1.8	3.1	4.1	4.5	4.6		
SSW	2.9	5.6	8.5	9.8	9.9		
SW	2.2	5.0	9.8	14.7	16.1	16.2	
WSW	4.3	8.4	11.7	12.2			
W	6.5	7.9	8.0				
WNW	5.7	6.4	6.5				
NW	5.5	5.8	5.8				
NNW	3.8	4.0					
N	3.7	3.8					

Water Depth Used = 13 m

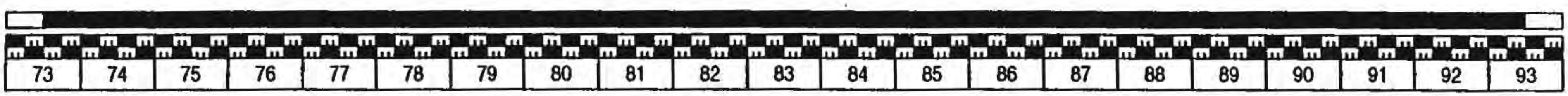


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Figure 3.5 Results of Snell's Law Refraction Analysis for LaSalle Park

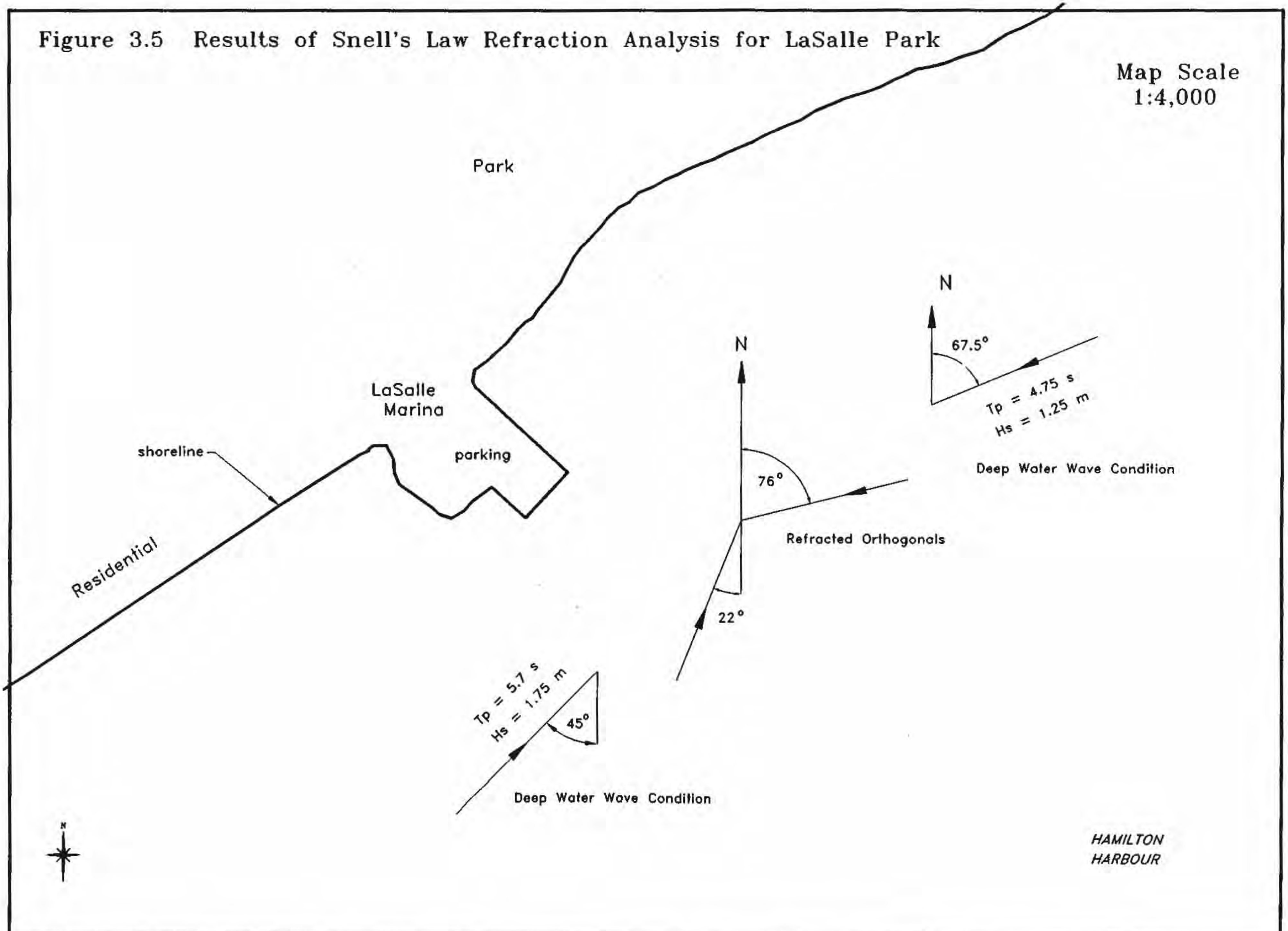


Figure 3.6 SW Wave Attack and Pre-development Conditions at Lasalle Park Template Approach to Wave Diffraction.

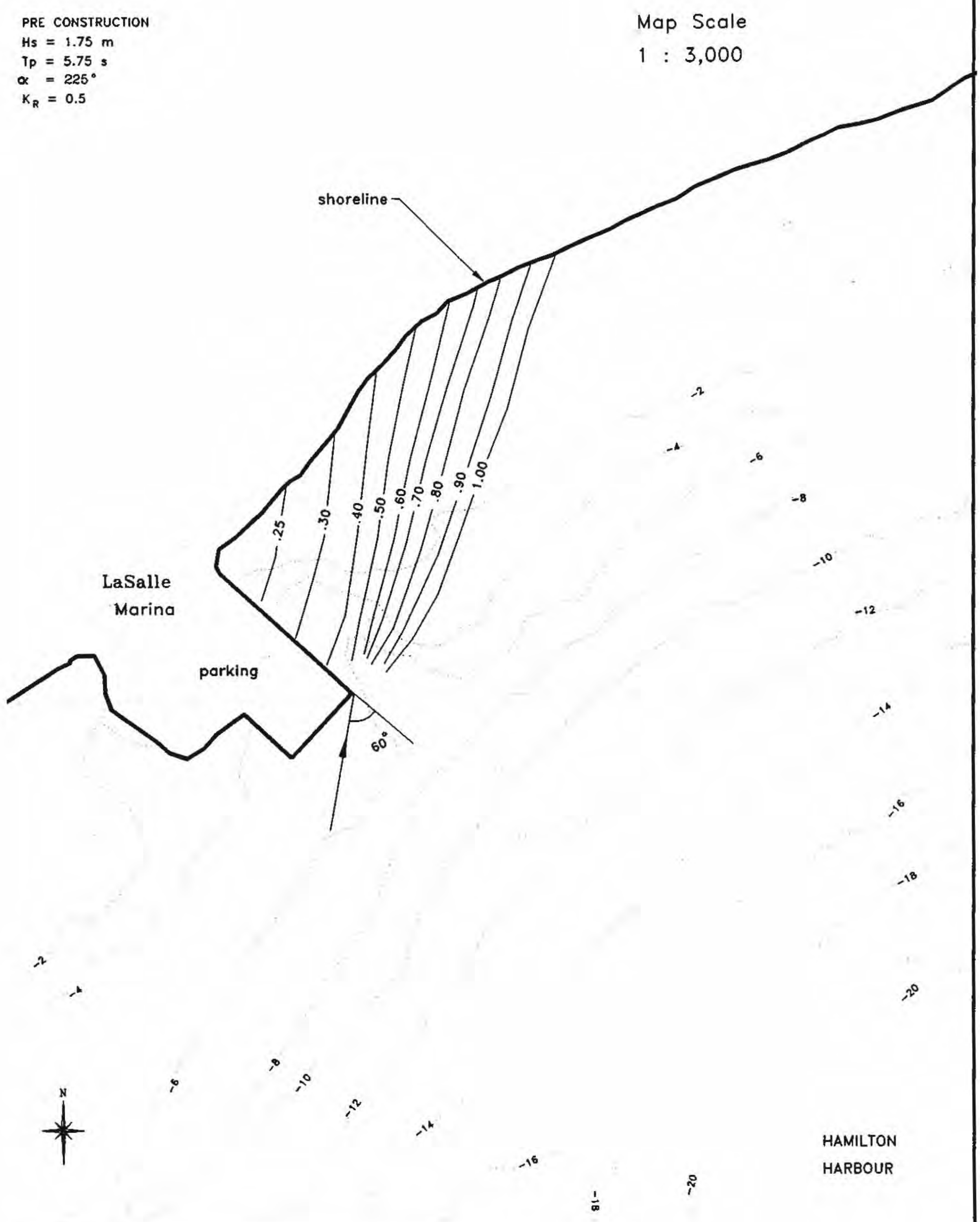


Figure 3.7 SW Wave Attack and Post-development Conditions at Lasalle Park Template Approach to Wave Diffraction.

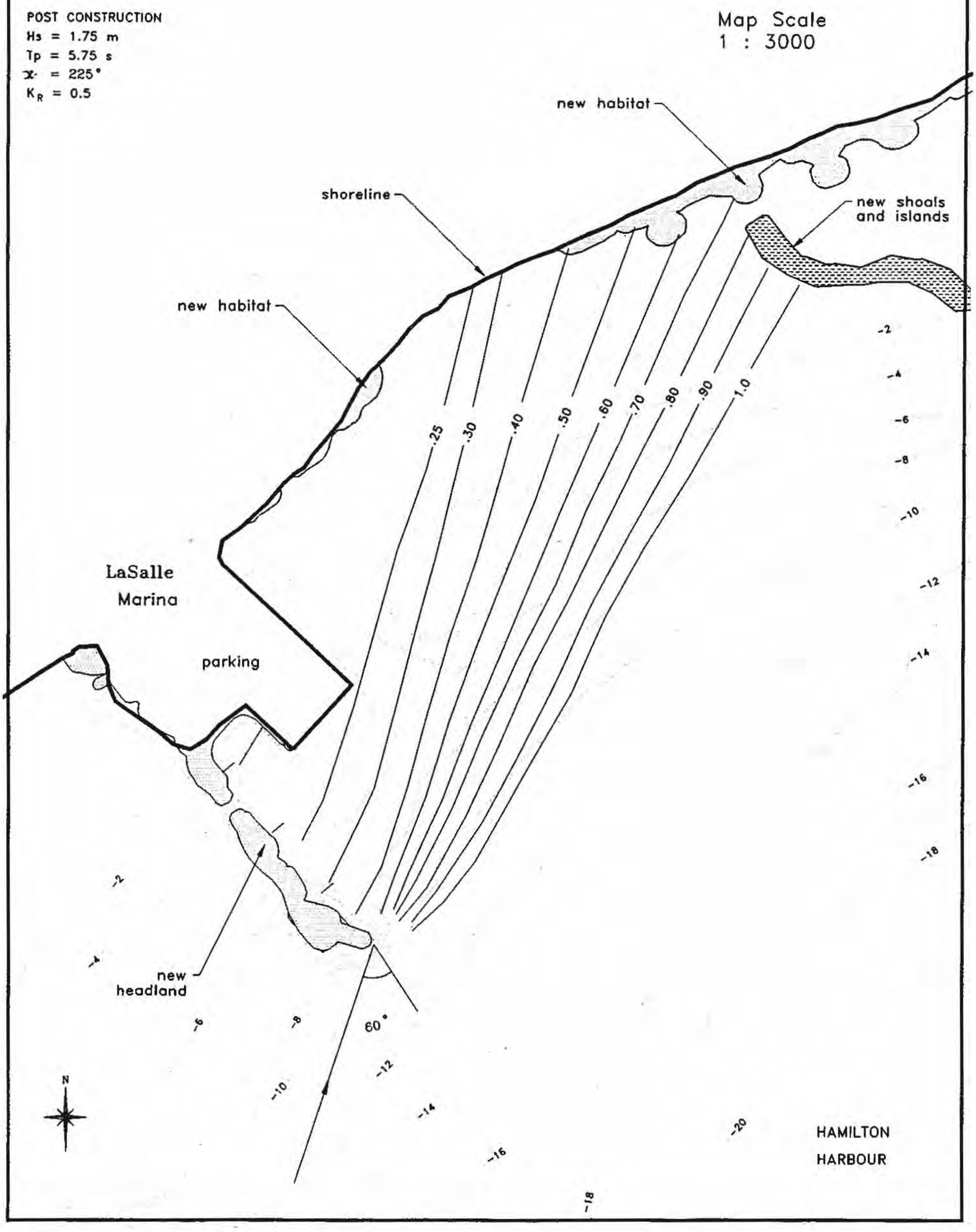


Figure 3.8 ENE Wave Attack and Pre-development Conditions at Lasalle Park Template Approach to Wave Diffraction.

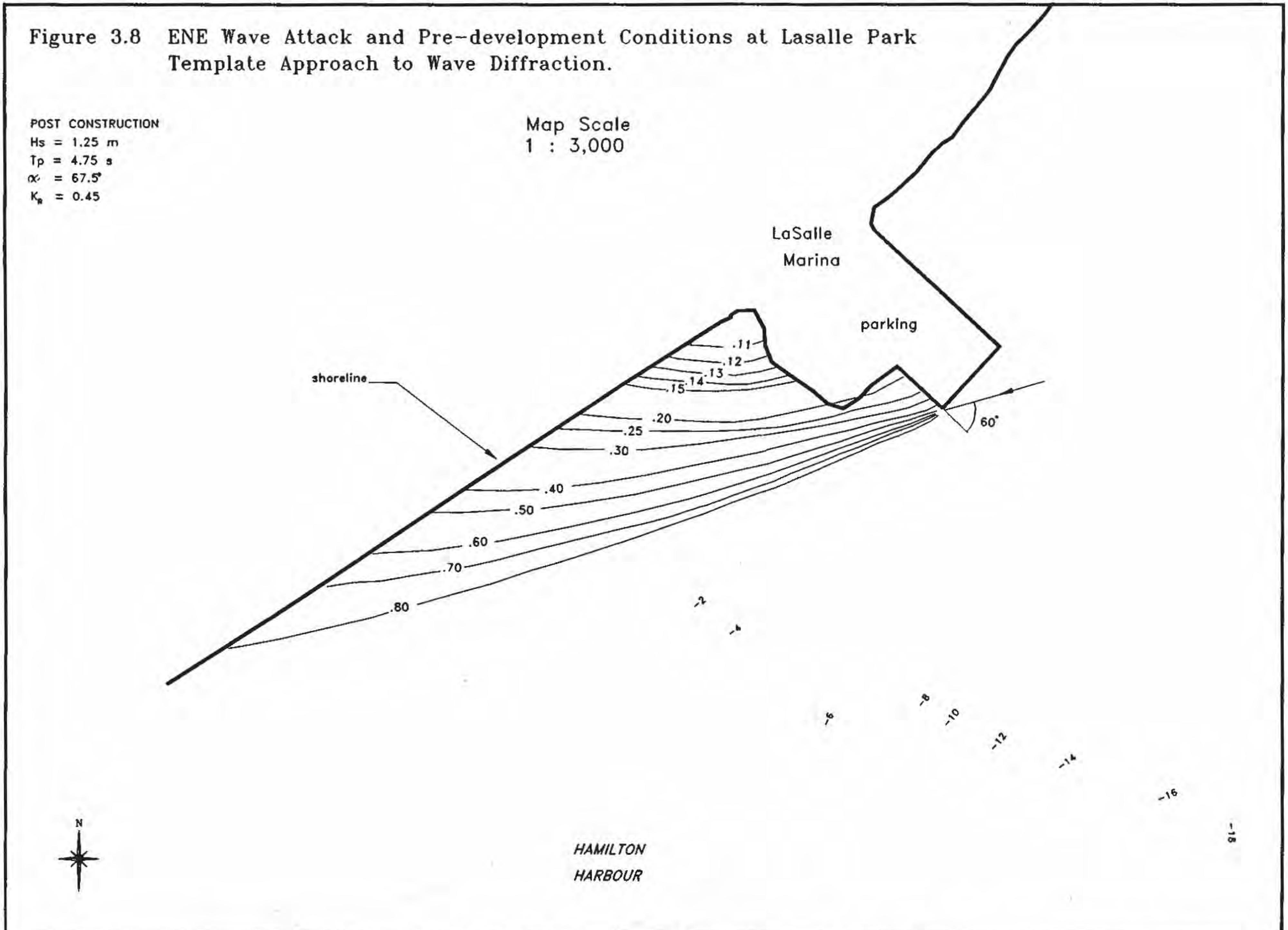
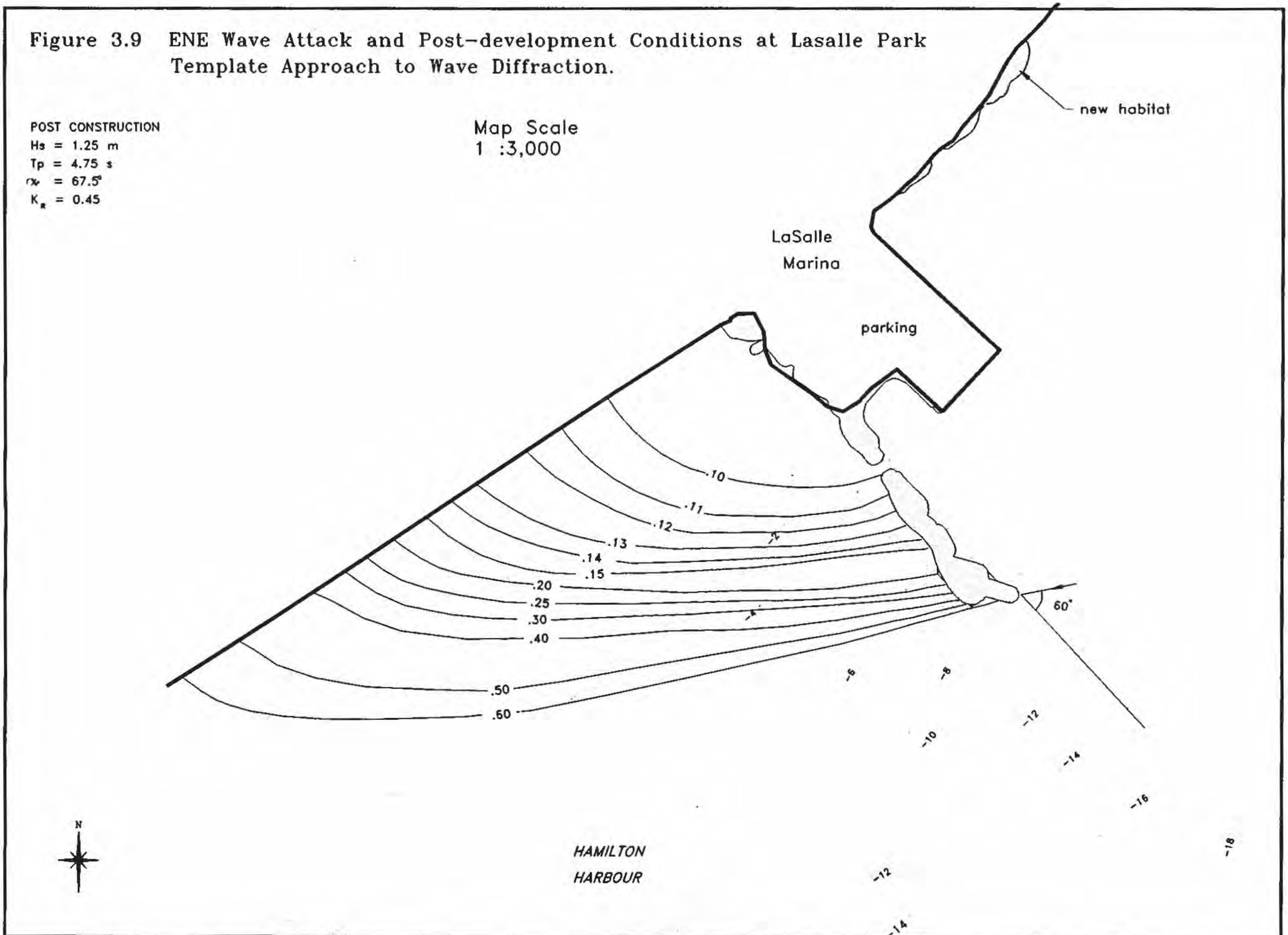


Figure 3.9 ENE Wave Attack and Post-development Conditions at Lasalle Park Template Approach to Wave Diffraction.



