ΕΡΓΟΔΟΤΗΣ

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ΕΡΓΟ

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ΕΚΤΙΜΗΣΗΣ ΕΠΙΠΤΩΣΕΩΝ ΣΤΟ ΠΕΡΙΒΑΛΛΟΝ (ΜΕΕΠ)
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ΤΙΤΛΟΣ ΕΓΓΡΑΦΟΥ

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ΜΕΛΕΤΗ ΚΥΜΑΤΙΚΗΣ ΔΙΑΤΑΡΑΧΗΣ

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1. ΣΥΝΟΠΤΙΚΗ ΠΕΡΙΓΡΑΦΗ

1.1. ΕΙΣΑΓΩΓΗ

Αντικείμενο του παρόντος Τεύχους είναι η προσομοίωση των κυματικών συνθηκών εισόδου στον λιμένα Βασιλικού, και της κυματικής διείσδυσης στην λιμενολεκάνη, πριν και μετά την σχεδιαζόμενη επέκταση του προς τα Ανατολικά. Η μελέτη εκπονείται με την χρήση εξελιγμένων Αριθμητικών Μοντέλων.

Η παρούσα μελέτη εκπονήθηκε από την Εταιρεία Συμβούλων Μηχανικών "ROGAN Associates S.A.", μέλος της Κ/Ξίας «Διον. Τουμαζής και Συνεργάτες – Ρογκάν και Συνεργάτες ΑΕ» στο πλαίσιο της μελέτης « ΕΠΙΚΑΙΡΟΠΟΙΗΜΈΝΗ ΜΕΛΈΤΗ ΕΚΤΊΜΗΣΗΣ ΠΕΡΙΒΑΛΛΟΝΤΙΚΏΝ ΕΠΙΠΤΏΣΕΩΝ (ΜΕΕΠ) ΓΙΑ ΤΗΝ ΕΠΈΚΤΑΣΗ ΤΟΥ ΛΙΜΈΝΑ ΒΑΣΙΛΙΚΟΎ» .

Η μελέτη λαμβάνει ως δεδομένα το κυματικό κλίμα της περιοχής και τις εναλλακτικές προτάσεις για της επέκταση του λιμένα του Βασιλικού και παρέχει ως αποτελέσματα τις κυματικές συνθήκες που επικρατούν στην είσοδο και εντός της λιμενολεκάνης για κάθε πιθανό σενάριο κυματισμών που επικρατούν στην περιοχή. Τα ύψη των κυμάτων στις διαφορετικές λιμενολεκάνες του λιμανιού καθορίζονται υπό διάφορες συνθήκες εισερχόμενων ανέμων που προκαλούν κύματα και διαφορετικούς βαθμούς απορρόφησης των εξωτερικών αλλά και εσωτερικών ορίων της λιμενολεκάνης.

Ο σκοπός της παρούσας μελέτης είναι να υποστηρίξει τη διαδικασία σχεδίασης των προτεινόμενων έργων του λιμένα, κυρίως όσον αφορά στην διάταξη των εξωτερικών έργων του (κυματοθραυστών, με στόχο την ελαχιστοποίηση της κυματικής διαταραχής στην περιοχή τα εισόδου και στις λιμενολεκάνες.

1.2. ΠΡΟΤΕΙΝΟΜΕΝΕΣ ΕΝΑΛΛΑΚΤΙΚΕΣ ΔΙΑΤΑΞΕΙΣ

Προτείνονται εναλλακτικές διατάξεις για την βέλτιστη επίτευξη της κυματικής ηρεμίας εντός των δύο λιμενολεκάνων του λιμένα του Βασιλικού. Στην πρώτη εναλλακτική λύση προτείνεται η προέκταση του προσήνεμου κυματοθραύστη και η δημιουργία κρηπιδώματος στην υπήνεμη πλευρά του. Επίσης στην θέση του υπήνεμου κυματοθραύστη θα δημιουργηθεί μία νέος Προβλήτας που θα εξυπηρετεί χύδην φορτία. Ο προσήνεμος κυματοθραύστης θα επεκταθεί κατά 1155 μέτρα. Ο νέος υπήνεμος κυματοθραύστης που θα δημιουργηθεί θα εκτείνεται στα 275 μέτρα. Στον λιμένα του βασιλικού θα δημιουργηθούν δύο λιμενολεκάνες μία με βάθος των -9 μέτρων από την Κ.Ρ. και μία των -15 μέτρων.