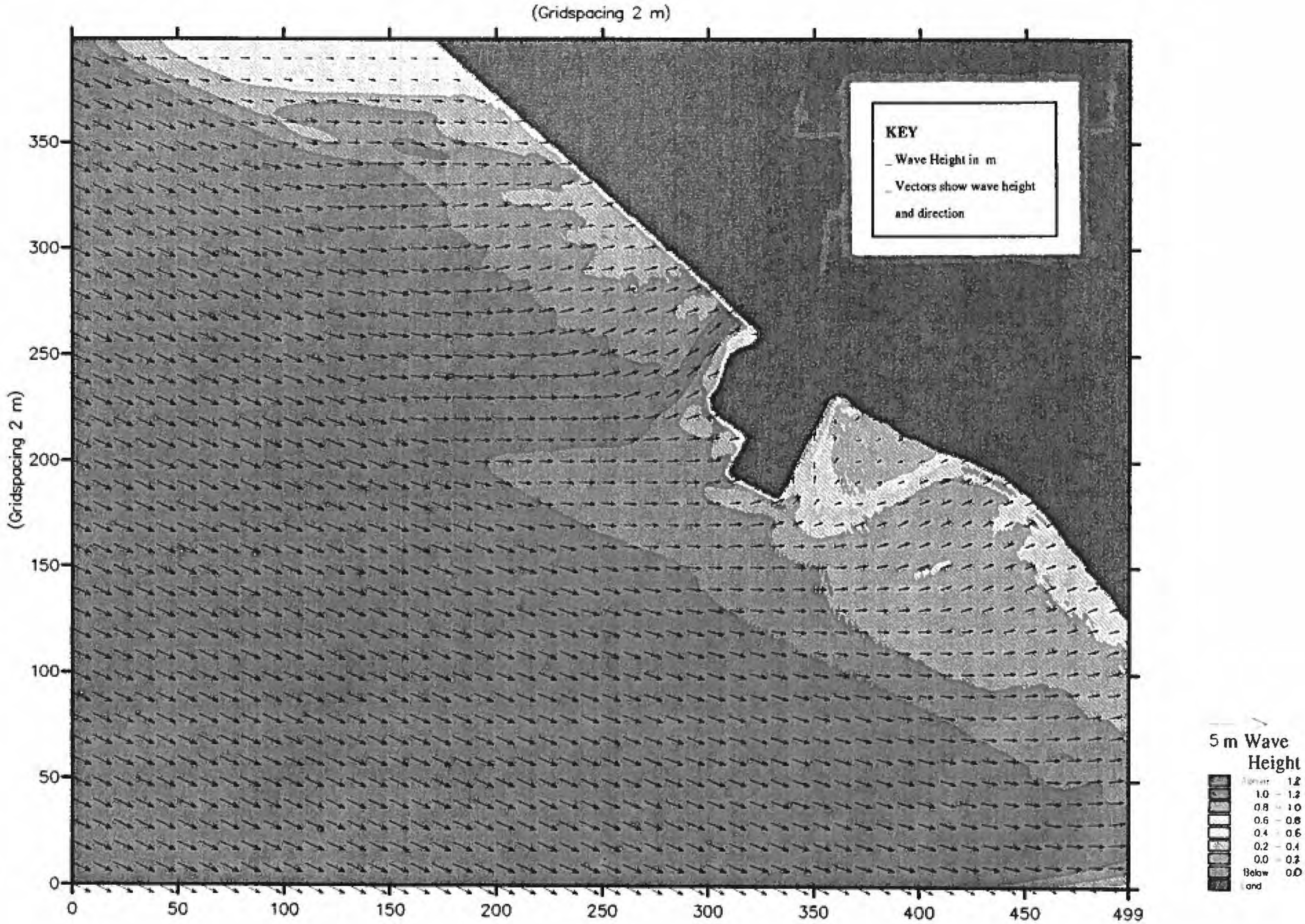


Figure 3.10 SW Wave Conditions and Pre-development Conditions at LaSalle Park Parabolic Mild Slope Approach to Refraction / Diffraction

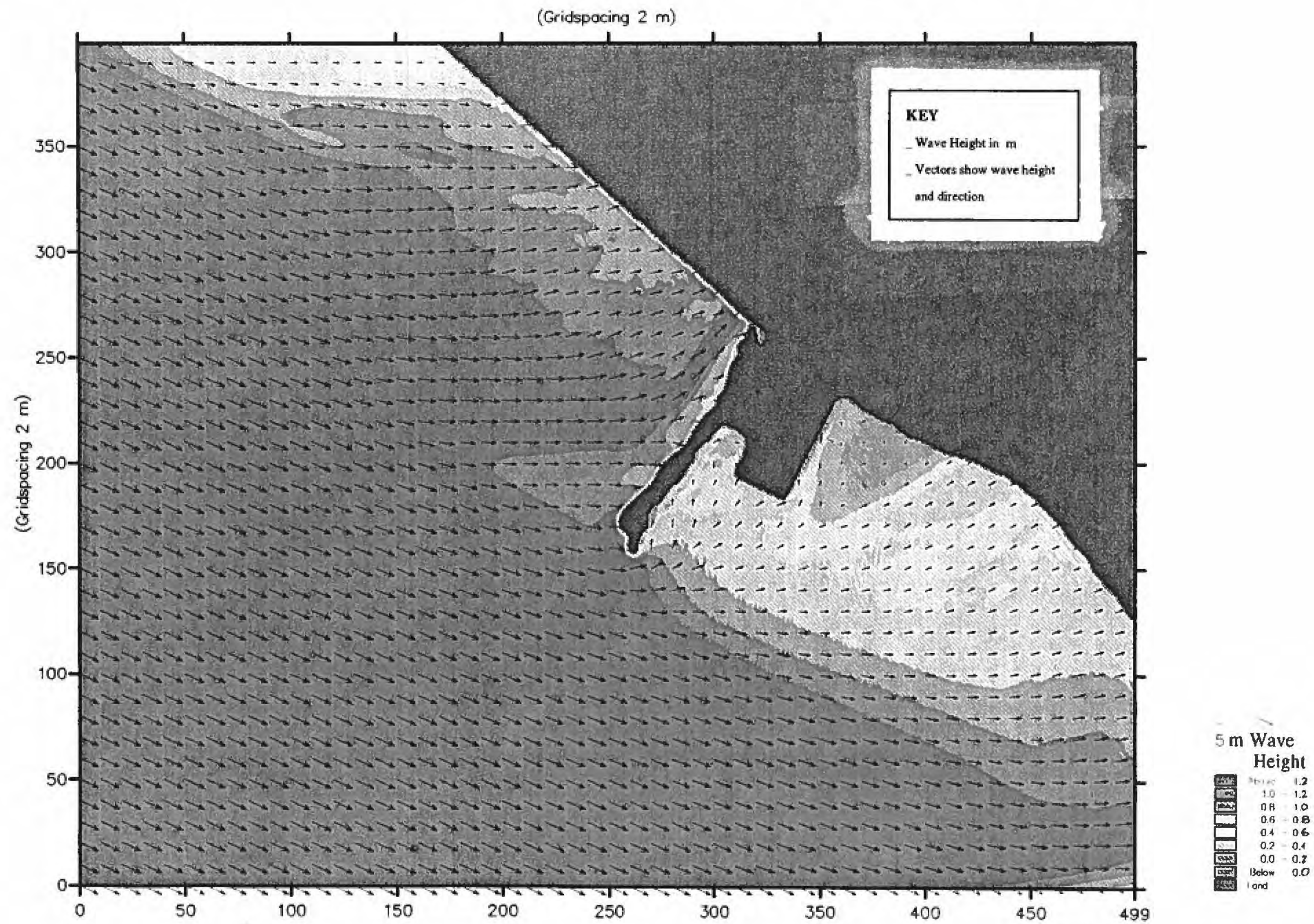


Figure 3.11 SW Wave Conditions and Post-development Conditions at LaSalle Park Parabolic Mild Slope Approach to Refraction / Diffraction

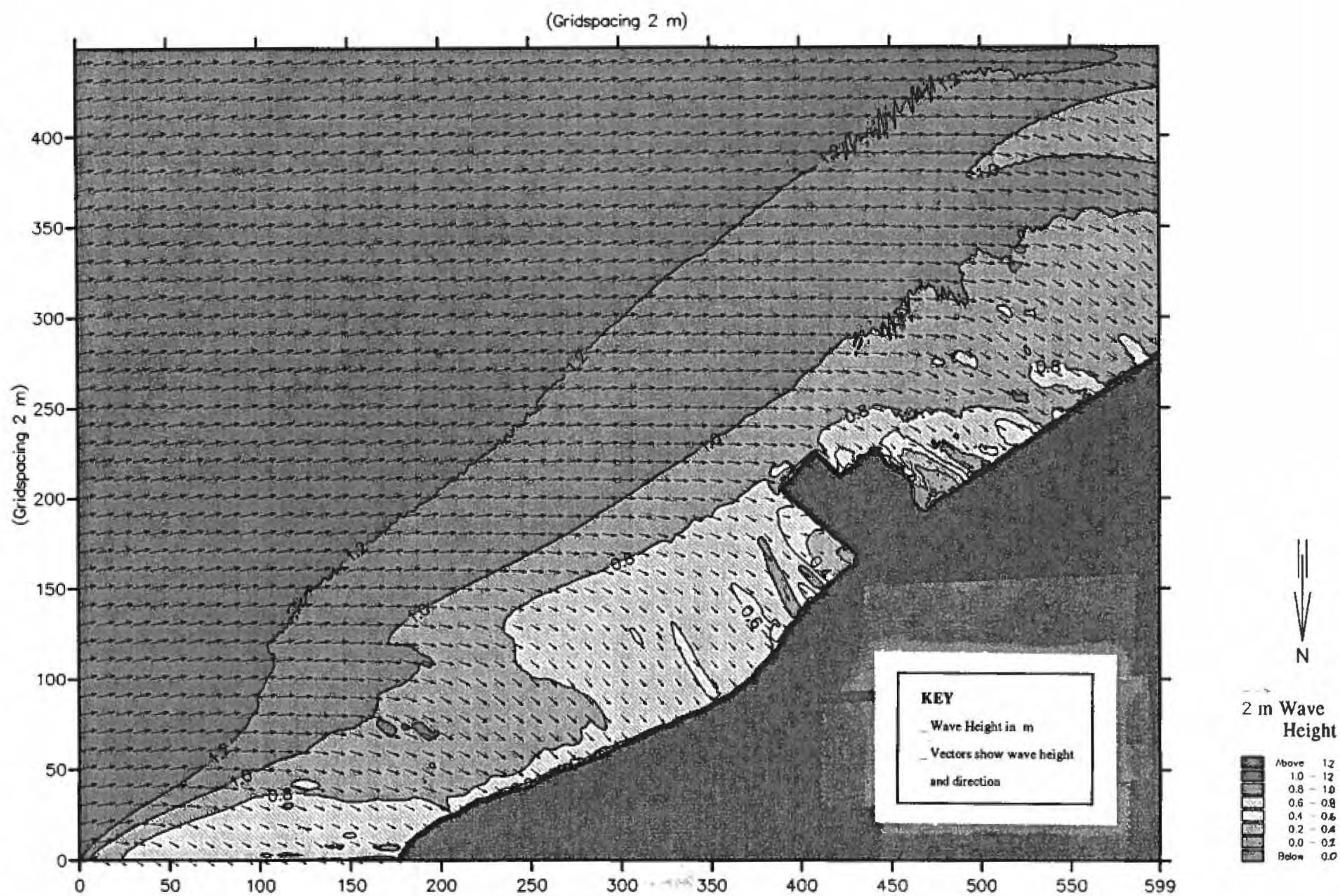


Figure 3.12 ENE Wave Conditions and Pre-development Conditions at LaSalle Park Parabolic Mild Slope Approach to Refraction / Diffraction

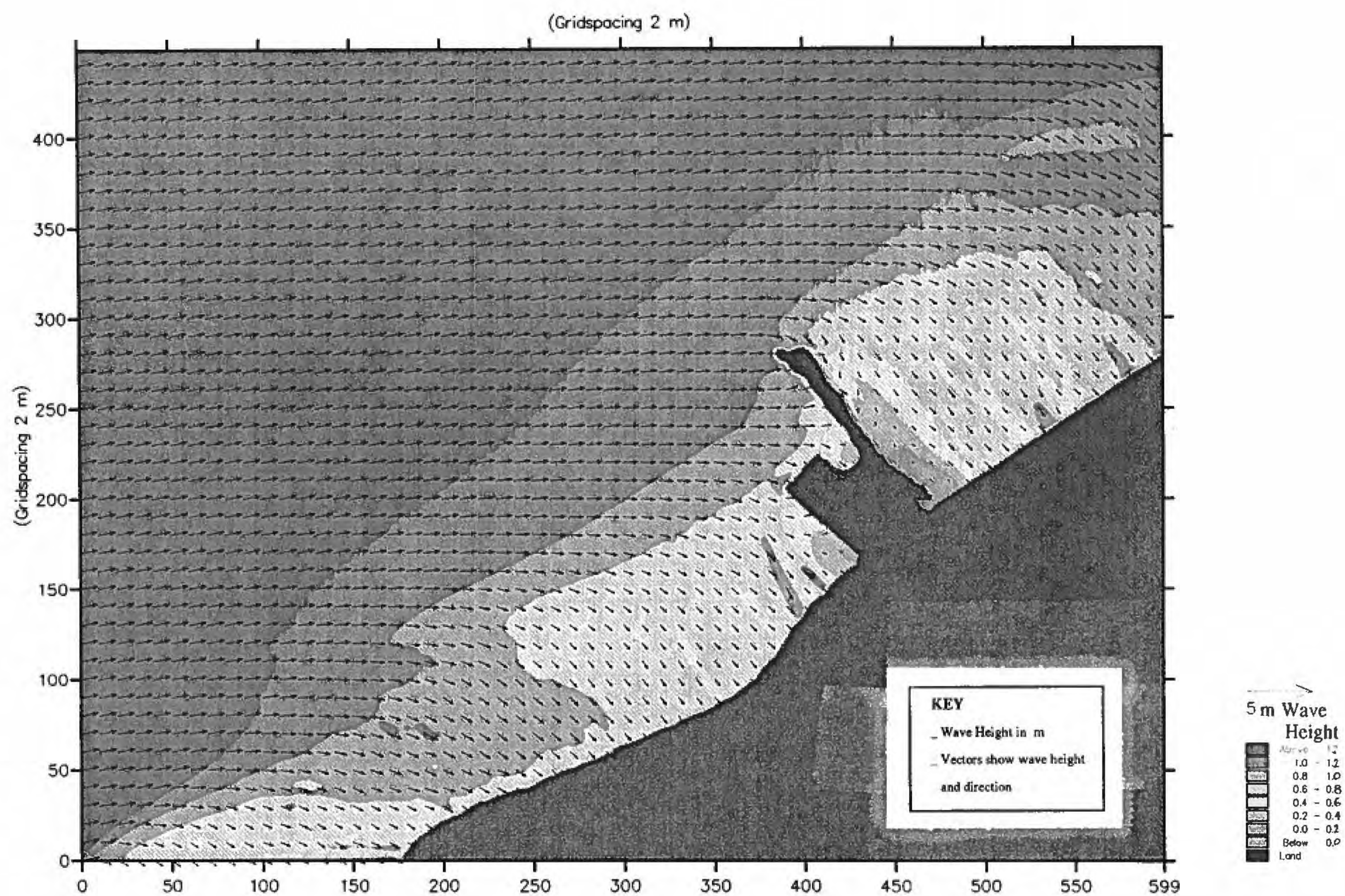


Figure 3.13 ENE Wave Conditions and Post-development Conditions at LaSalle Park Parabolic Mild Slope Approach to Refraction / Diffraction

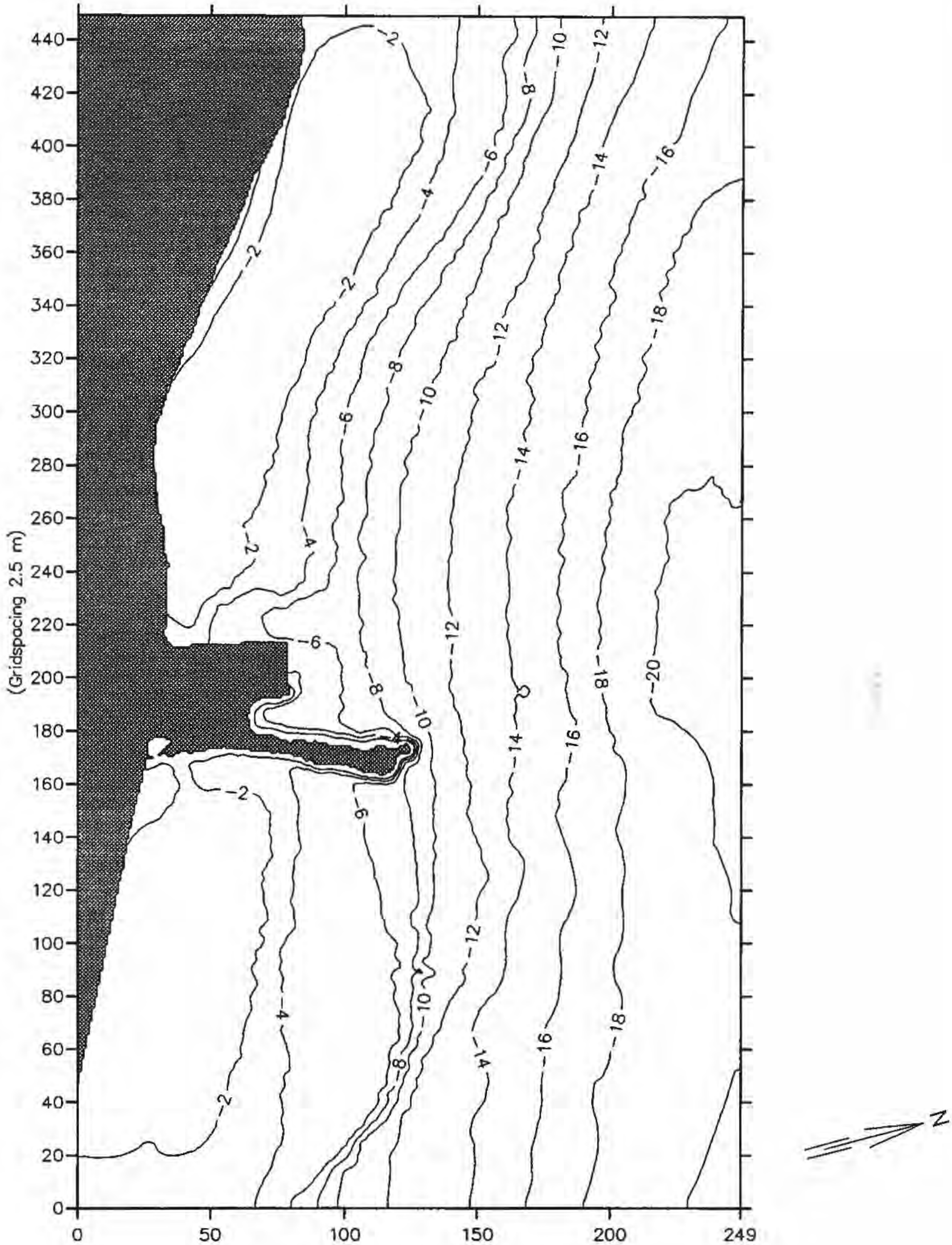


Figure 3.14		Depth Contours in Metres	MIKE 21
		Project:	
File:	Date: Thu Feb 8 1996	Actual Bathymetry – Lasalle Harbour	Drawing no.
Scale: 1:5500	Init: baird		

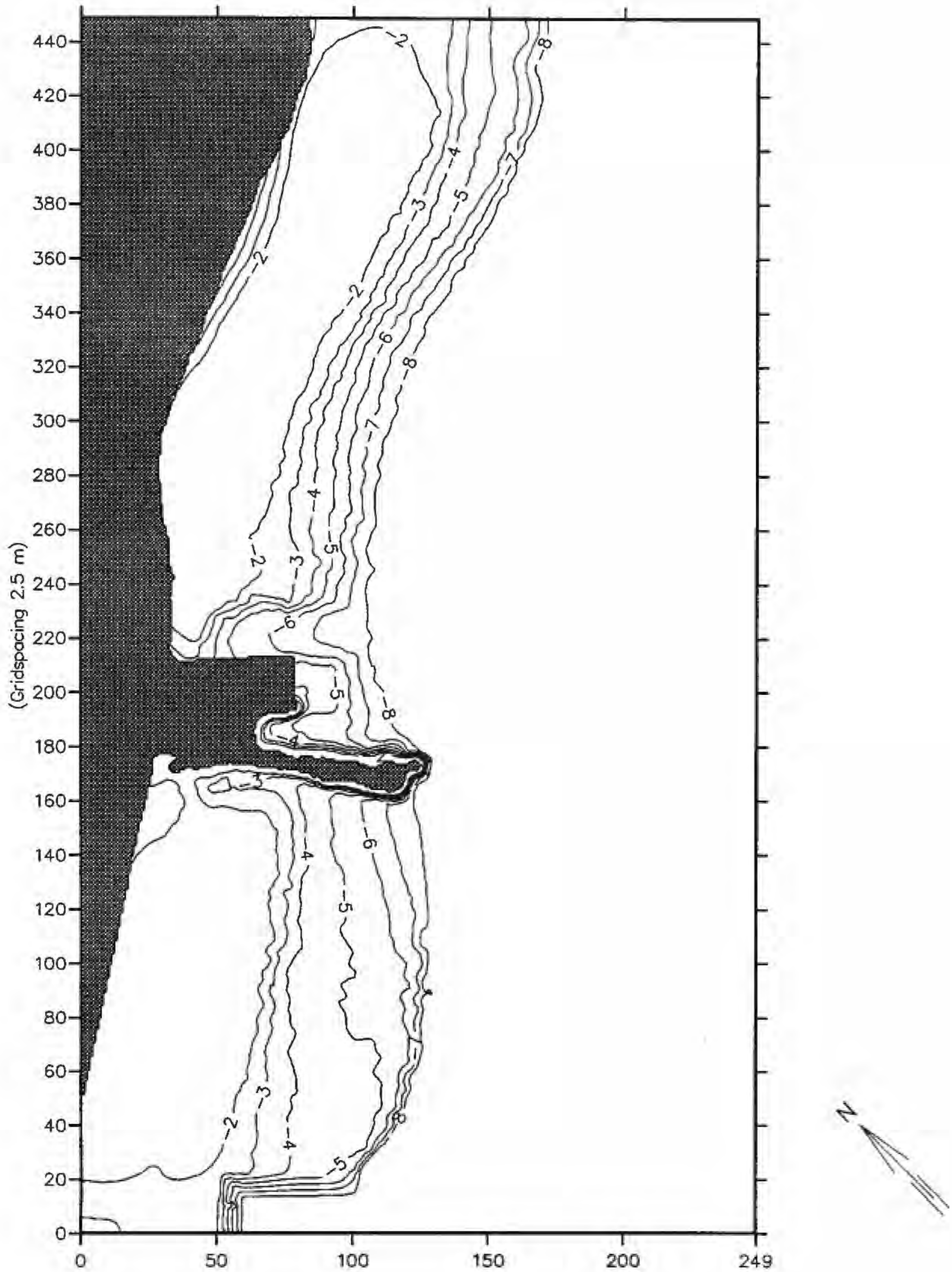


Figure 3.15		Depth Contours in Metres	MIKE 21
		Project:	
File:	Date: Thu Feb 8 1996	Boussinesq Model Bathymetry	Drawing no.
Scale: 1:5500	Init: baird	Lasalle Harbour	

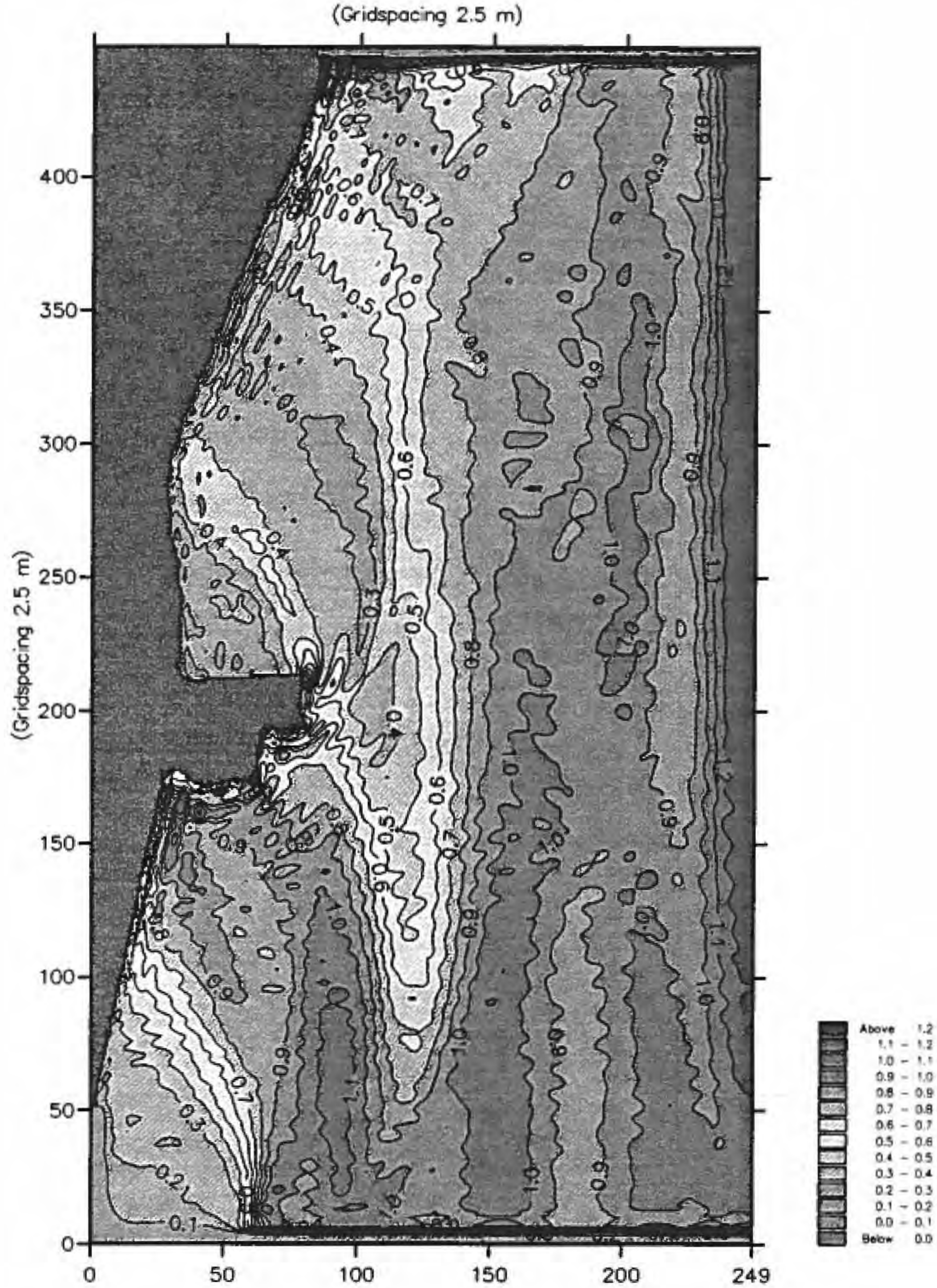


Figure 3.16a		Boussinesq Model Results - Pre Development Project:		MIKE 21
File:	Date: Fri Feb 2 1996	HmO Distribution [m]. SW Waves	Drawing no.	
Scale: 1:6300	Init: baird	Wave Conditions: 1m, 5s, 15 deg. sprd.		