Στην δεύτερη εναλλακτική διάταξη θα διερευνηθεί η χρήση απορροφητικών κρηπιδωμάτων στα κρηπιδώματα στην υπήνεμη πλευρά του προσήνεμου κυματοθραύστη για την λεκάνη των -9 μέτρων και στον προβλήτα που θα κατασκευαστεί στην Ανατολική και Νότια πλευρά του.

Τέλος θα διερευνηθεί μία επιπλέον διάταξη για την επέκταση του προσήνεμου κυματοθραύστη που προτάθηκε στην πρώτη εναλλακτική ώστε να μειώσει επιπλέον την κυματική διαταραχή που μπορεί να υπάρχει εντός της λιμενολεκάνης του λιμένα του Βασιλικού και για να παρουσιαστούν συγκριτικά αποτελέσματα σε σχέση με την χρήση απορροφητικών Κρηπιδωμάτων.

1.3. ΜΕΘΟΔΟΛΟΓΙΑ ΚΑΙ ΕΠΙΣΤΗΜΟΝΙΚΟ ΥΠΟΒΑΘΡΟ ΑΡΙΘΜΗΤΙΚΩΝ ΜΟΝΤΕΛΩΝ

Η μεθοδολογία που εφαρμόζεται στην παρούσα μελέτη περιλαμβάνει τα εξής:

Η παρούσα μελέτη χρησιμοποιεί τα υπάρχοντα δεδομένα κυμάτων που αναπτύχθηκαν από το Κέντρο Υδραυλικών Ερευνών του Delft στο πλαίσιο της μελέτης "Διαχείρισης Παράκτιας Ζώνης για την Κύπρο: Ανάλυση του Κλίματος των Κυμάτων κοντά στην Ακτή από τους Xenia Loizidou και John Dekker (Delft Hydraulics), Μάρτιος 1994". Οι κατευθύνσεις του ανέμου που μπορούν να προκαλέσουν κύματα που διεισδύουν στο λιμάνι είναι Ανατολικές, Νοτιοανατολικές, Νότιες και Νοτιοδυτικές.

Η μέγιστη τιμή σημαντικού ύψους κυμάτων Hs για τις προαναφερθείσες κατευθύνσεις ανέμου είναι ίση με 5,75 μέτρα, με αντίστοιχη κορυφαία περίοδο 9,59 δευτερολέπτων. Τα χαρακτηριστικά του κυματικού κλίματος στη θάλασσα και τα διαγράμματα βαθυμετρίας χρησιμεύουν ως δεδομένα εισόδου στο αριθμητικό μοντέλο για την προσομοίωση της διάδοσης των κυμάτων, λαμβάνοντας υπόψη όλα τα κυρίαρχα φαινόμενα όπως η ανάκλαση, η διάθλαση, η περίθλαση, η ρήχωση και η θραύση.
Οι προσομοιώσεις πραγματοποιούνται για την υπάρχουσα κατάσταση (Do-Nothing σενάριο), αλλά και στις εναλλακτικές διατάξεις που προτείνονται για την επίτευξη της κυματικής ηρεμίας εντός της λιμενολεκάνης.