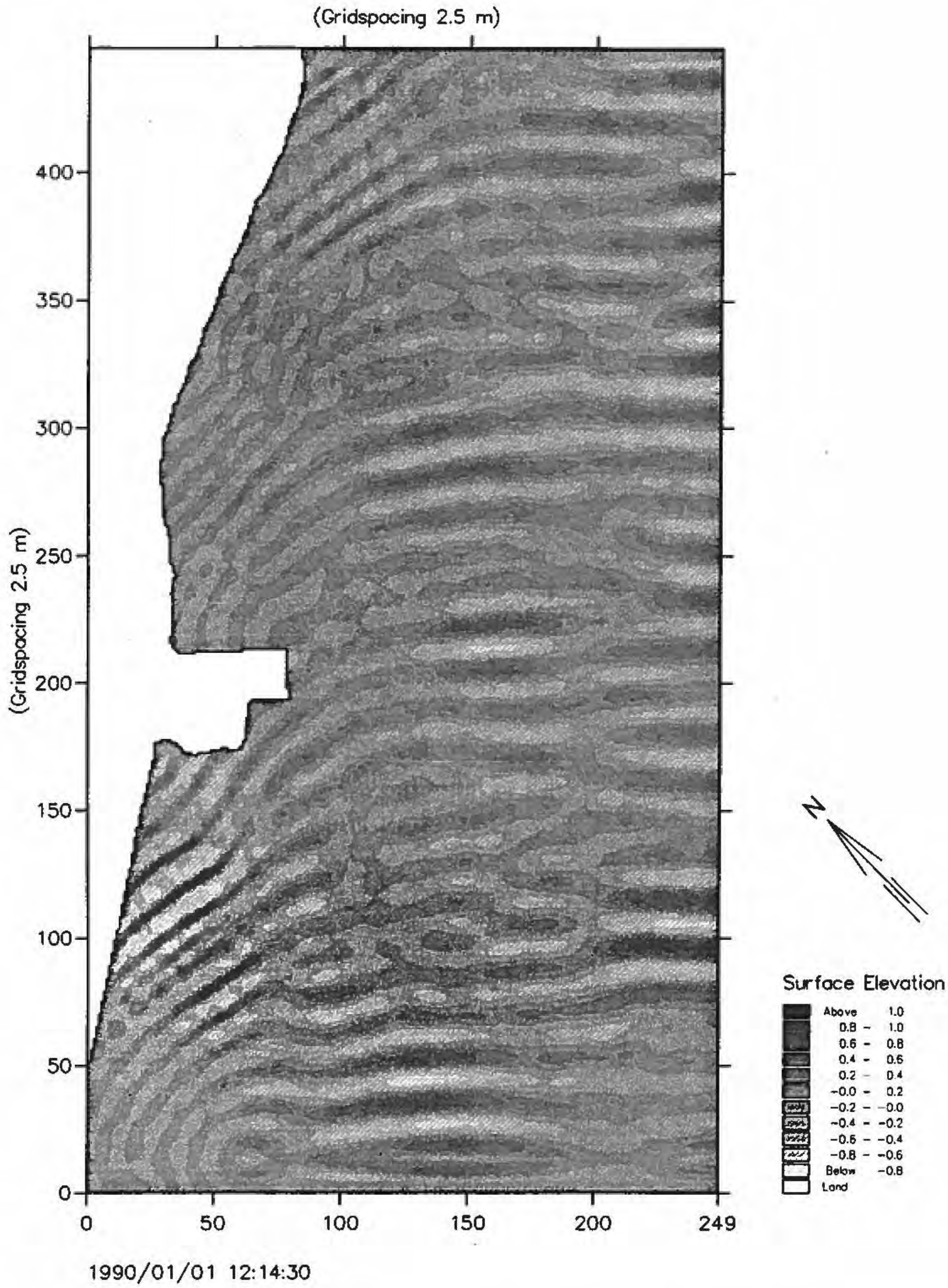


Figure 3.16b		Boussinesq Model Results - Pre Development Project:	MIKE 21
File:	Date: Fri Feb 2 1996	Surface Elevation [m] Relative To Still Water Level. SW Waves. Wave Conditions: 1m, 5s, 15 deg. sprd.	Drawing no.
Scale: 1:6500	Init: baird		

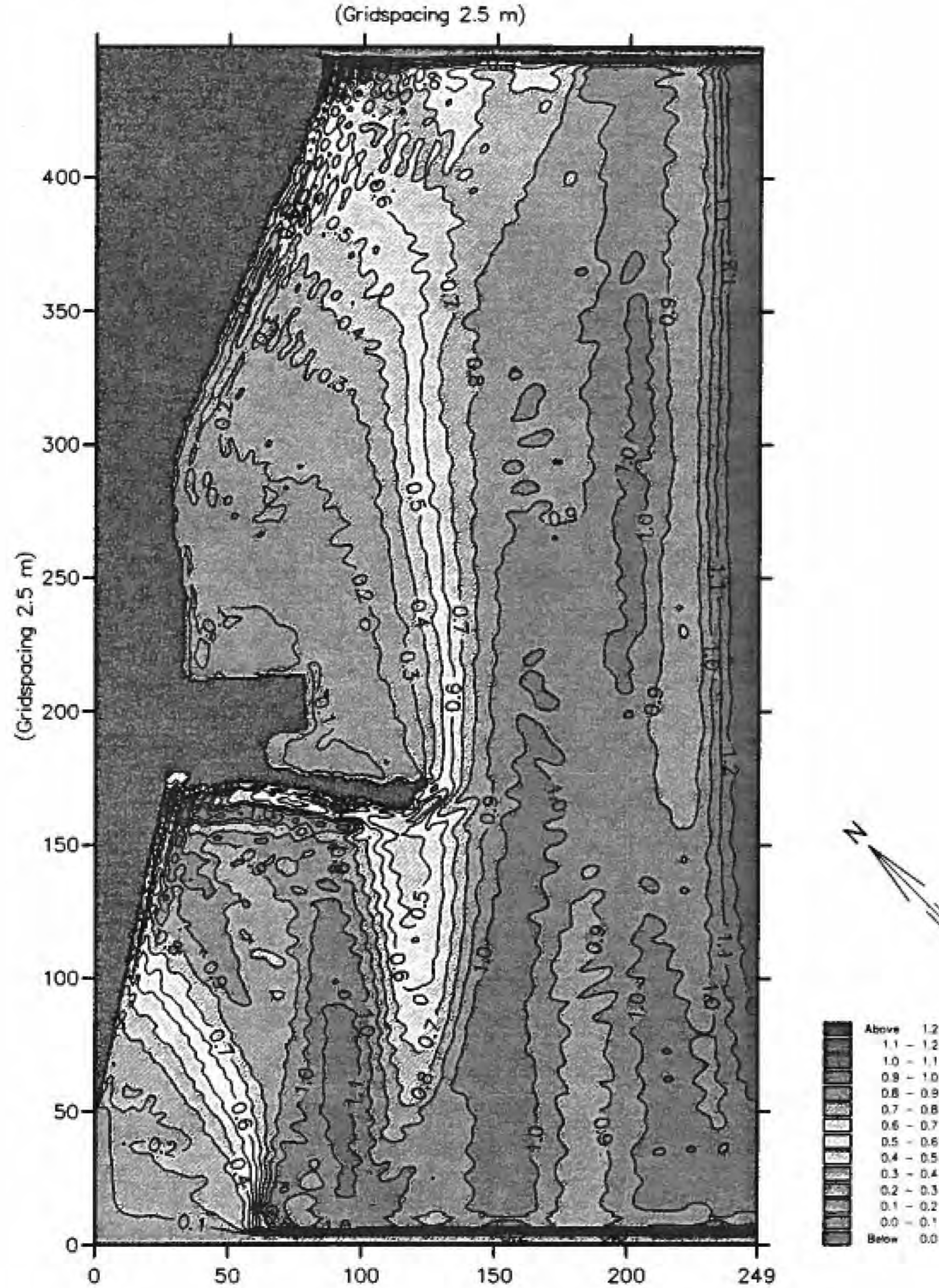


Figure 3.17a	Boussinesq Model Results - Post Development Project:		MIKE 21
File:	Date: Fri Feb 2 1996	HmO Distribution [m]. SW Waves	Drawing no.
Scale: 1:6300	Init: baird	Wave Conditions: 1m, 5s, 15 deg. sprd.	

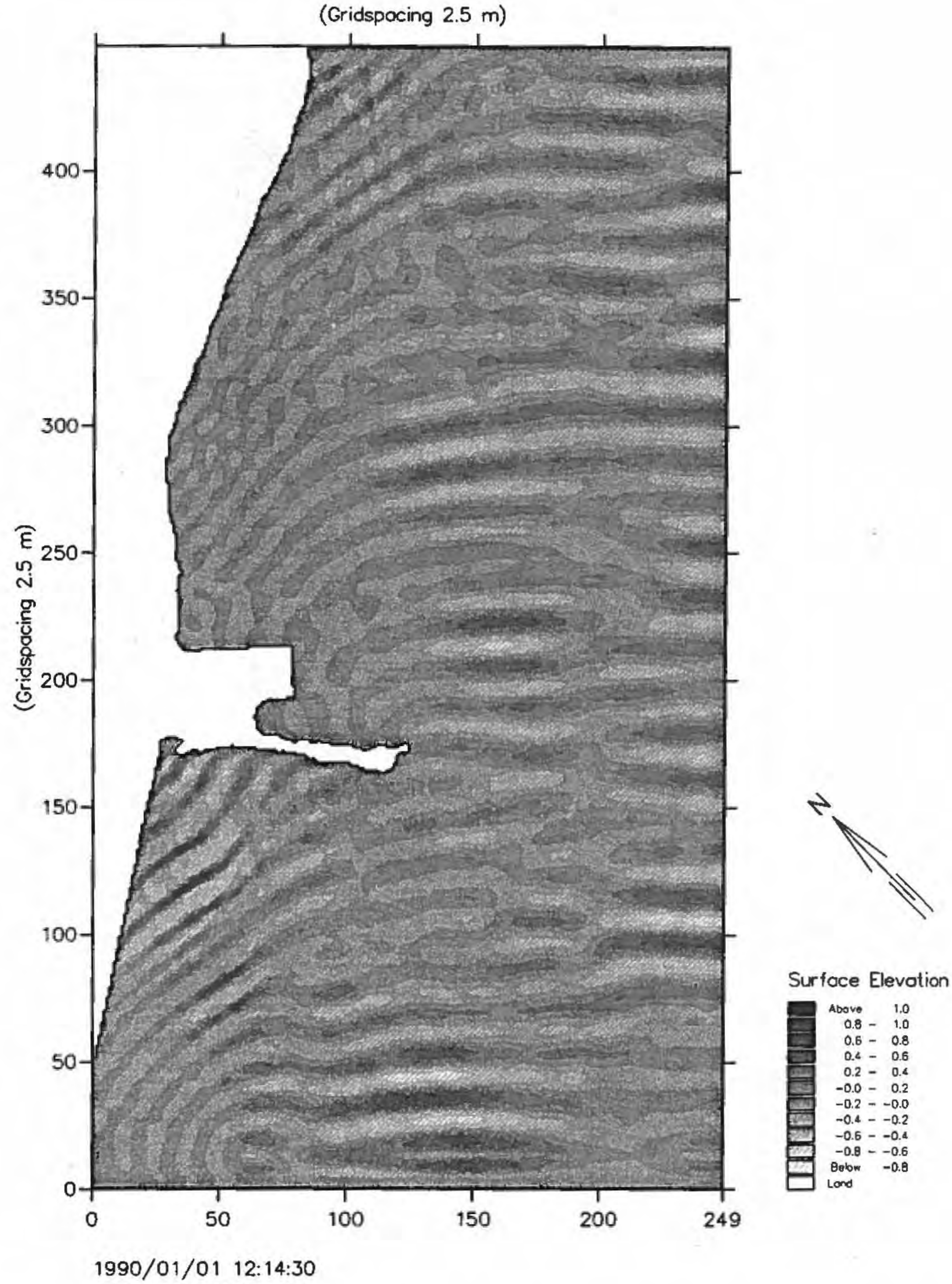


Figure 3.17b		Boussinesq Model Results - Post Development		MIKE 21
		Project:		
File:	Date: Fri Feb 2 1996	Surface Elevation [m] Relative To Still Water Level. SW Waves. Wave Conditions: 1m, 5s, 15 deg. sprd.	Drawing no.	
Scale: 1:6500	Init: baird			

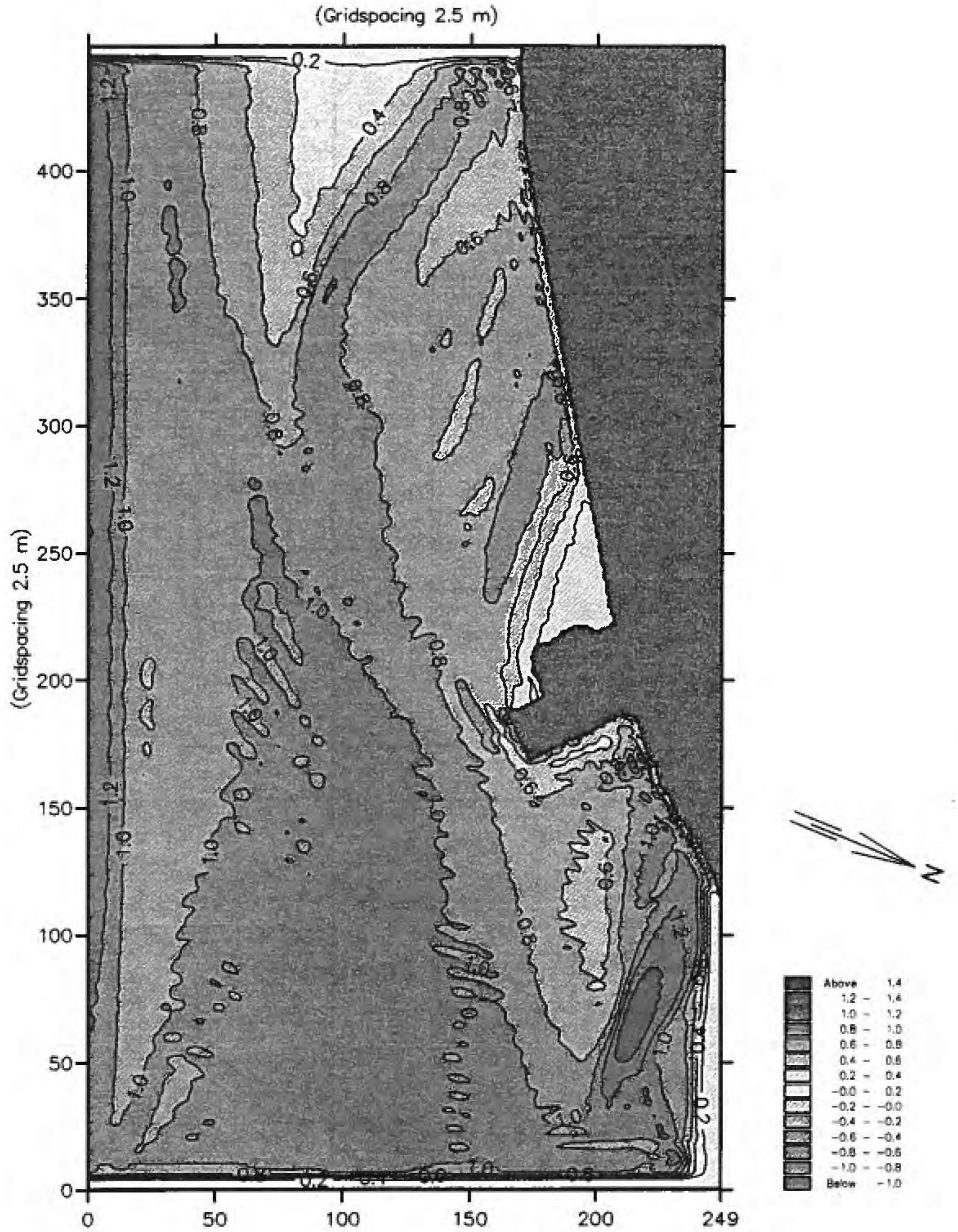


Figure 3.18a		Boussinesq Model Results - Pre Development Project:		MIKE 21
File:	Date: Thu Feb 1 1996	HmO Distribution [m] ENE Waves Wave Conditions: 1m, 5s, 15 deg. sprd.	Drawing no.	
Scale: 1:6300	Init: baird			

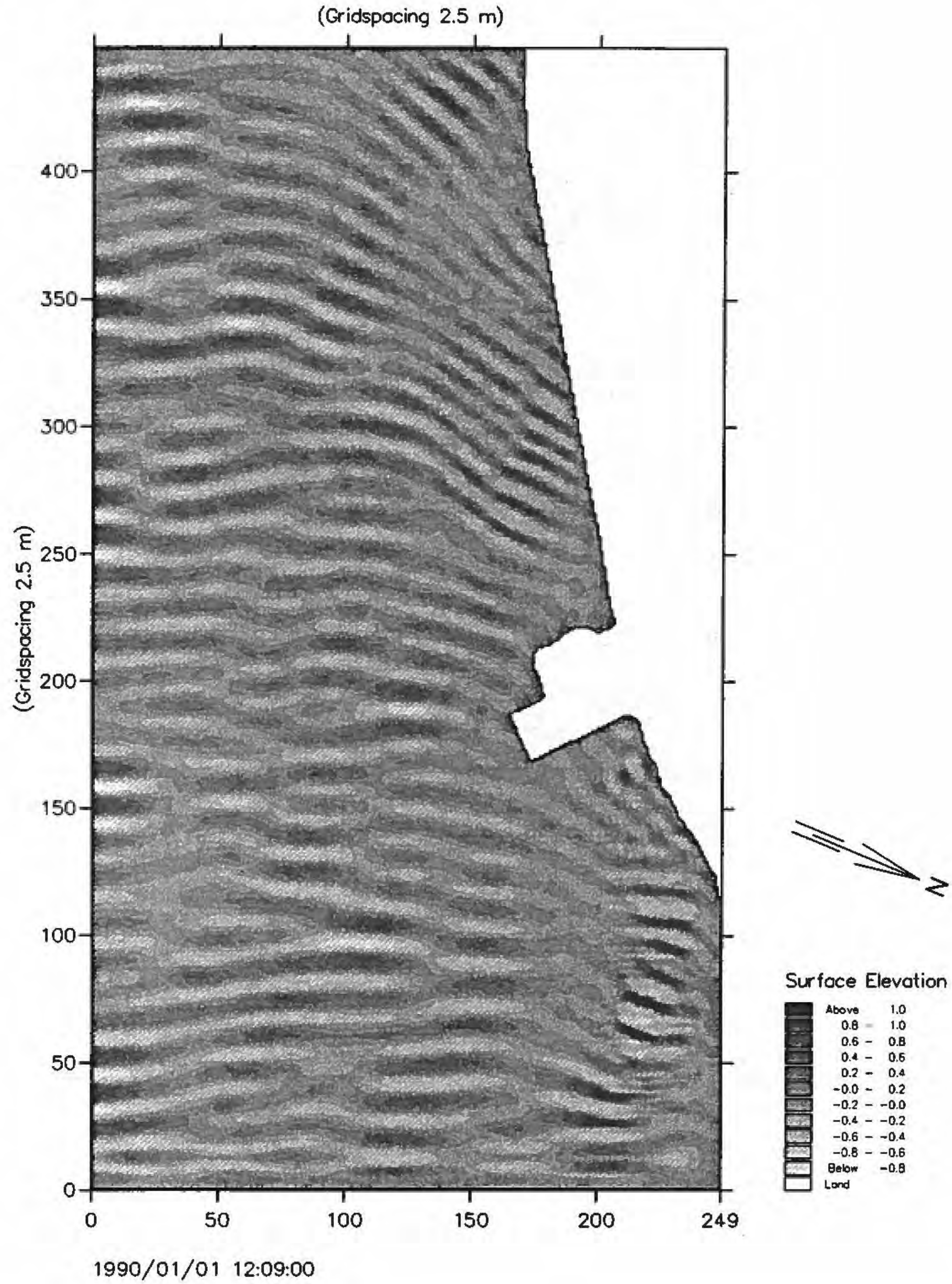


Figure 3.18b		Boussinesq Model Results - Pre Development	MIKE 21
		Project:	
File:	Date: Thu Feb 1 1996	Surface Elevation [m] Relative To Still Water Level ENE Waves Wave Conditions: 1m, 5s, 15 deg. sprd.	Drawing no.
Scale: 1:6500	Init: baird		

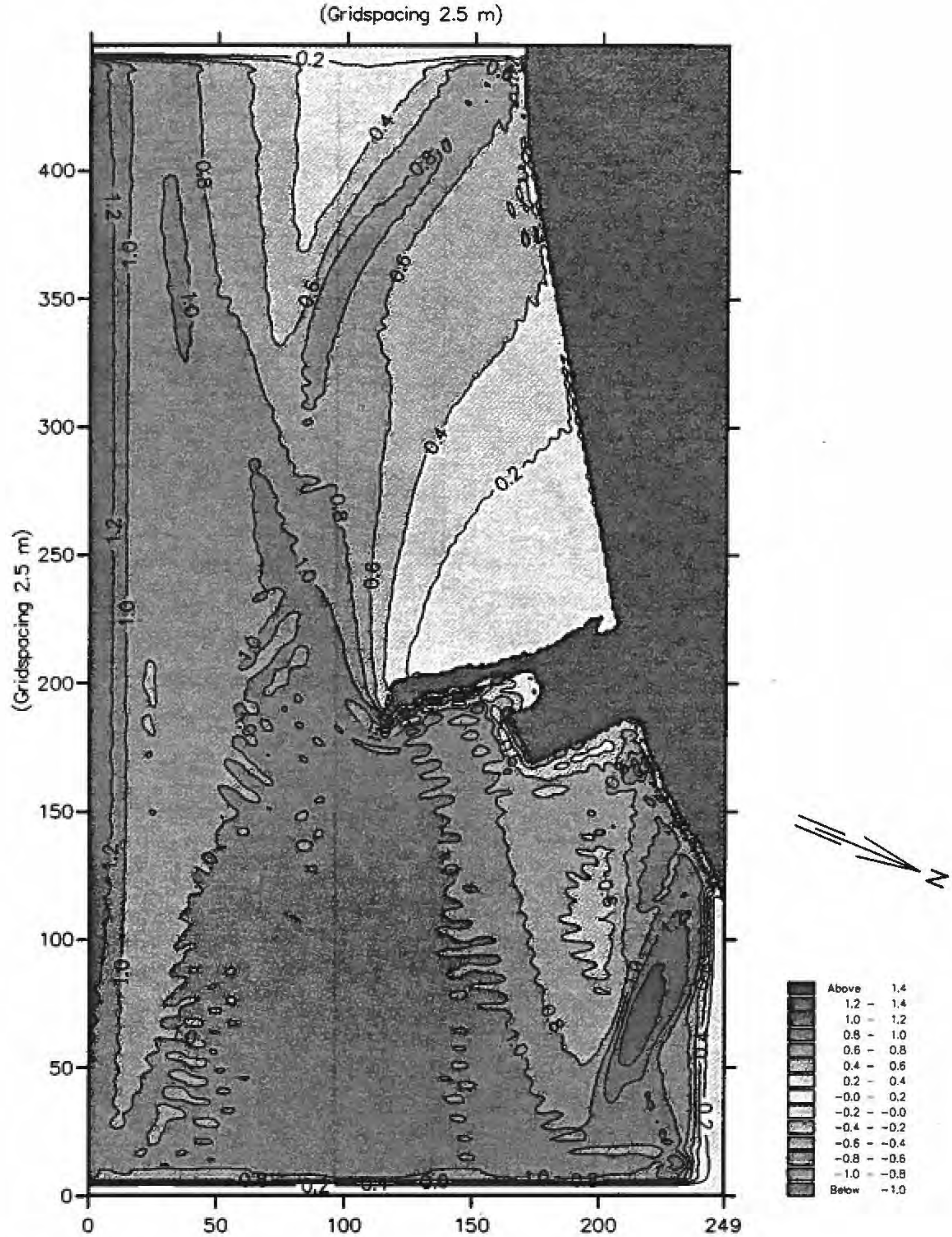


Figure 3.19a		Boussinesq Model Results - Post Development Project:		MIKE 21
File:	Date: Thu Feb 1 1996	HmO Distribution [m] E North East Waves Wave Conditions: 1m, 5s, 15 deg. sprd.	Drawing no.	
Scale: 1:6300	Init: baird			

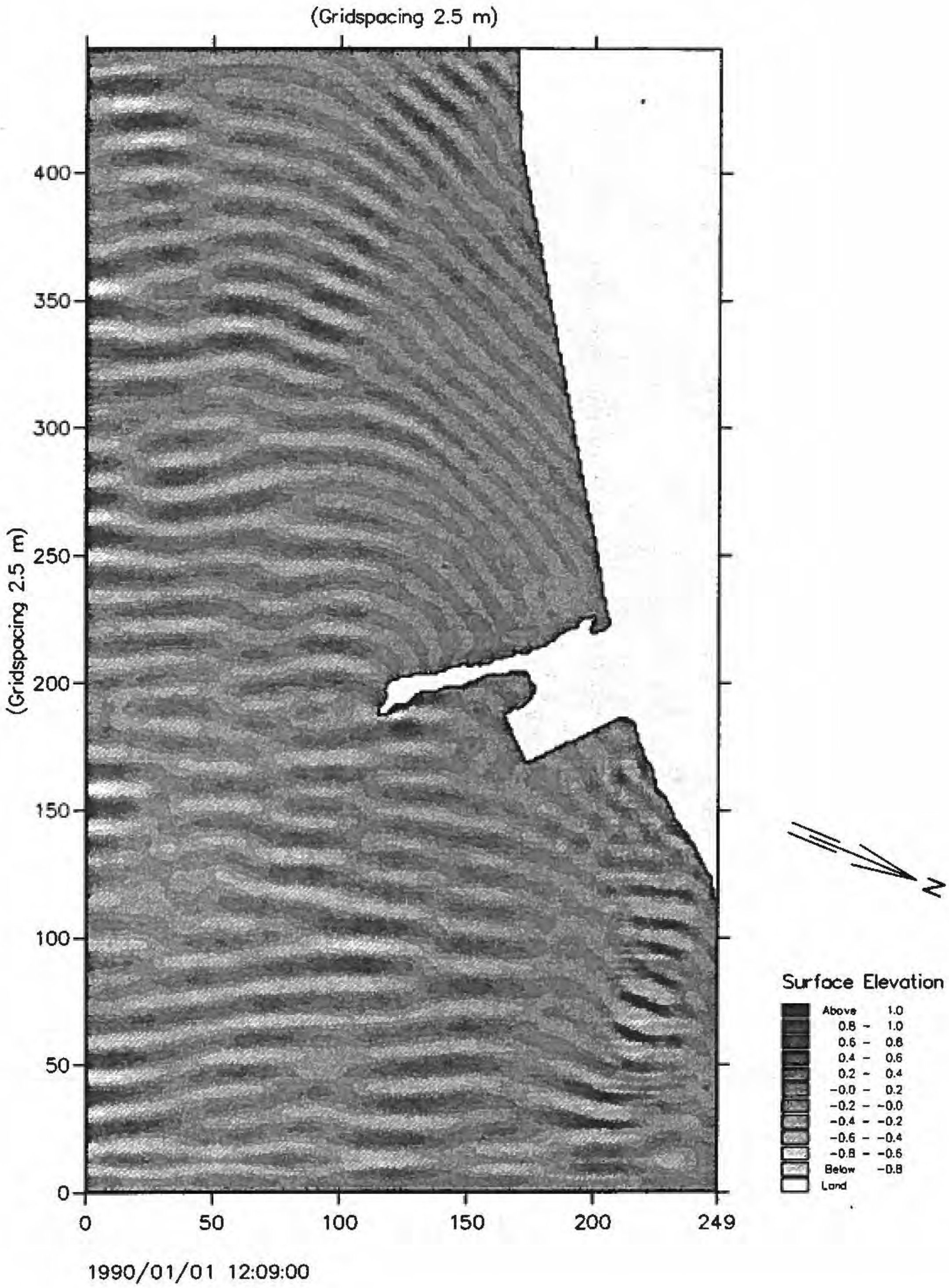


Figure 3.19b		Boussinesq Model Results - Post Development Project:	MIKE 21
File:	Date: Thu Feb 1 1996	Surface Elevation [m] Relative To Still Water Level. ENE Waves Wave Conditions: 1m, 5s, 15 deg. sprd.	Drawing no.
Scale: 1:6500	Init: baird		

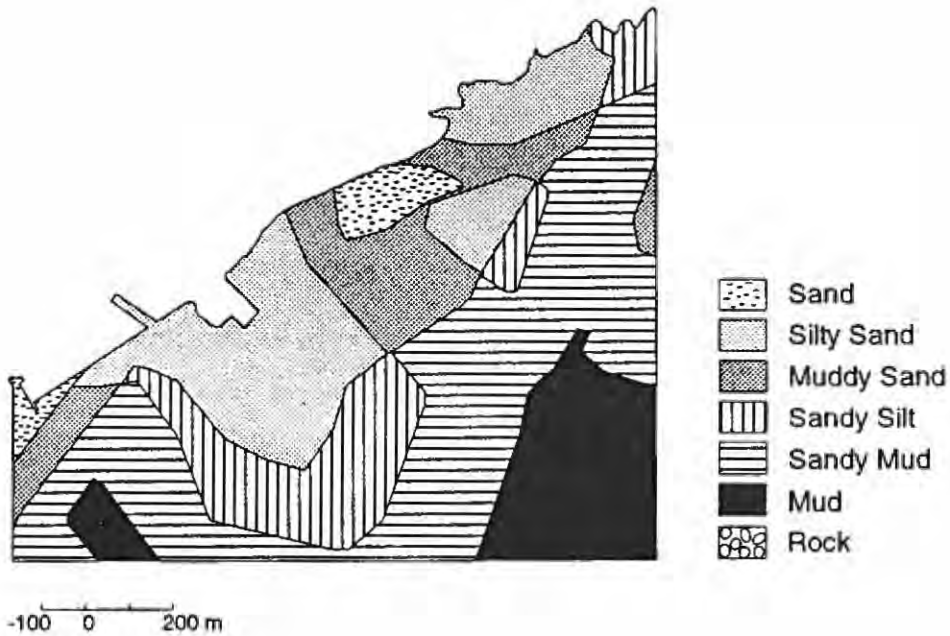


Figure 3.20 The Inferred Bottom Substrate conditions
(after Mins et al., 1995 based on data of Rukavina and Versteeg, 1995)

Figure 3.21 Location of COSMOS Profiles at LaSalle Park

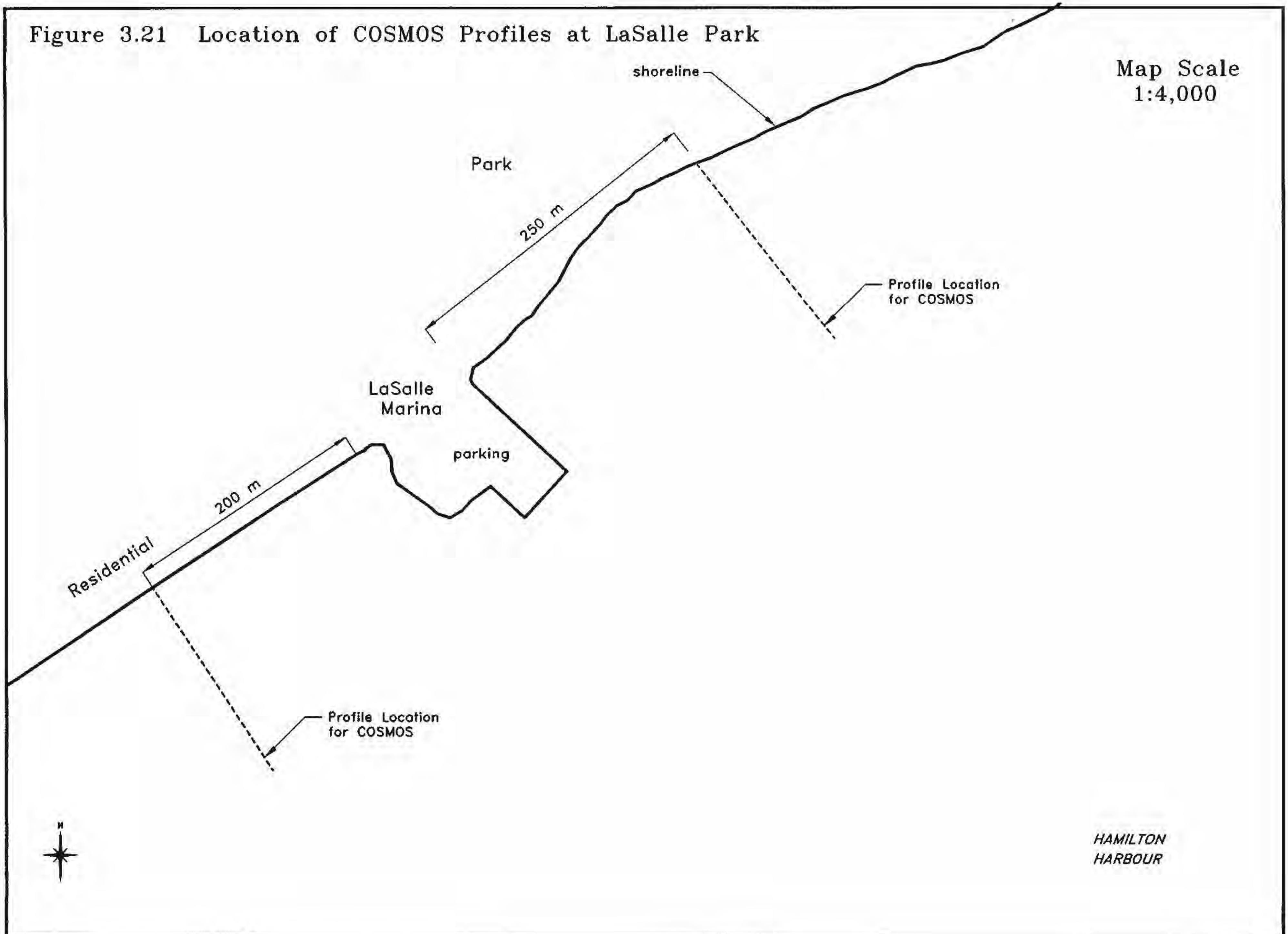
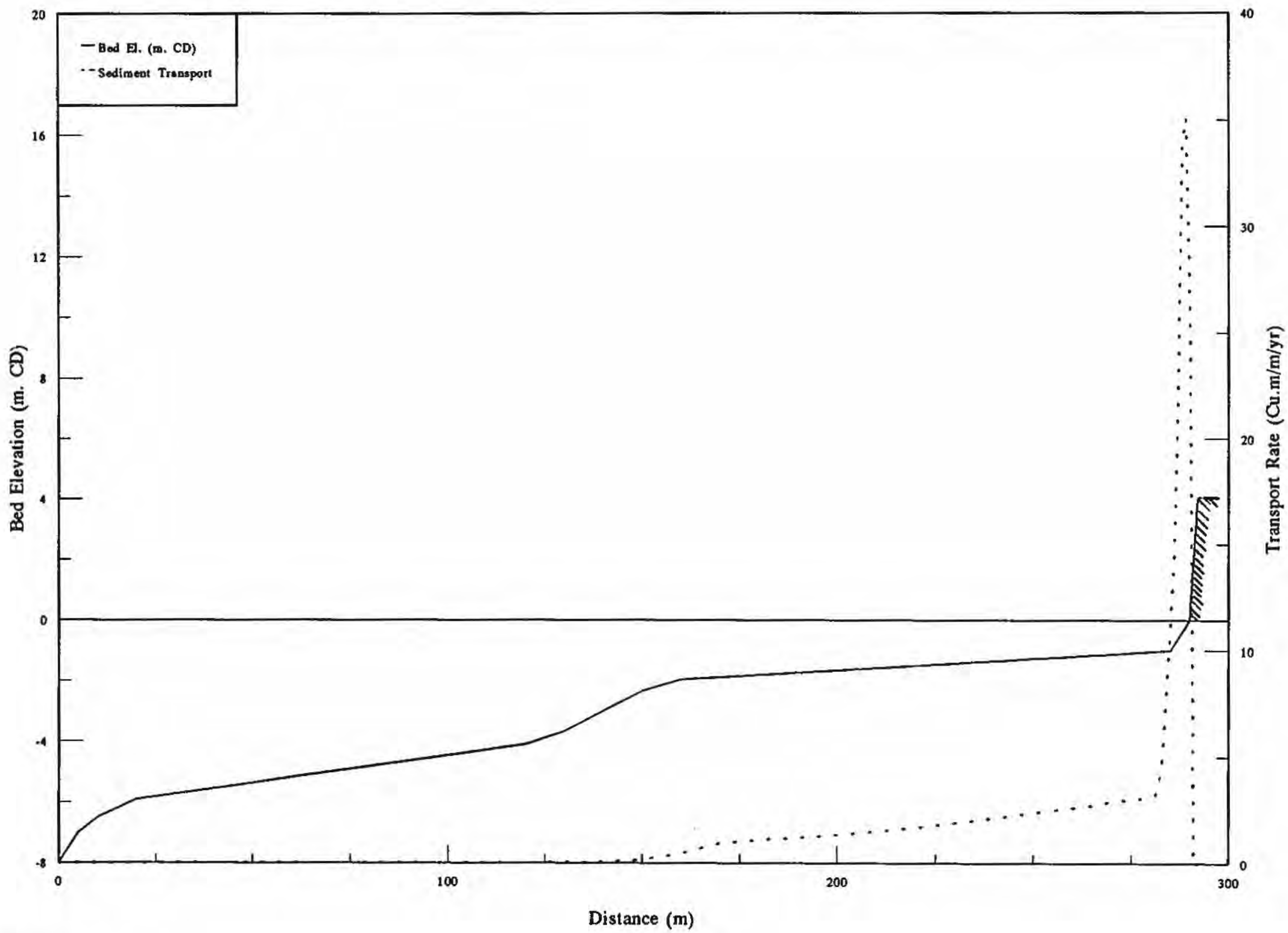
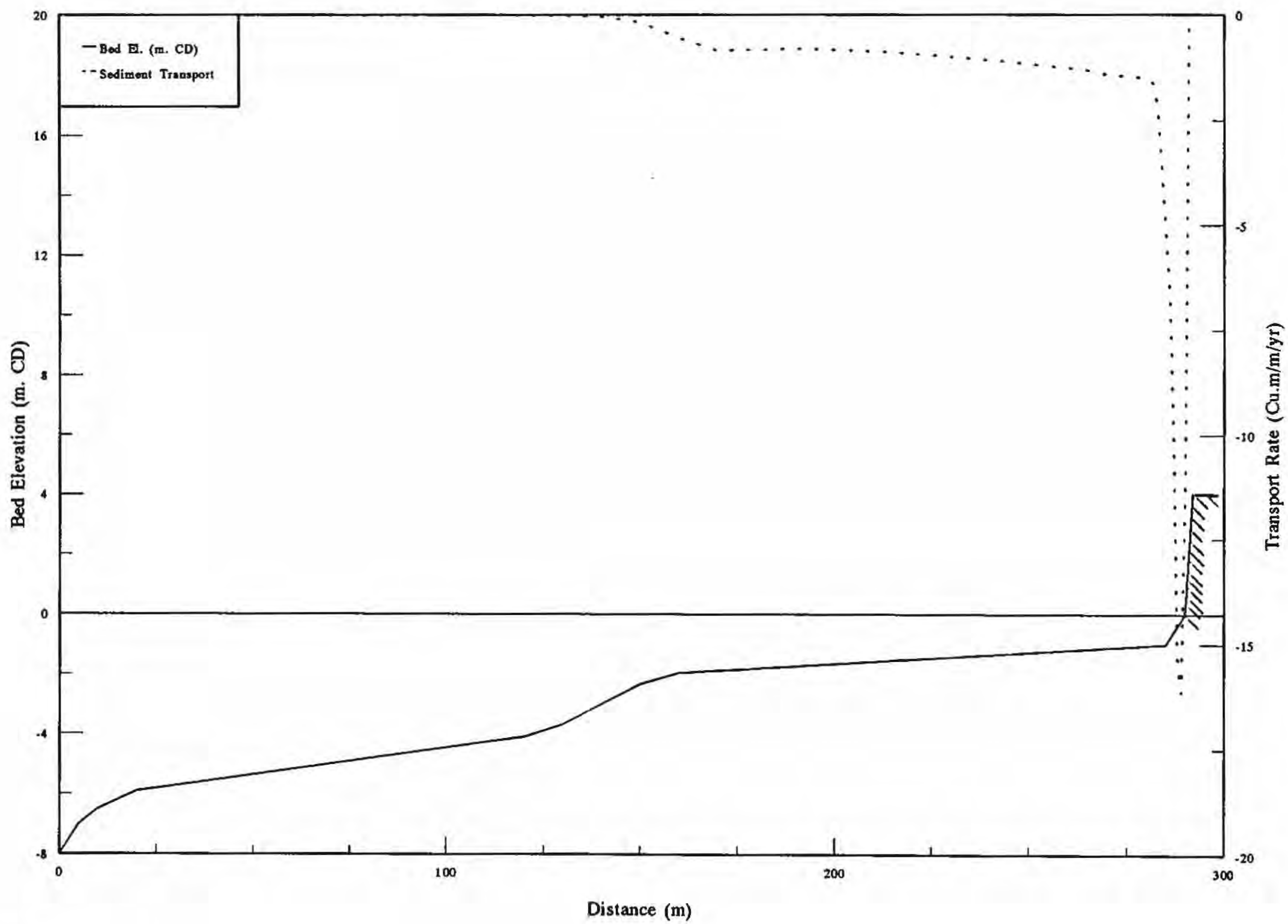


Figure 3.22a LaSalle Park Marina
COSMOS Average Annual Alongshore Transport Calculation
South side of Breakwater



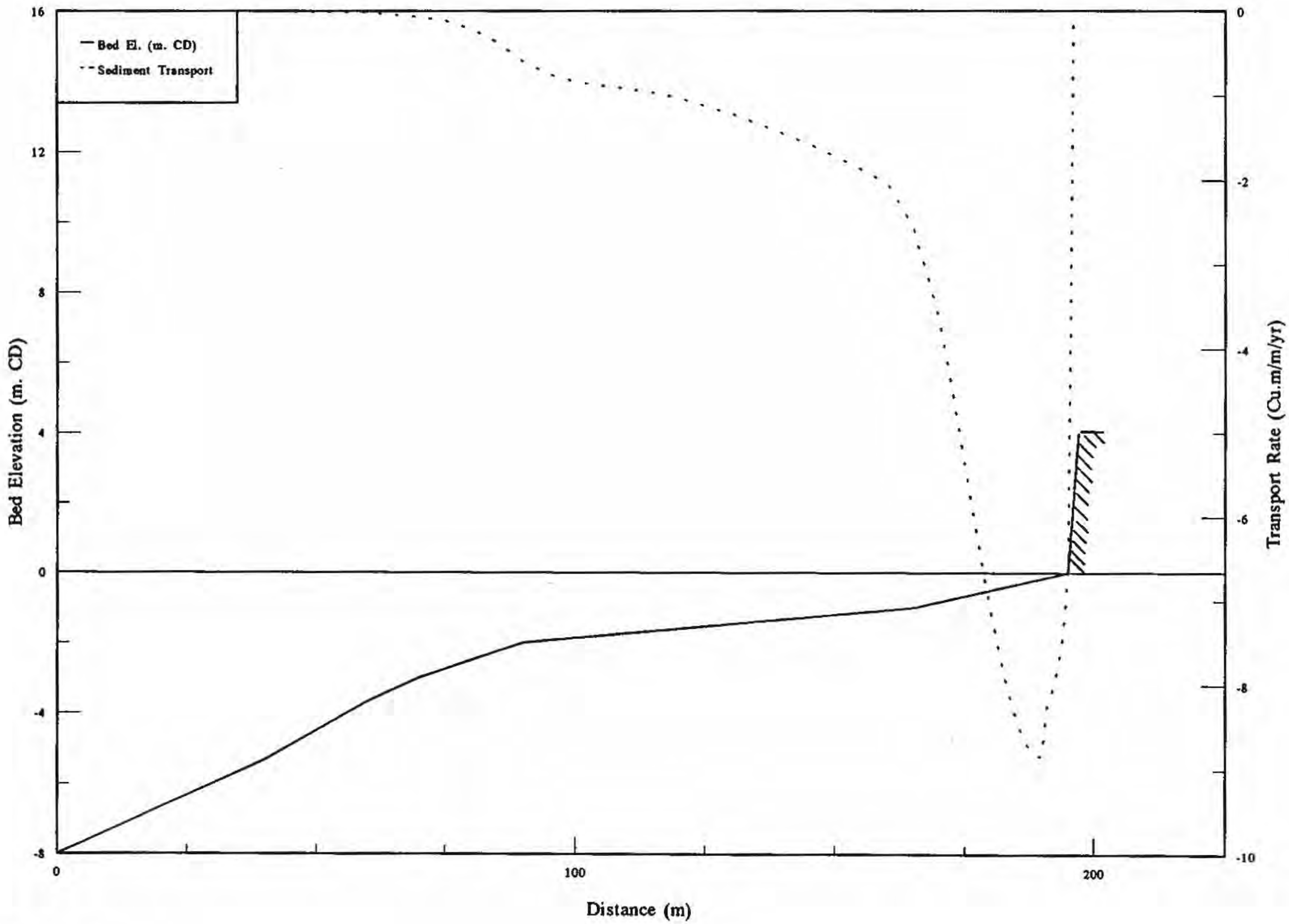
Northerly directed transport = 385. Cu.m/yr
d50 = 0.10 mm; Profile Azimuth = 145. deg.

Figure 3.22b LaSalle Park Marina
COSMOS Average Annual Alongshore Transport Calculation
South side of Breakwater



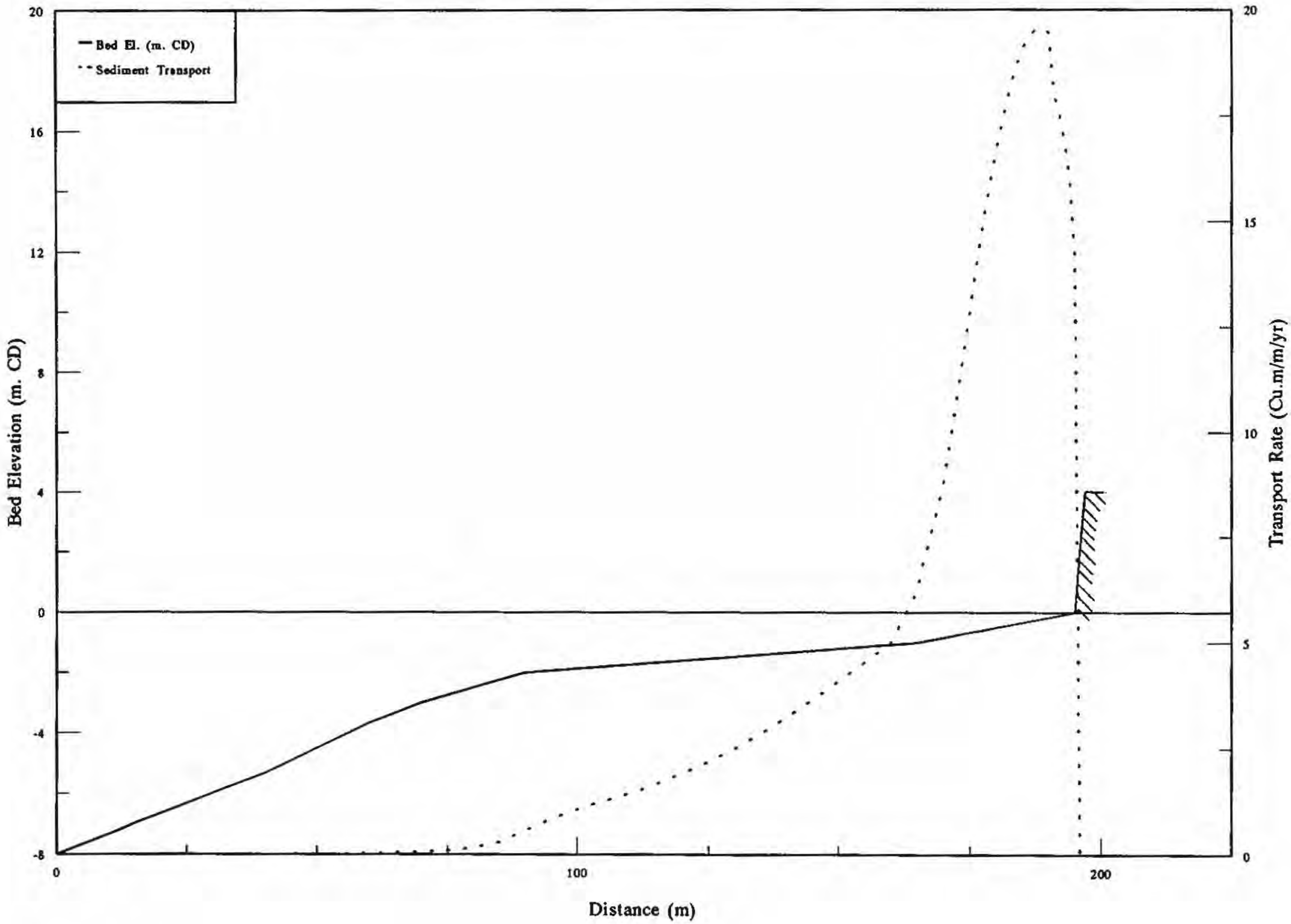
Southerly directed transport = -200. Cu.m/yr
d50 = 0.10 mm; Profile Azimuth = 145. deg.

Figure 3.23a LaSalle Park Marina
COSMOS Average Annual Alongshore Transport Calculation
North side of Breakwater



Southerly directed transport = -295. Cu.m/yr
d50 = 0.10 mm; Profile Azimuth = 150. deg.

Figure 3.23b LaSalle Park Marina
COSMOS Average Annual Alongshore Transport Calculation
North side of Breakwater



Northerly directed transport = 650. Cu.m/yr
d50 = 0.10 mm; Profile Azimuth = 150. deg.

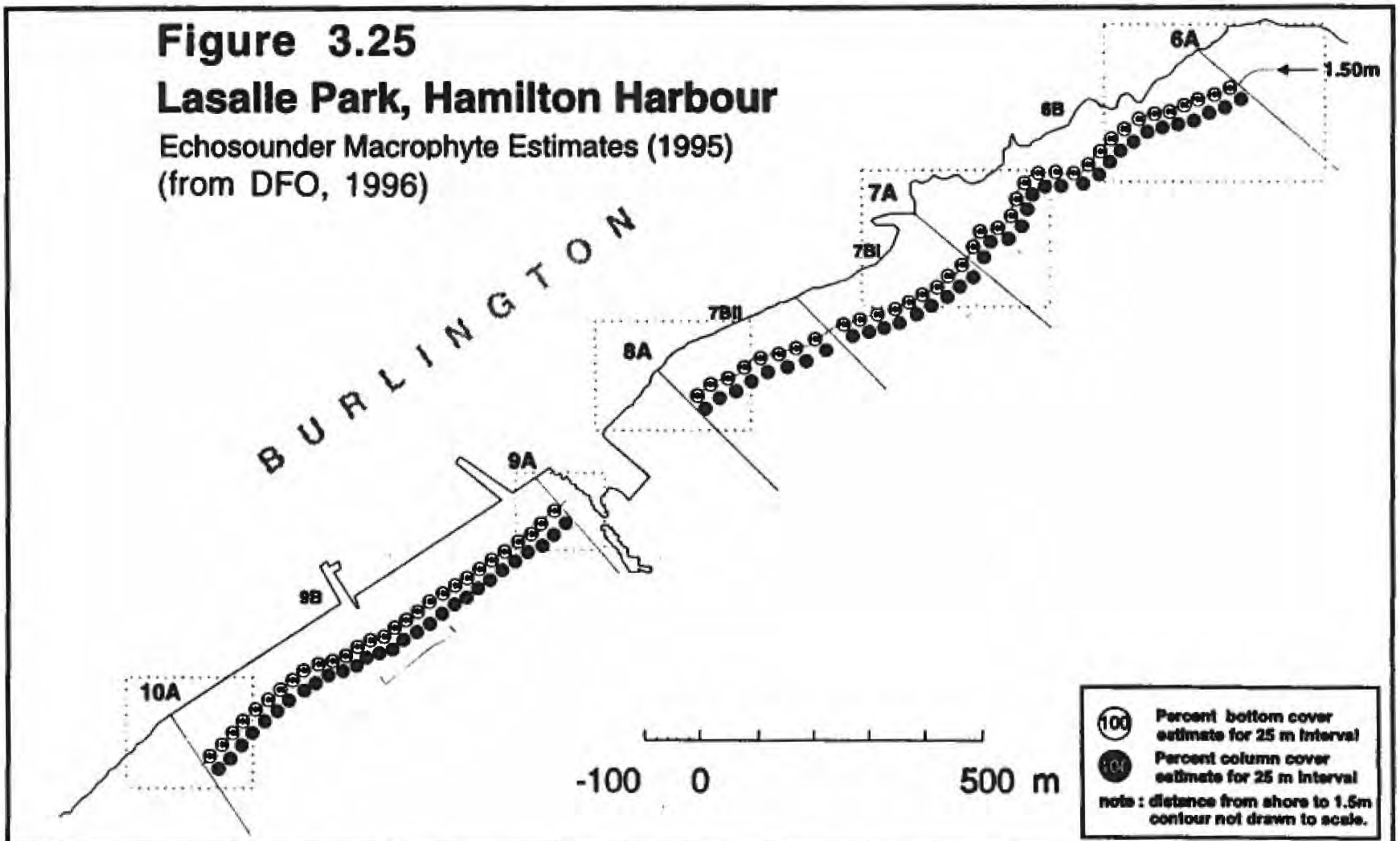


Figure 3.25

Lasalle Park, Hamilton Harbour

Echosounder Macrophyte Estimates (1995)
(from DFO, 1996)

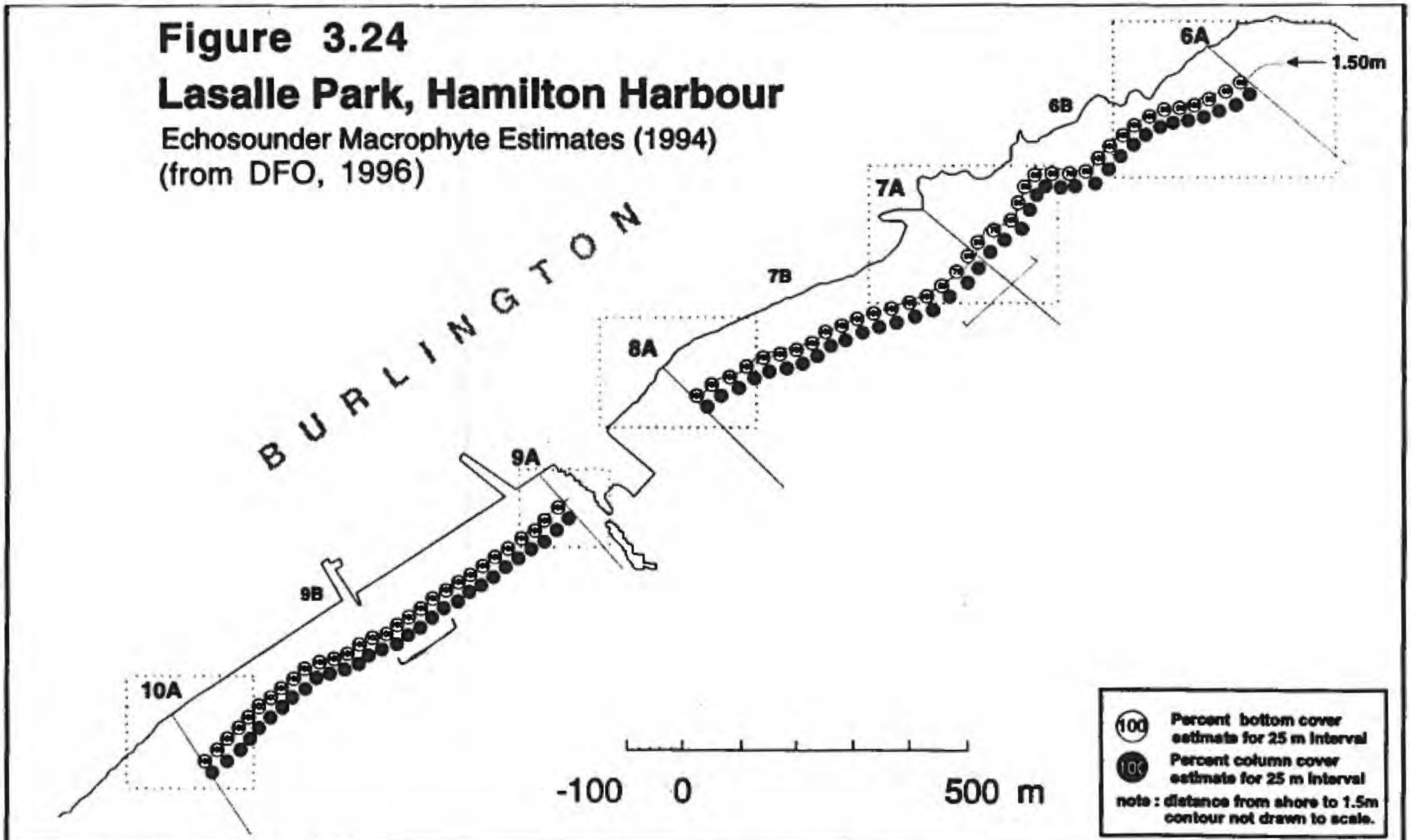


Figure 3.24
Lasalle Park, Hamilton Harbour
Echosounder Macrophyte Estimates (1994)
(from DFO, 1996)

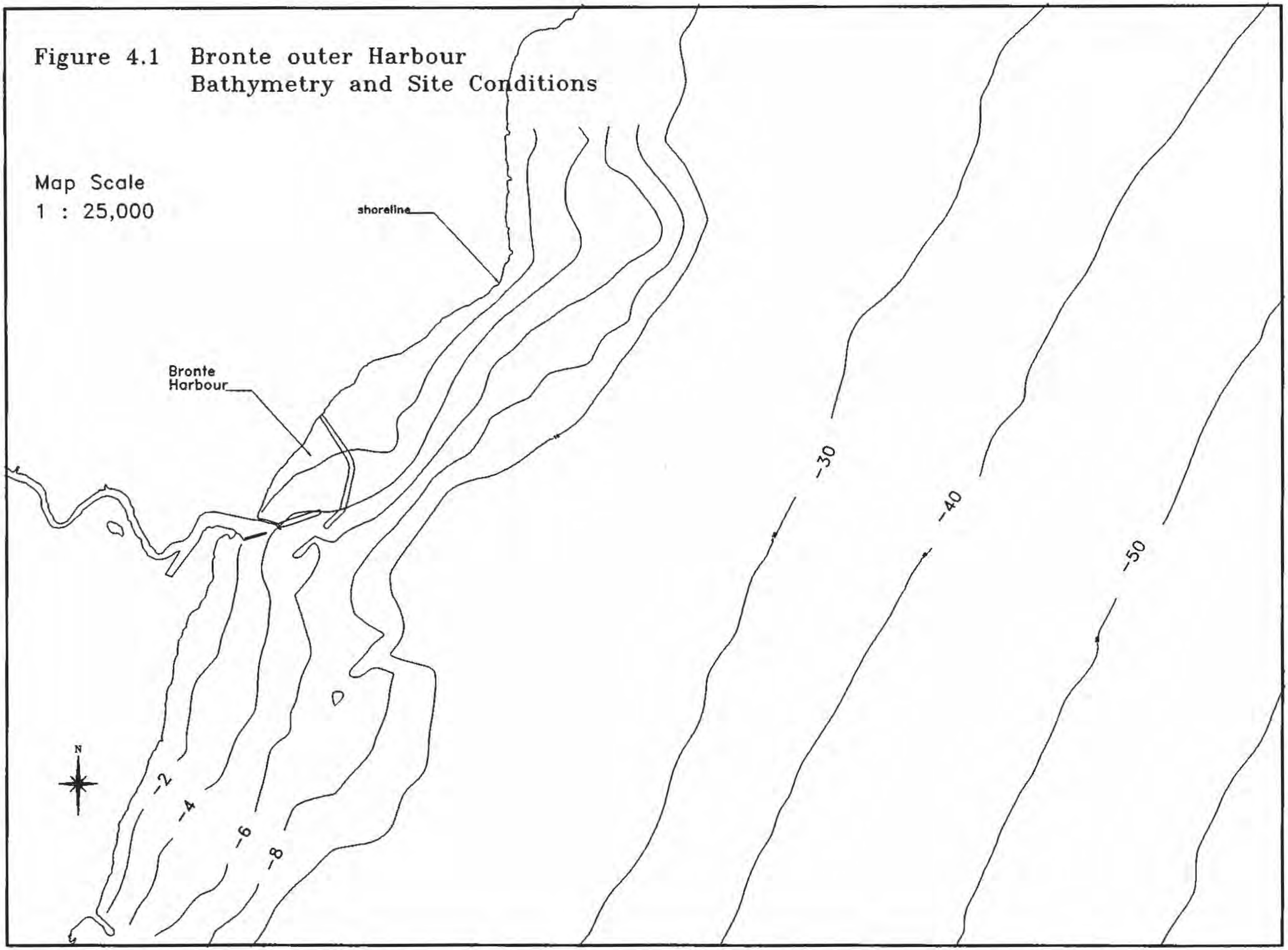
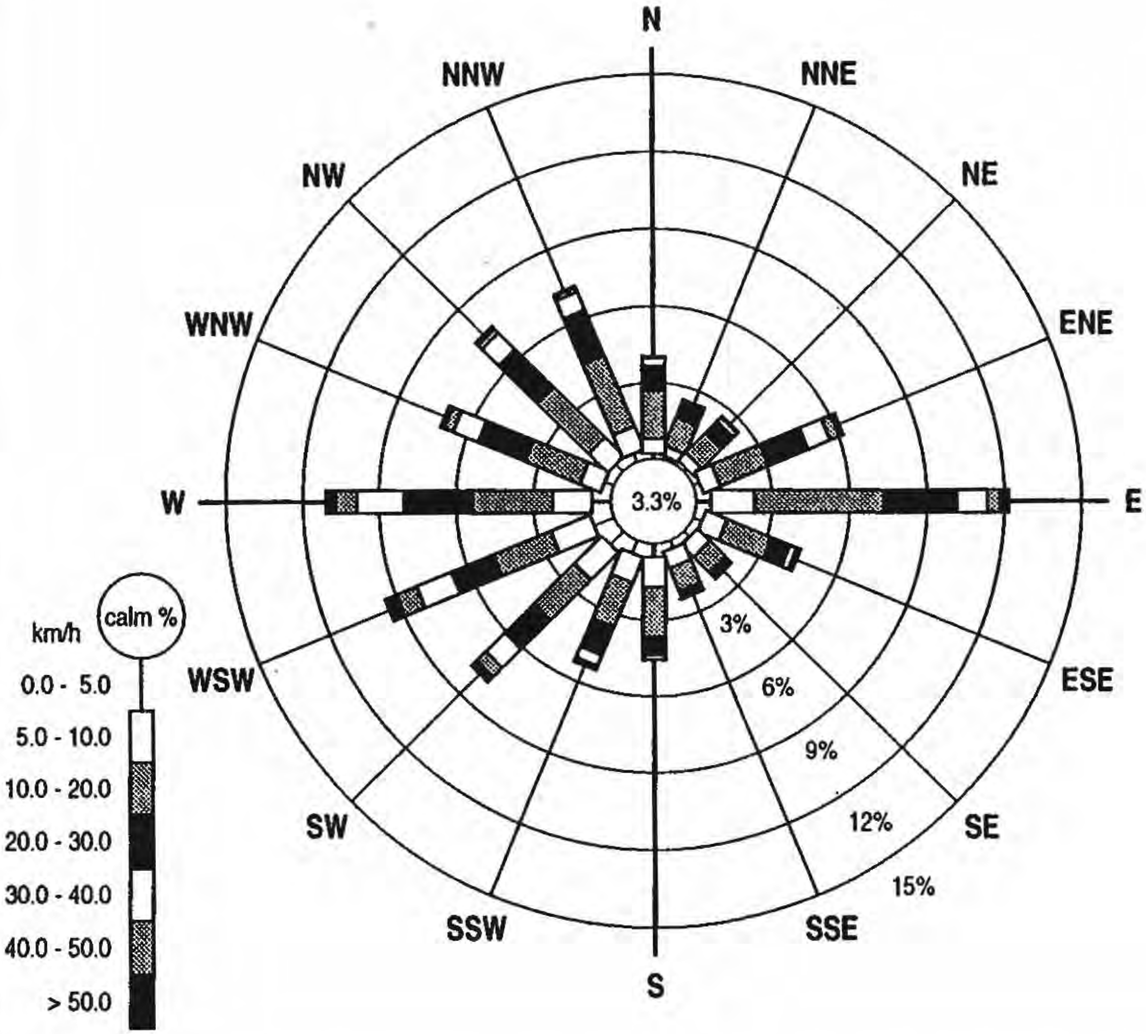


Figure 4.1 Bronte outer Harbour Bathymetry and Site Conditions

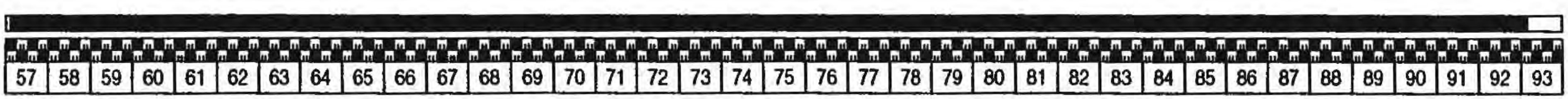
Figure 4.2 Wind Rose

Wind Station: Toronto Island A



Cumulative Distribution (%)

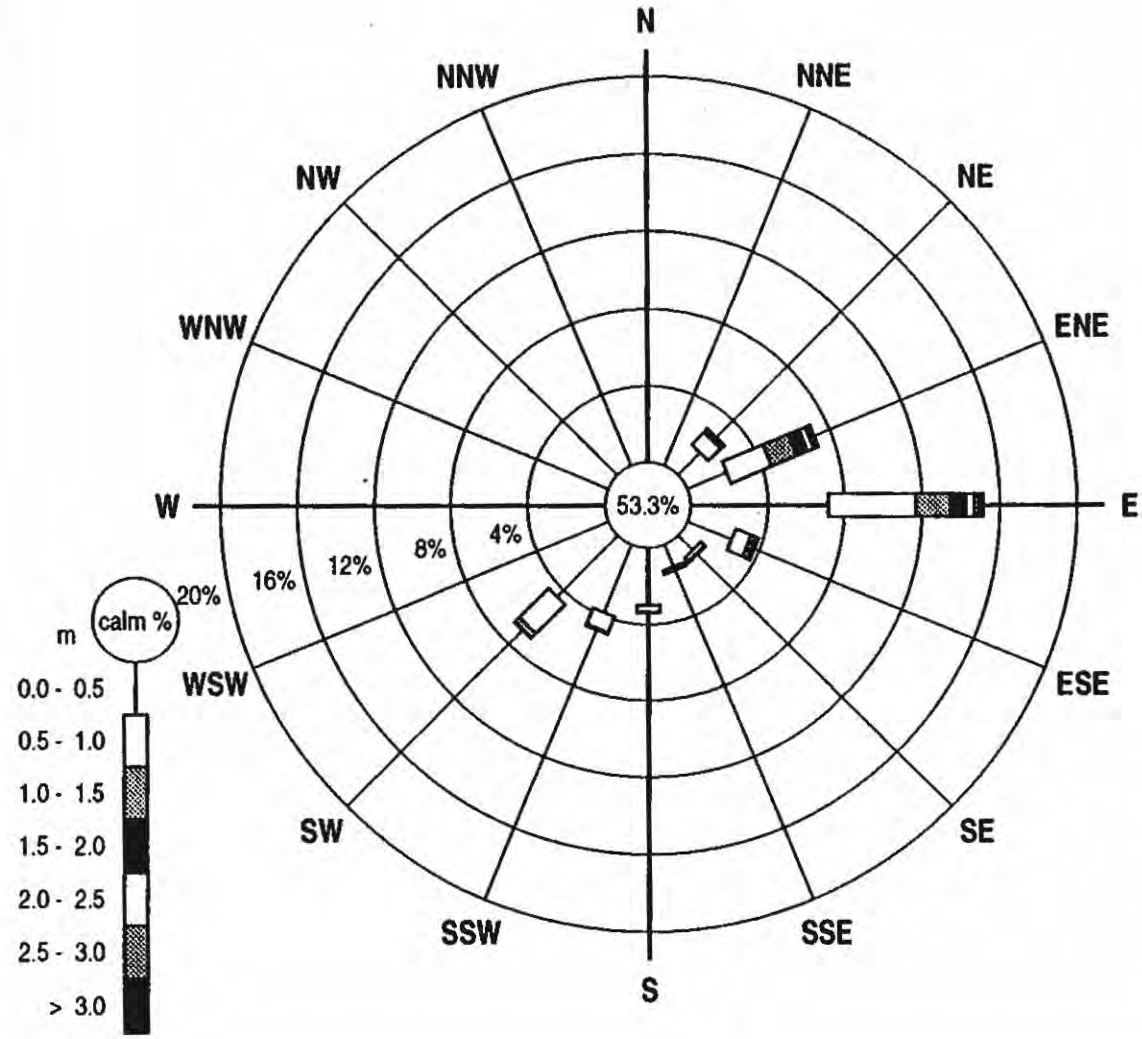
	0.0	5.0	10.0	20.0	30.0	40.0	50.0 km/h
NNE	0.1	0.5	1.7	2.3	2.5	2.5	
NE	0.2	0.6	1.7	2.3	2.5	2.6	2.6
ENE	0.3	1.0	3.0	4.7	5.6	6.0	6.2
E	0.6	2.3	7.3	10.1	11.3	11.9	12.2
ESE	0.4	1.3	3.2	3.9	4.2	4.3	4.4
SE	0.3	1.0	1.9	2.1	2.2	2.2	
SSE	0.3	1.0	2.0	2.2	2.3	2.3	
S	0.5	1.7	3.6	4.4	4.5	4.6	4.6
SSW	0.5	1.6	3.5	4.7	5.1	5.3	5.3
SW	0.7	2.2	4.4	6.1	7.1	7.6	7.9
WSW	0.8	2.5	4.9	6.6	8.1	8.9	9.4
W	0.7	2.2	5.3	8.0	9.8	10.7	11.1
WNW	0.4	1.2	3.5	5.5	6.6	6.9	7.1
NW	0.4	1.4	4.3	6.4	7.3	7.5	7.6
NNW	0.3	1.3	4.4	6.3	7.0	7.2	7.3
N	0.2	0.8	2.7	3.7	4.0	4.0	4.1



Baird

Figure 4.3a Wave Rose

Wave Station: Bronte Harbour



Cumulative Distribution (%)

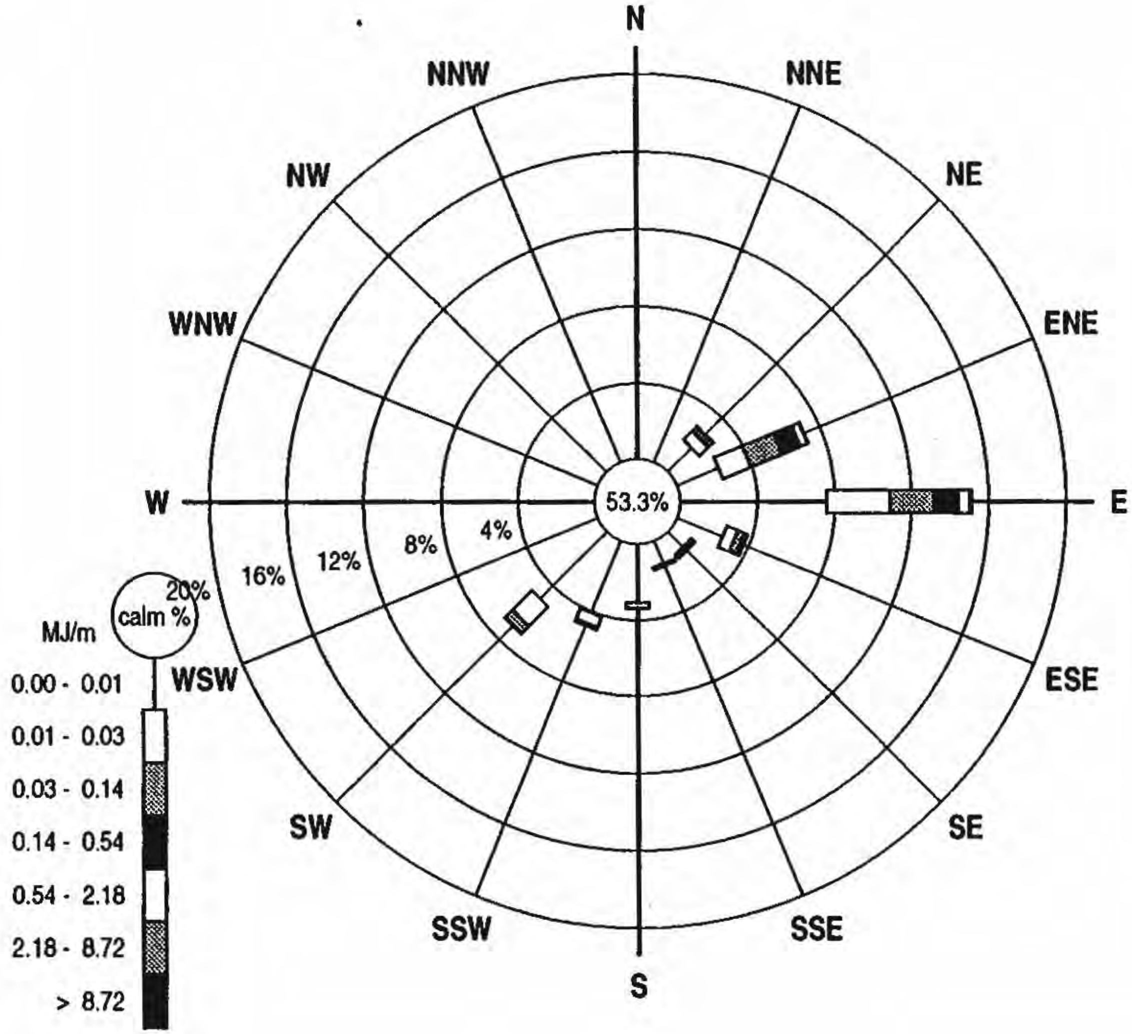
	0.0 - 0.5	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0	2.0 - 2.5	2.5 - 3.0	3.0 m
NNE	0.0						
NE	1.6	2.5	2.7	2.8			
ENE	2.2	4.5	5.9	6.5	6.8	7.0	7.1
E	7.1	11.7	13.4	14.2	14.7	14.9	15.1
ESE	2.4	3.3	3.6	3.7	3.7		
SE	1.1	1.3	1.4				
SSE	1.2	1.4	1.4				
S	3.0	3.3	3.4				
SSW	3.8	4.7	4.8				
SW	4.5	6.6	6.9	7.0			
WSW	0.0						
W	0.0						
WNW	0.0						
NW	0.0						
NNW	0.0						
N	0.0						

58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92

Baird

Figure 4.3b Wave Energy Rose

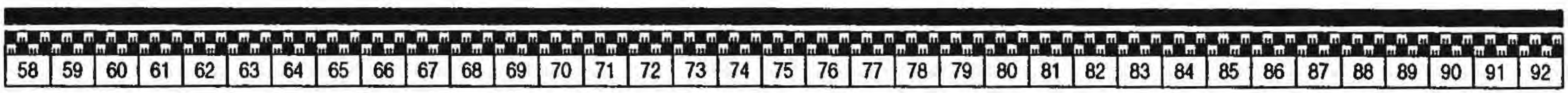
Wave Station: Bronte Harbour



Cumulative Distribution (%)

	0.00	0.01	0.03	0.14	0.54	2.18	8.72 MJ/m
NNE	0.0						
NE	1.8	2.4	2.7	2.8			
ENE	2.3	3.9	5.7	6.7	7.1	7.1	
E	7.6	10.8	13.2	14.5	15.0	15.1	
ESE	2.6	3.2	3.5	3.7	3.7		
SE	1.1	1.3	1.4	1.4			
SSE	1.3	1.4	1.4				
S	3.1	3.3	3.4				
SSW	4.1	4.6	4.8	4.8			
SW	5.0	6.4	6.9	7.0			
WSW	0.0						
W	0.0						
WNW	0.0						
NW	0.0						
NNW	0.0						
N	0.0						

Water Depth Used = 5 m



Baird

Figure 4.4 Bronte Outer Harbour - Marina & Breakwater

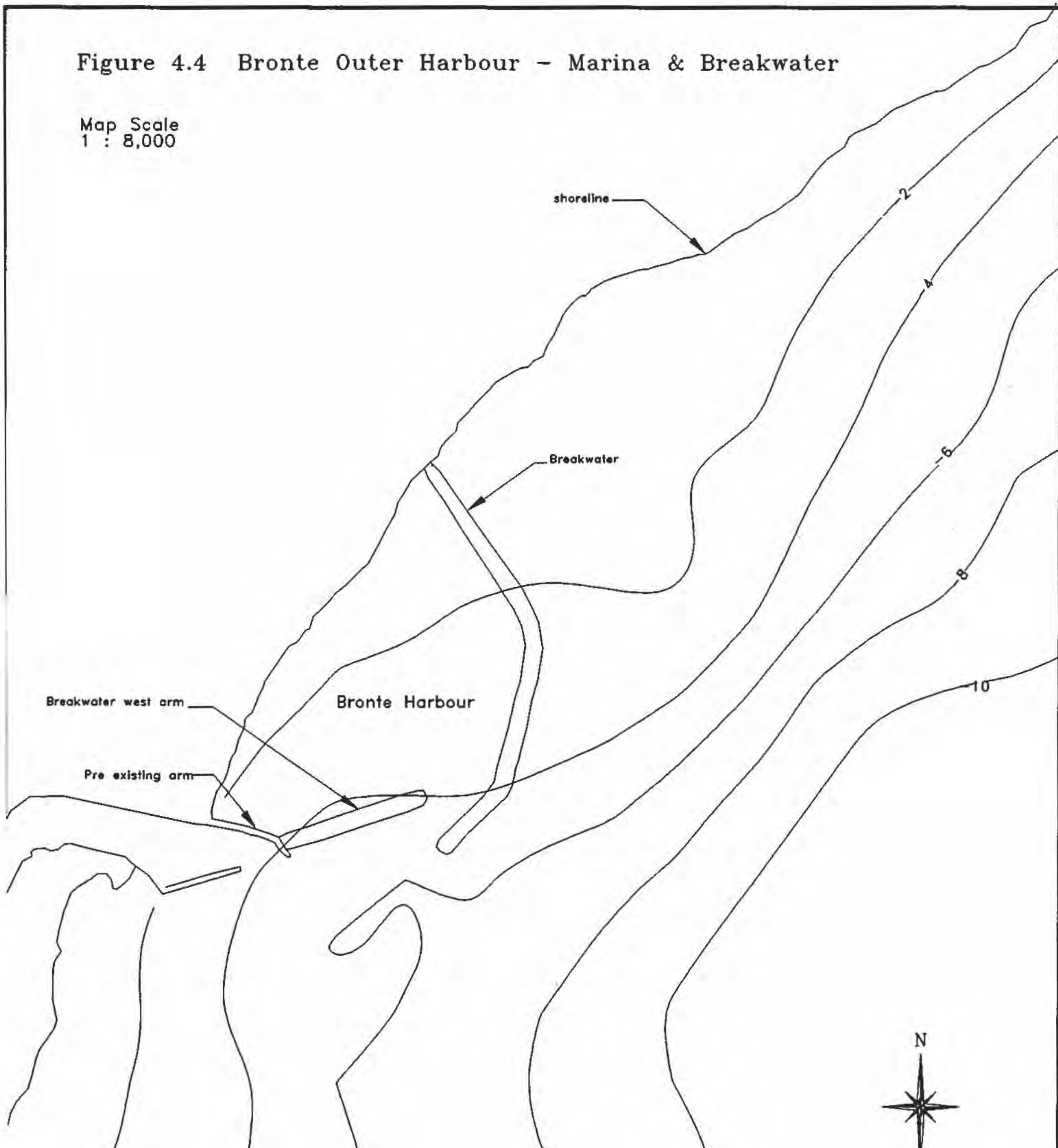
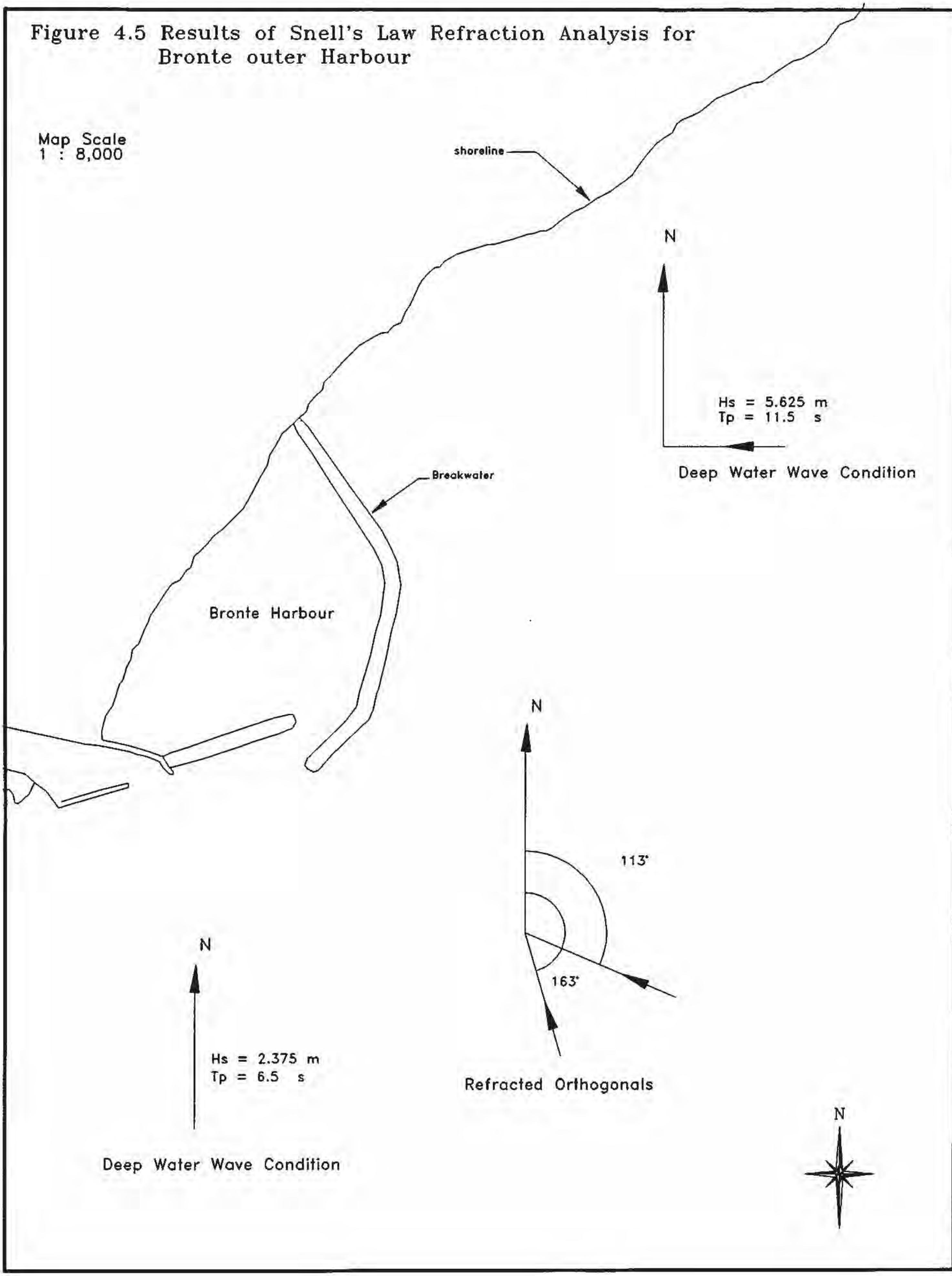


Figure 4.5 Results of Snell's Law Refraction Analysis for Bronte outer Harbour



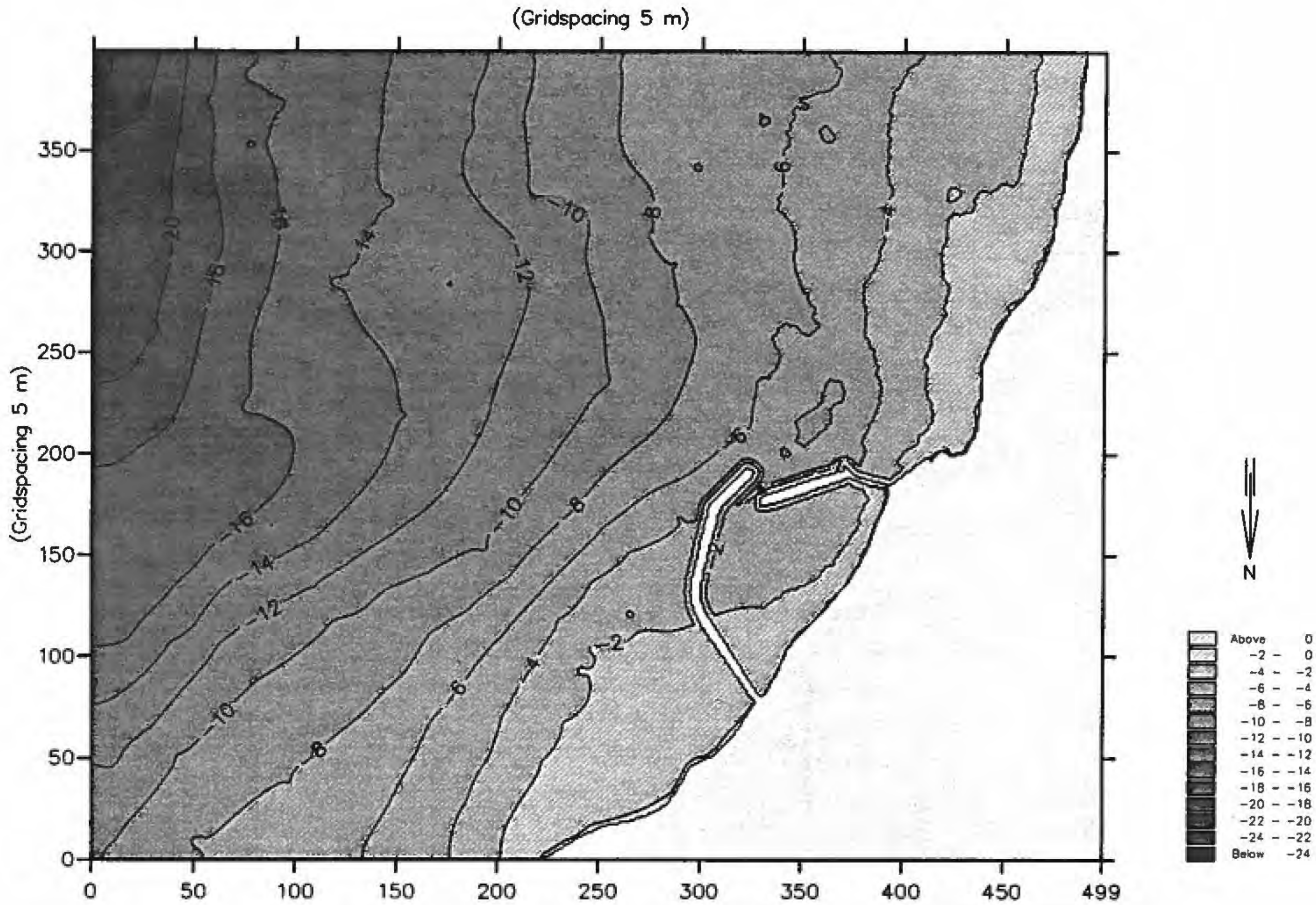


Figure 4.6		Parabolic Mild Slope Model Project:	MIKE 21
File:	Date: Fri Feb 2 1996	Bathymetry – Bronte Harbour Simulations East Waves Wave Conditions: 5.63 m, 11.5 s .	Drawing no.
Scale: 1:17000	Init: baird		

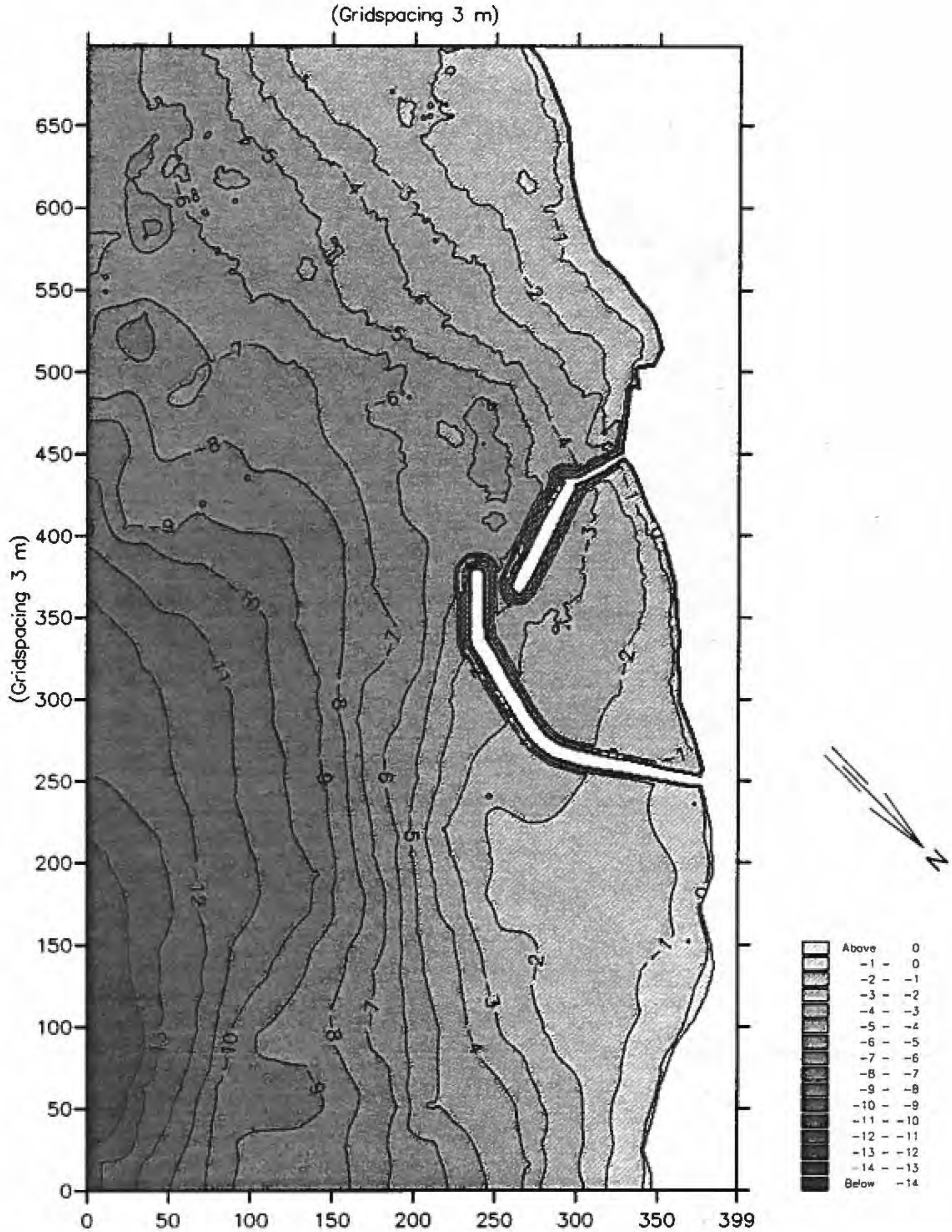


Figure 4.7		Parabolic Mild Slope Model Project:	MIKE 21
File:	Date: Fri Feb 2 1996	Bathymetry – Bronte Harbour Simulations South Waves Wave Conditions: 2.38 m, 6.5 s .	Drawing no.
Scale: 1:12000	Init: baird		

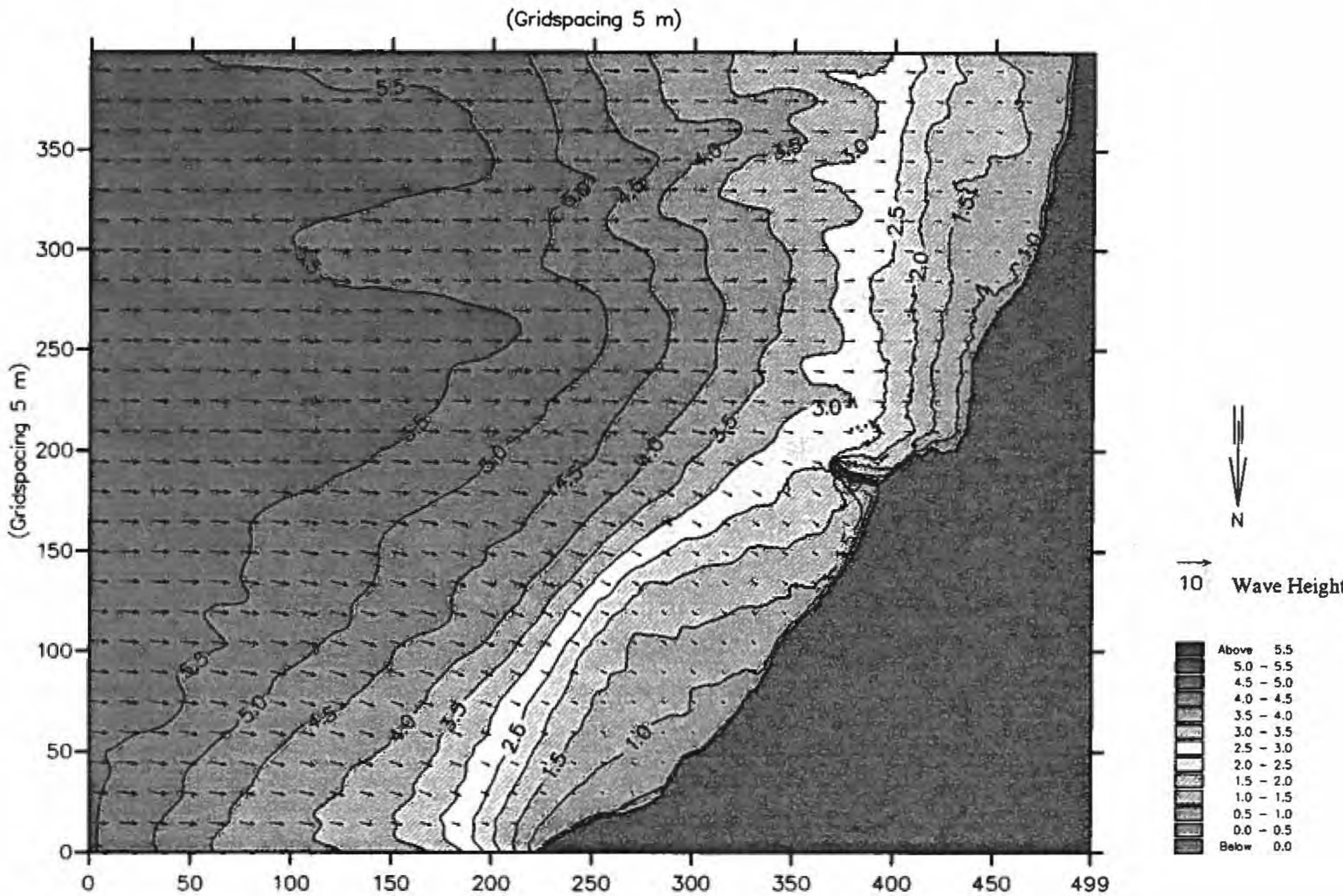


Figure 4.8		Parabolic Mild Slope Model - Pre Development Project:		MIKE 21
File:	Date: Fri Feb 2 1996	Bronte Harbour Hm0 Distribution [m]. East Waves Wave Conditions: 5.63 m, 11.5 s .	Drawing no.	
Scale: 1:17000	Init: baird			

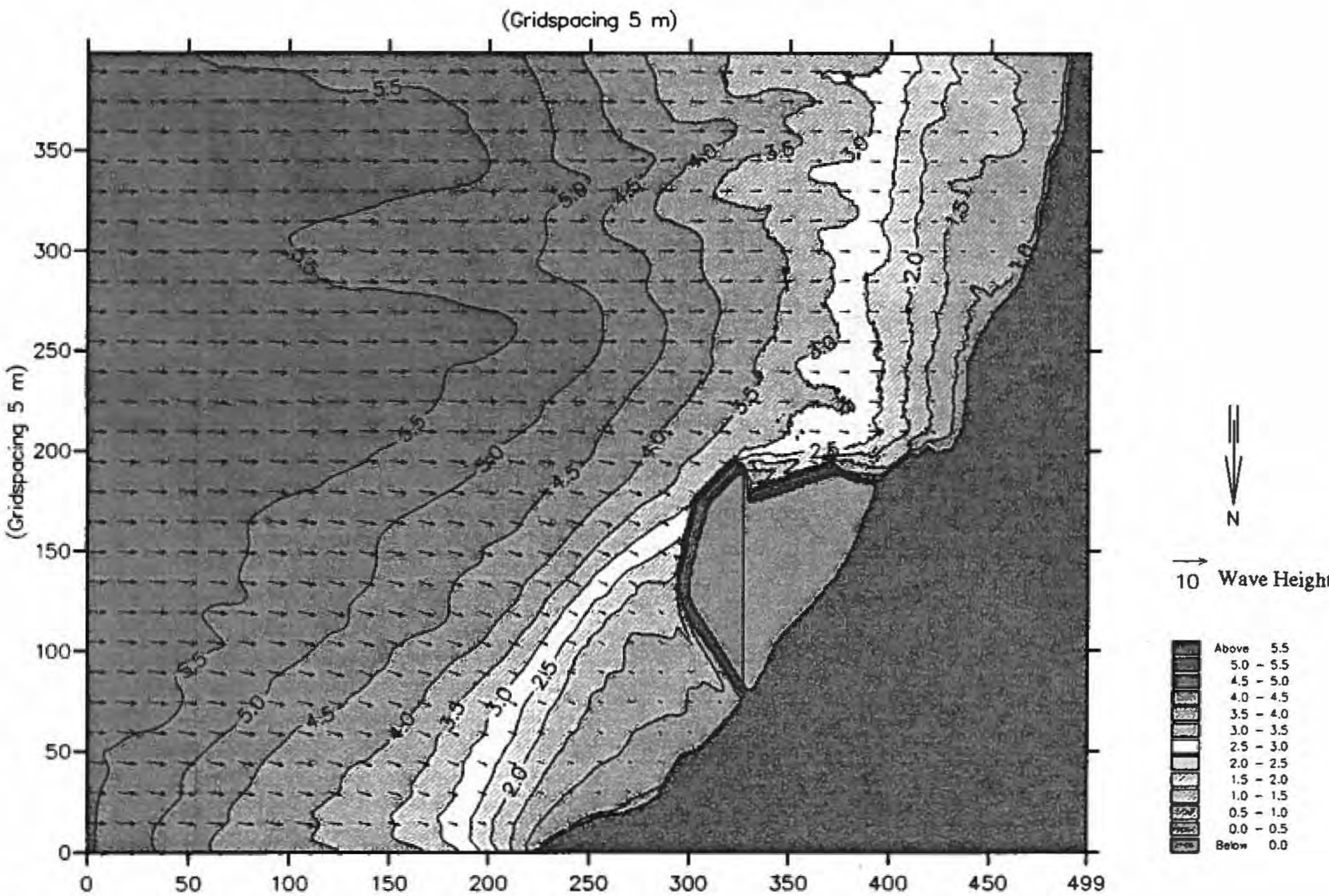


Figure 4.9		Parabolic Mild Slope Model - Post Development Project:		MIKE 21
File:	Date: Fri Feb 2 1996	Bronte Harbour HmO Distribution [m]. East Waves Wave Conditions: 5.63 m, 11.5 s .	Drawing no.	
Scale: 1:17000	Init: baird			

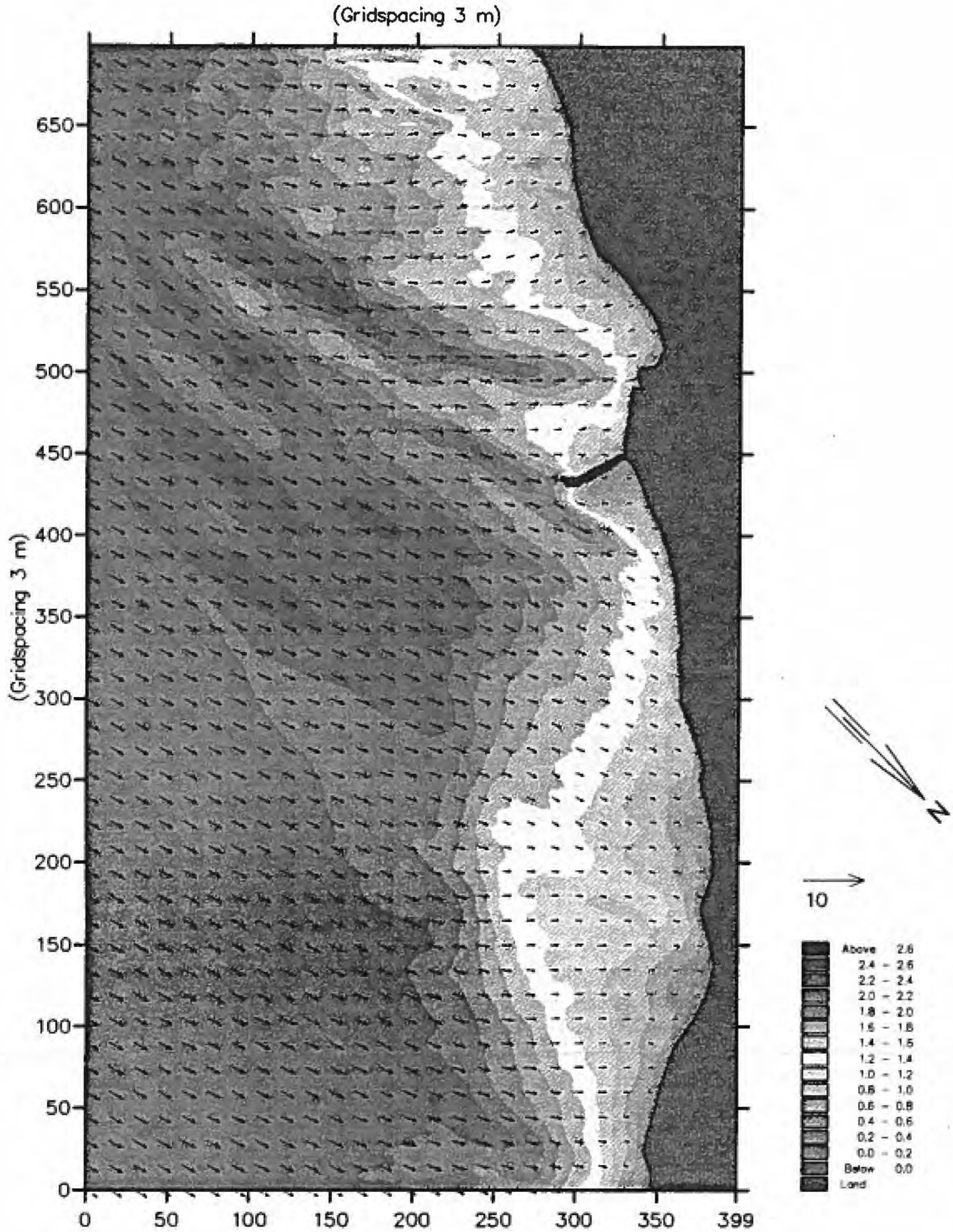


Figure 4.10		Parabolic Mild Slope Model - Pre Development Project:		MIKE 21
File:	Date: Fri Feb 2 1996	Bronte Harbour Hm0 Distribution [m].	Drawing no.	
Scale: 1:12000	Init: baird	Wave Conditions: 2.38 m, 6.5 s . South Waves		

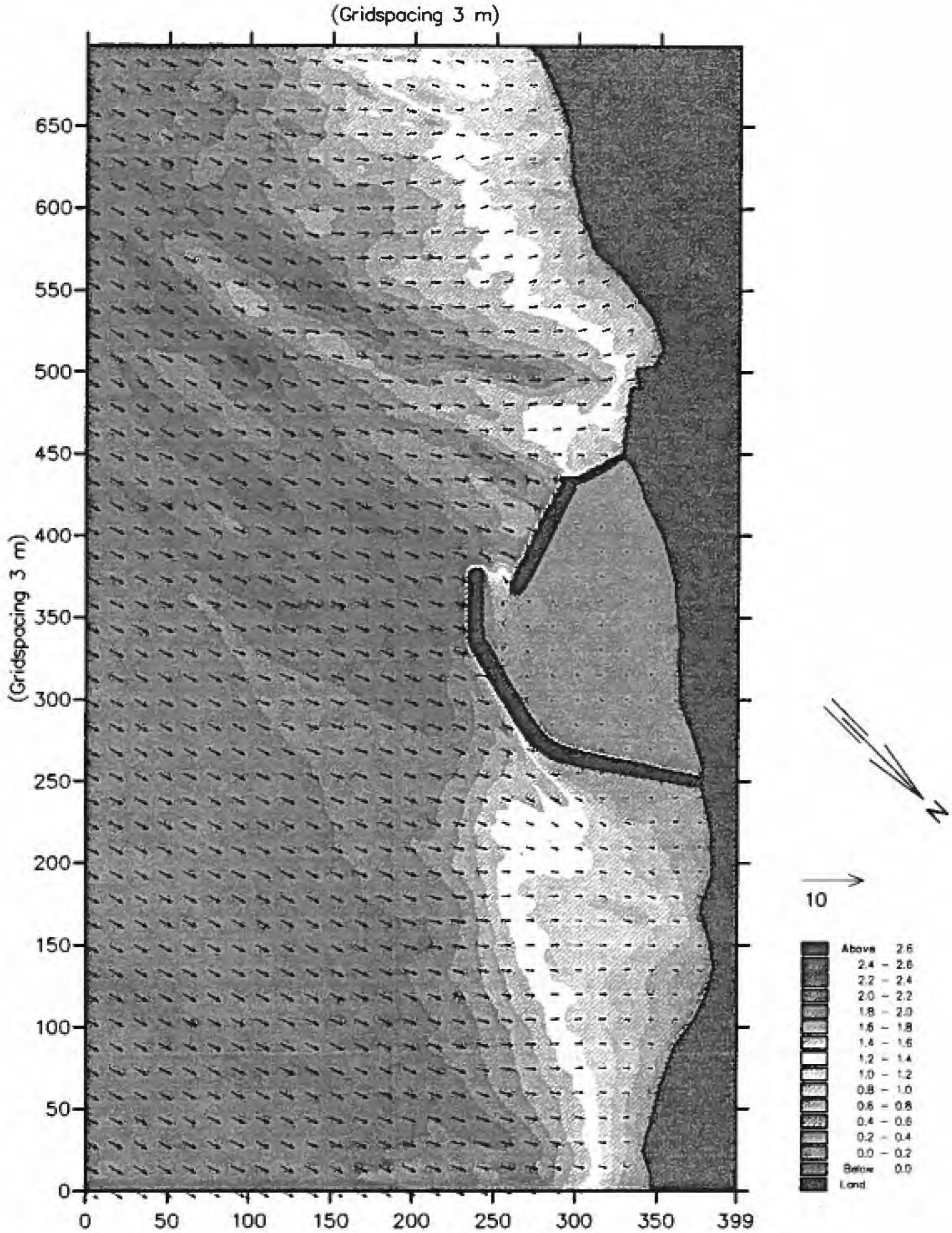


Figure 4.11		Parabolic Mild Slope Model - Post Development Project:		MIKE 21
File:	Date: Fri Feb 2 1996	Bronte Harbour Hm0 Distribution [m]. Wave Conditions: 2.38 m, 6.5 s . South Waves	Drawing no.	
Scale: 1:12000	Init: baird			

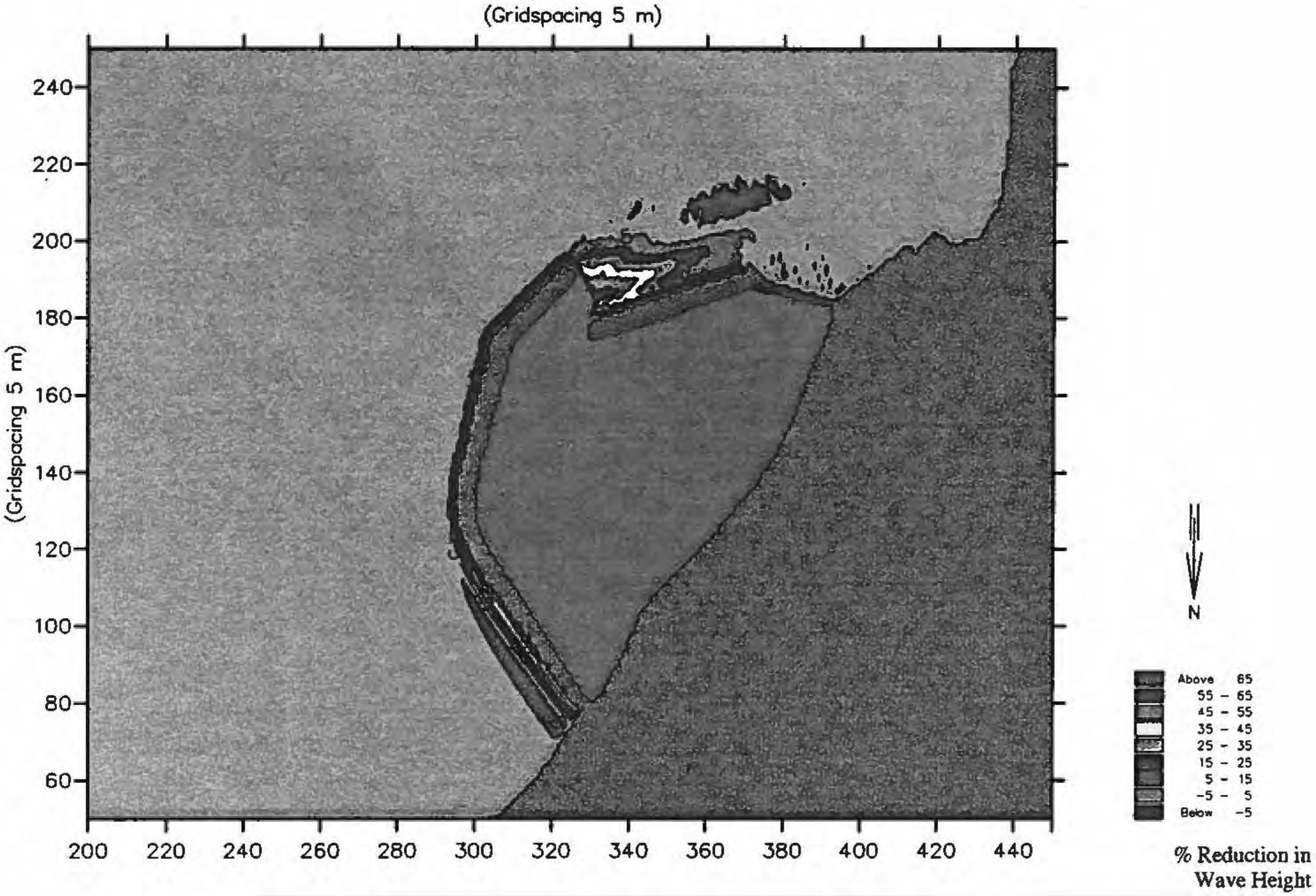


Figure 4.12		Parabolic Mild Slope Model Project:	MIKE 21
File:	Date: Fri Feb 2 1996	Bronte Harbour Reduction In Hm0 Relative To Pre-structure Conditions Wave Conditions: 5.63 m, 11.5 s . East Waves	Drawing no.
Scale: 1:9000	Init: baird		

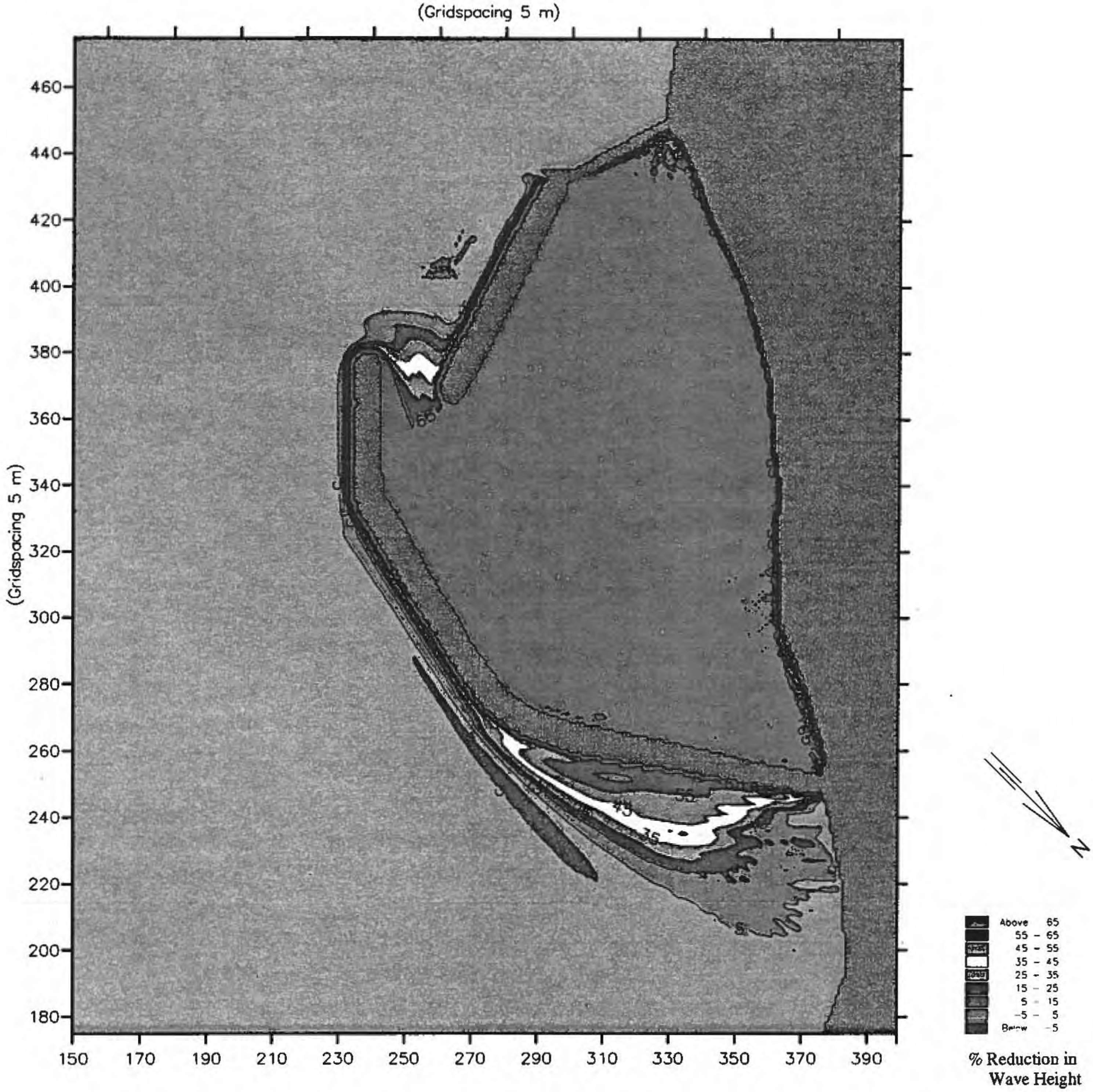
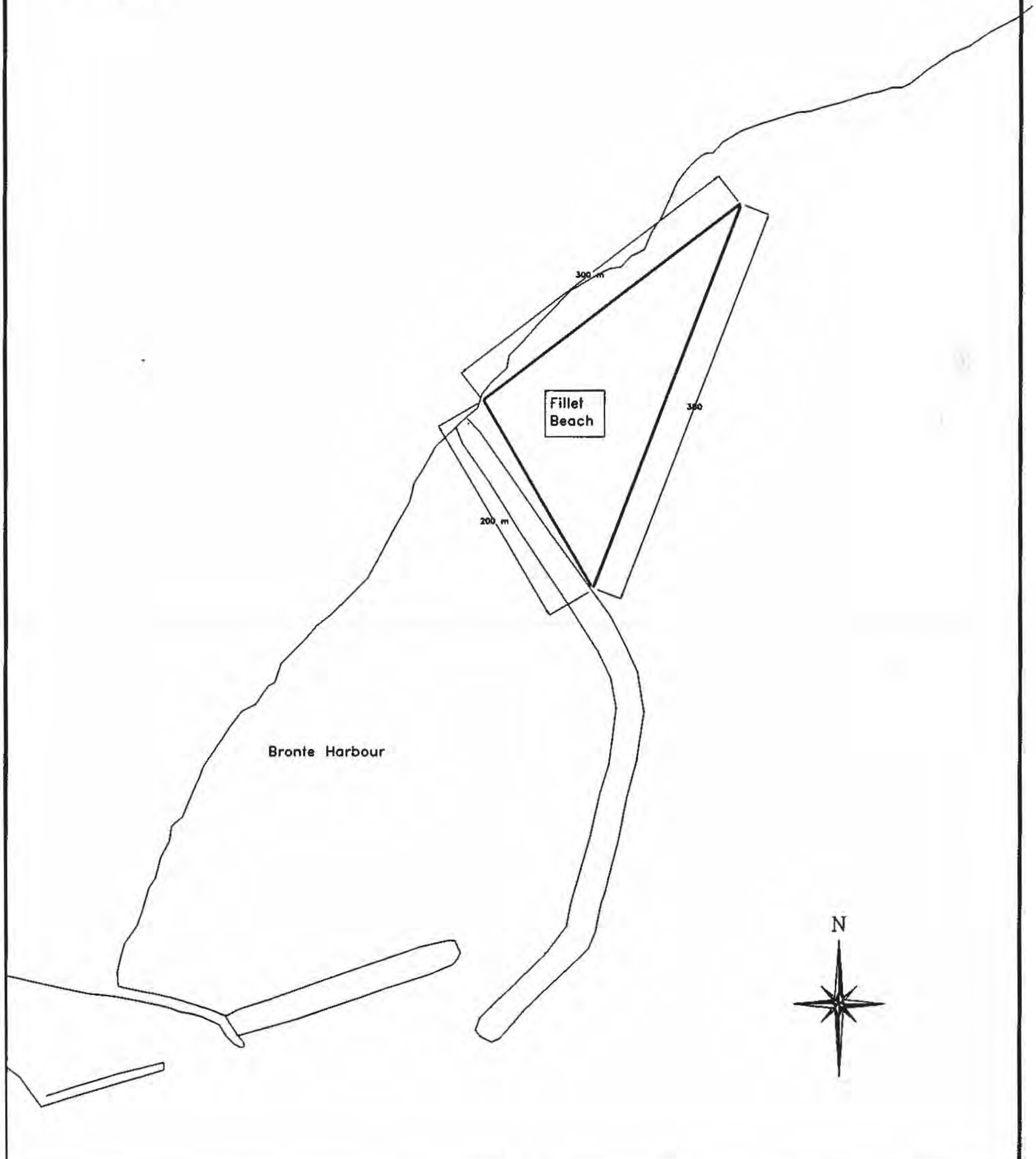


Figure 4.13		Parabolic Mild Slope Model Project:	MIKE 21
File:	Date: Fri Feb 2 1996	Bronte Harbour Reduction In HmO Relative To Pre-structure Conditions Wave Conditions: 2.38 m, 6.5 s . South Waves	Drawing no.
Scale: 1:5000	Init: baird		

Figure 4.14 Possible Fillet Beach Configuration at Bronte after Harbour

Map Scale
1 : 5,000



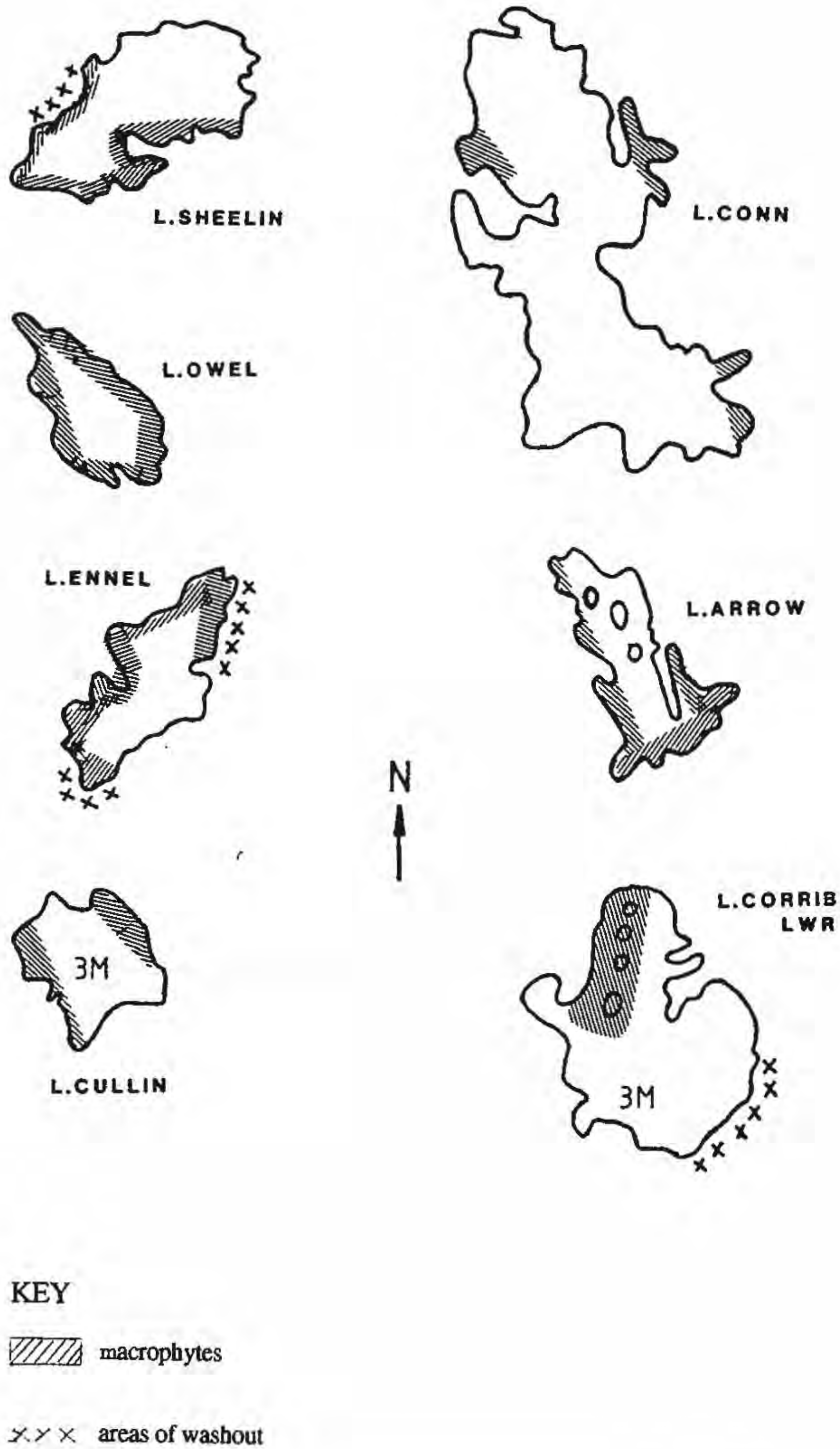


Figure 5.1a Areas of Macrophyte Growth and Washout
(after Hodnett and King 1987)

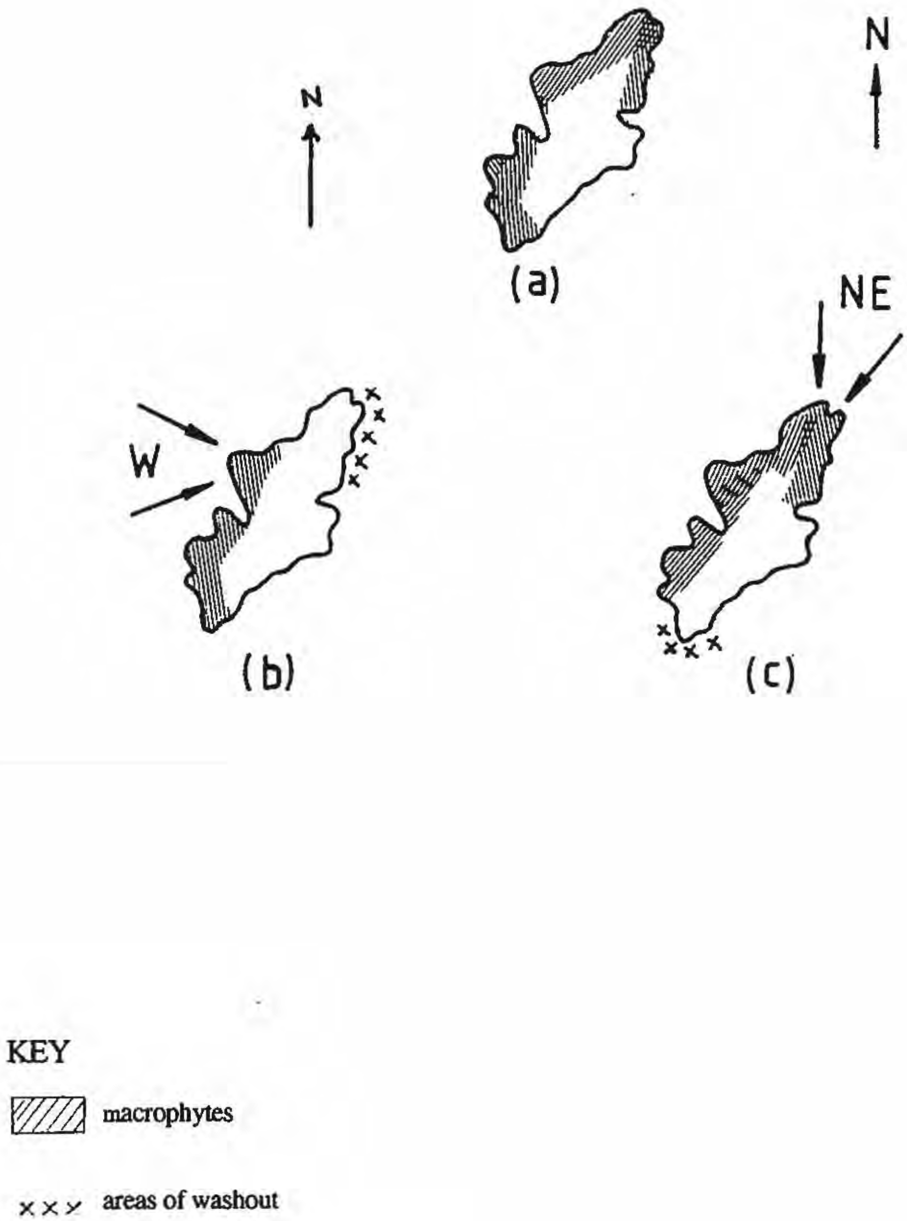


Figure 5.1b Areas of Macrophyte Growth and Washout for L.Ennel

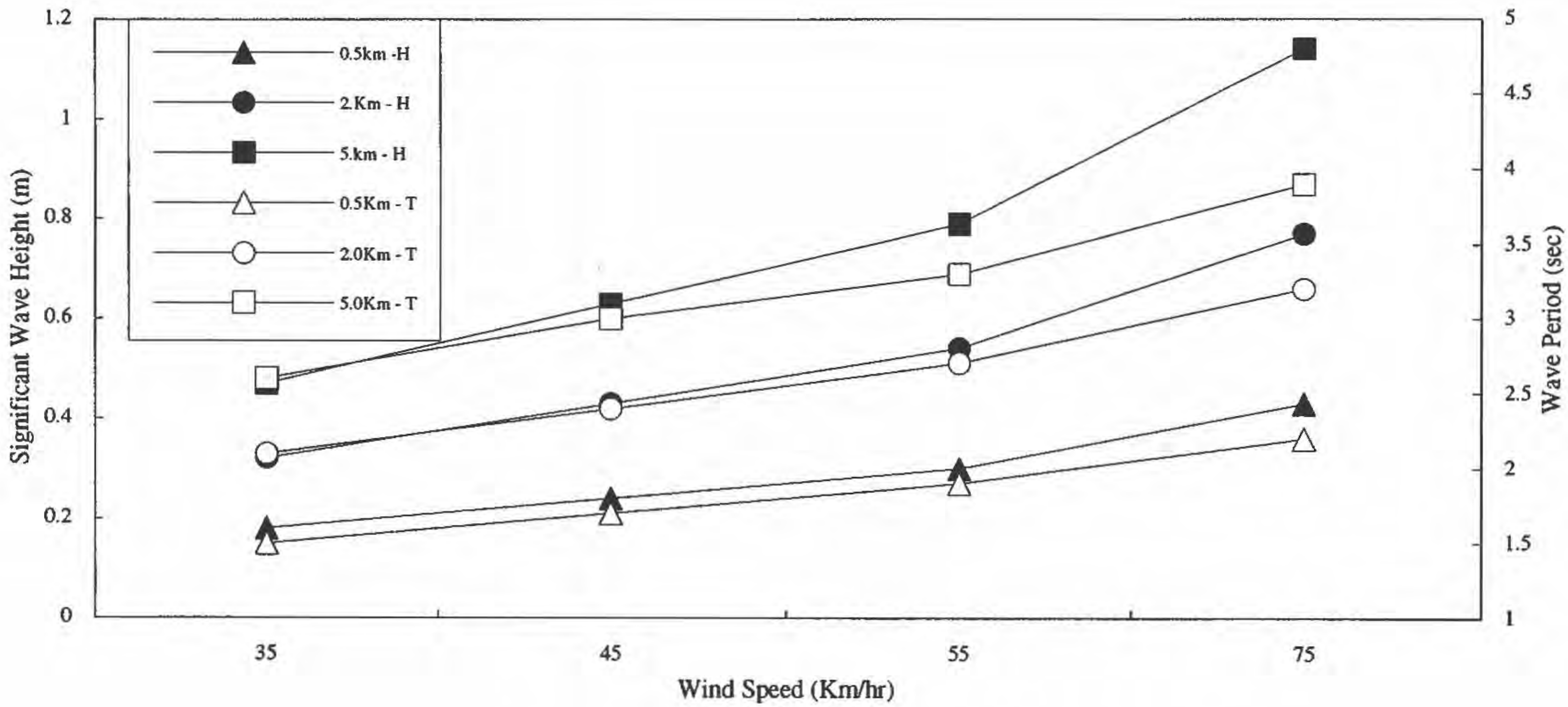


Figure 5.2 Wave Height and Period Vs. Wind Speed and Fetch Length

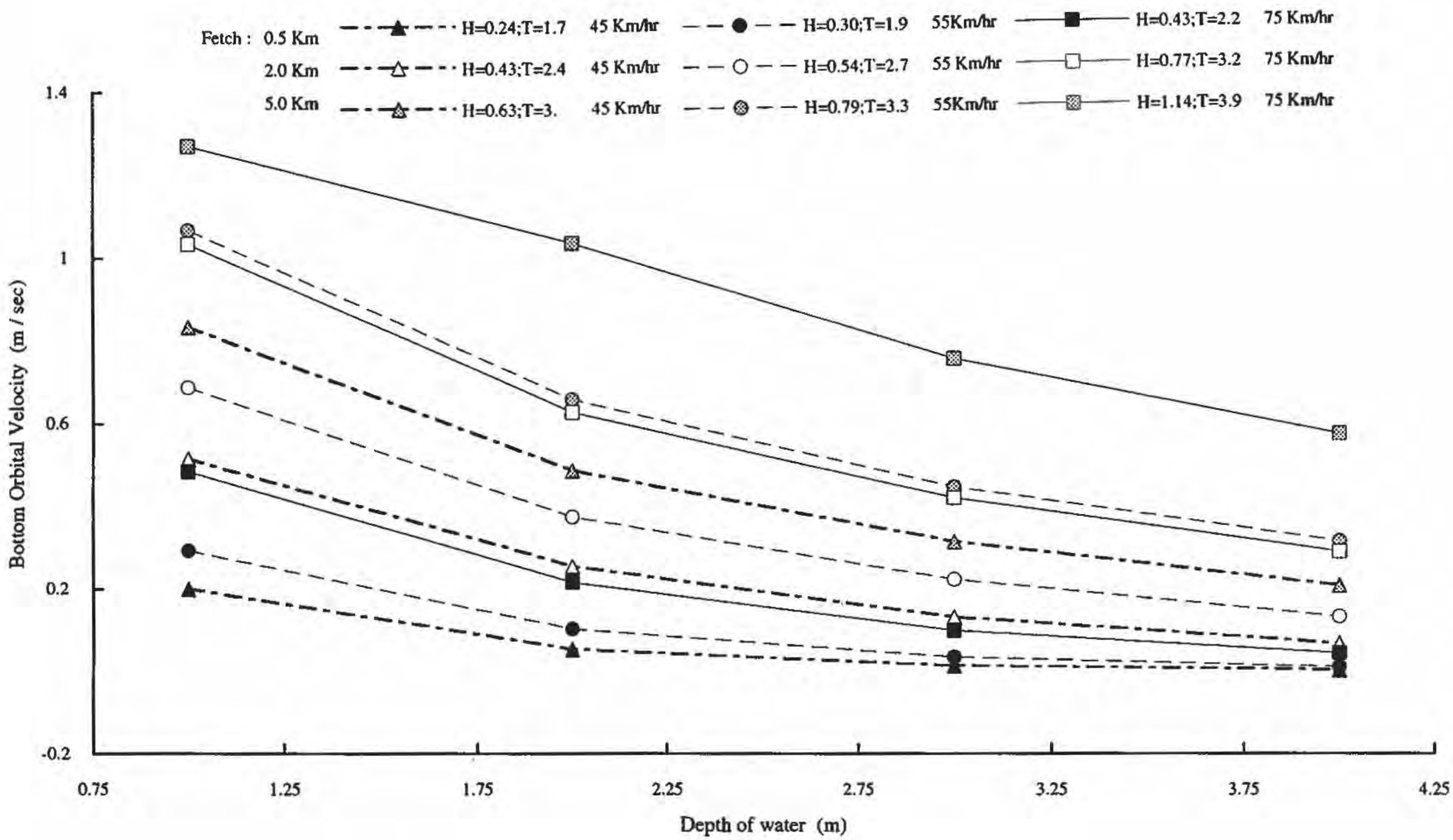


Figure 5.3 Wave Orbital Velocities Vs. Wind Speed, Fetch and Depth

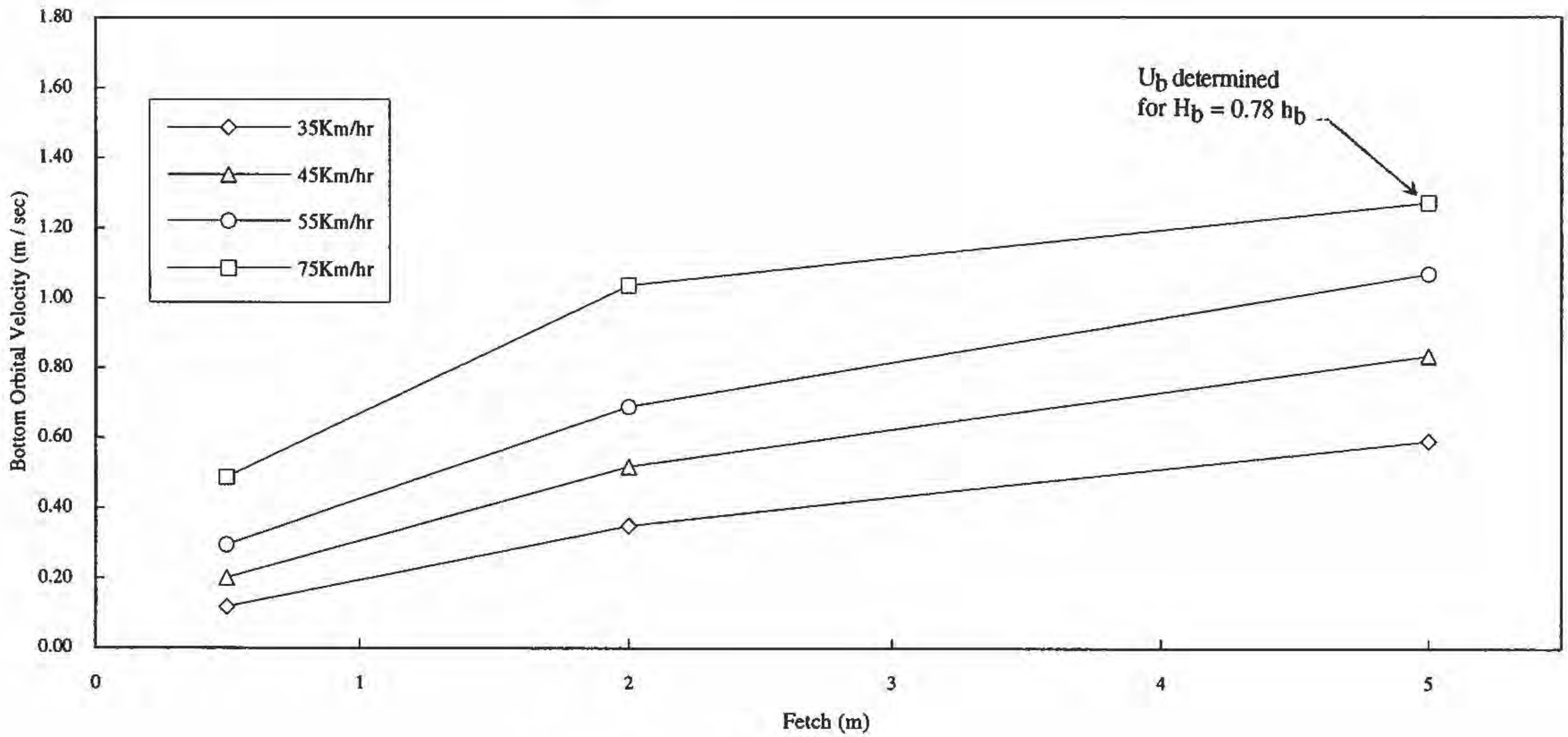


Figure 5.4a Wave Orbital Velocity Vs. Fetch

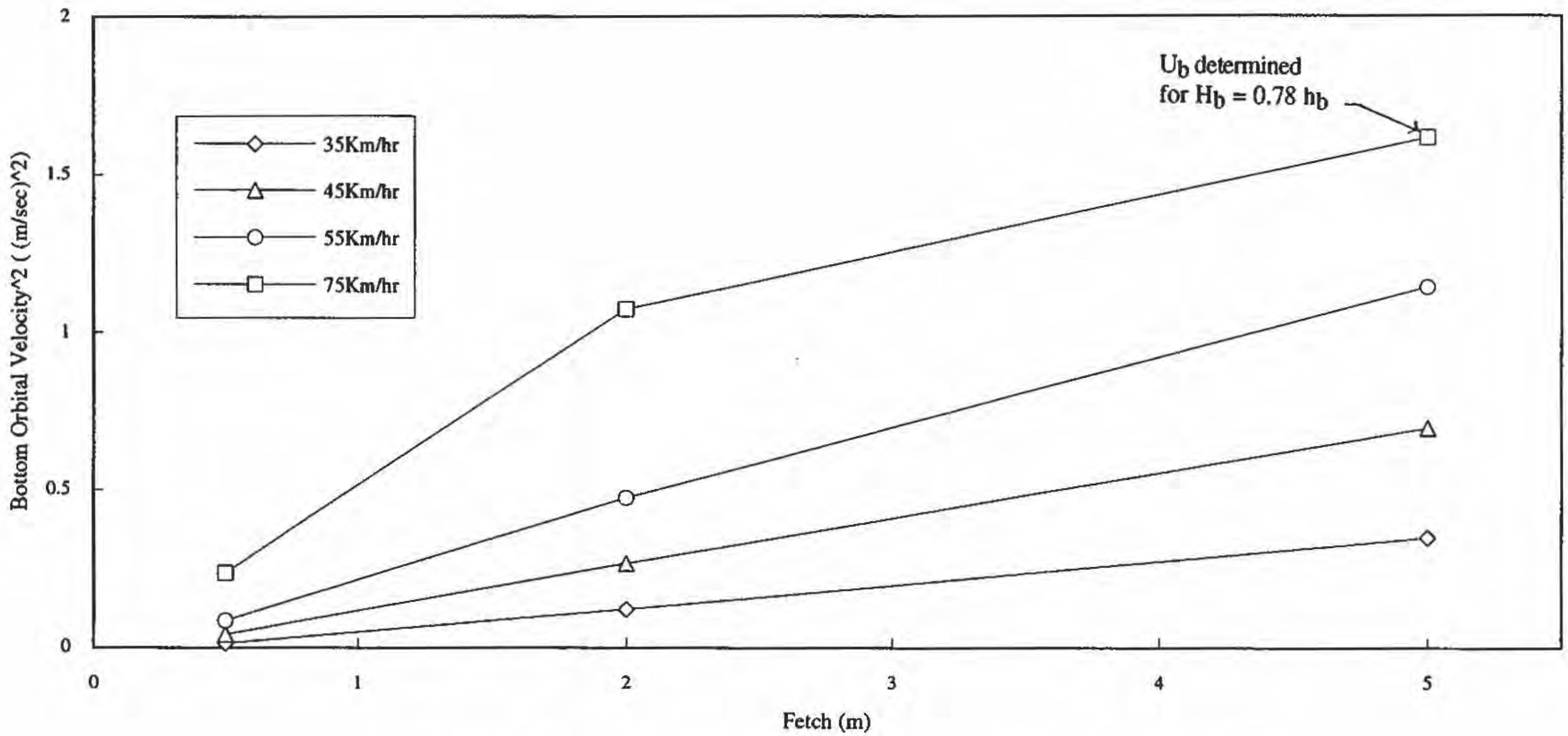


Figure 5.4b The Square of Wave Orbital Velocity Vs. Fetch