Σε αυτή τη μελέτη, χρησιμοποιείται το μαθηματικό μοντέλο διάδοσης κυμάτων, Maris HMS (μη γραμμικό υπερβολικό μοντέλο ήπιας κλίσης), που αναπτύχθηκε από τη Scientia Maris. Αντιπροσωπεύει ένα προηγμένο μη γραμμικό μοντέλο των κυματικών εξισώσεων ήπιας κλίσης που προσομοιώνει την χώρο-χρονική διάδοση των φασματικών κυματισμών σε παράκτιες περιοχές και λιμένες. Αναπαριστά με ακρίβεια όλα τα περίπλοκα φαινόμενα που συμβαίνουν σε μια παράκτια περιοχή, συμπεριλαμβανομένων:

- Διάδοση πολύπλοκων μη γραμμικών κυμάτων
- Ρήχωση
- Διάθλαση
- Περίθλαση
- Μερική ή ολική ανάκλαση
- Διάχυση ενέργειας λόγω τριβών πυθμένα και θραύση

Αυτό το μοντέλο αποτελεί ένα πολύτιμο εργαλείο για τη διεξαγωγή μελετών κυματικών διαταραχών σε κλειστές θαλάσσιες περιοχές (όπως κόλποι, λιμάνια) και την προσομοίωση φαινομένων όπως ο συντονισμός των κυμάτων μέσα σε μία λιμενολεκάνη. Επιπλέον, μπορεί να εφαρμοστεί σε παράκτιες ζώνες όπου η ανάκλαση των κυμάτων επηρεάζει σημαντικά τις ακτομηχανικές μελέτες. Οι μεταβλητές που υπολογίζονται από αυτό το μοντέλο περιλαμβάνουν το ύψος των κυμάτων, την περίοδο και την κατεύθυνση των κυμάτων, καθώς και το ύψος της ελεύθερης επιφάνειας του νερού και τις τάσεις της ακτινοβολίας.

1.4. ΣΥΜΠΕΡΑΣΜΑΤΑ

- Ανεξάρτητα από το μήκος του κυματοθραύστη, τα κύματα που εισέρχονται από τις ανατολικές-νοτιοανατολικές κατευθύνσεις θα εμποδίσουν τη λειτουργία του ανατολικού κρηπιδώματος για ετήσιο ποσοστό 1,73%. Αυτά τα κύματα που διαδίδονται ανακλόνται στην ανατολική πλευρά του προτεινόμενου προβλήτα χύδην ξηρού φορτίου και δημιουργούν κυματική διαταραχή στο εσωτερικό της λεκάνης. Η σύγκριση των αποτελεσμάτων που ενσωματώνουν απορροφητικούς κρηπιδότοιχους με τα αντίστοιχα που ενσωματώνουν πλήρως ανακλαστικούς κρηπιδότοιχους, καταδεικνύει τη μείωση της κυματικής διαταραχής στο εσωτερικό της λιμενικής λεκάνης. Ως εκ τούτου, η παρούσα μελέτη υπογραμμίζει τη χρήση τέτοιων κρηπιδωμάτων στην ανατολική πλευρά του προβλήτα χύδην ξηρού φορτίου.
- Υπάρχει διάδοση κυματισμών στο ανατολικό κρηπίδωμα κυρίως για κυματισμούς Ανατολικής-ΝότιοΑνατολικής, Νότιας-ΝότιοΑνατολικής, Νότιας και Νότιο-ΝοτιοΔυτικής προέλευσης. Το ανατολικό κατακόρυφο μέτωπο του προτεινόμενου προβλήτα είναι εκτεθειμένο στους παραπάνω εισερχόμενους κυματισμούς.
- Η εναλλακτική με απορροφητικά κρηπιδώματα δεν παρέχει βελτίωση του χρόνου λειτουργίας του λιμένα σε σύγκριση με την επιλογή Β παρόλο που το ύψος κύματος μειώνεται
- **Σύμφωνα με τα αποτελέσματα της κυματικής διαταραχής επιλέγεται η Εναλλακτική Διάταξη 2 καθώς παρέχει τη μικρότερη κυματική διαταραχή ανεξάρτητα από τα σκάφη που είναι ελλιμενισμένα**

2. INTRODUCTION

2.1. GENERAL

An investigation of wave disturbance is carried out, by means of numerical simulation, for the proposed expansion of Limassol Port – Terminal 2 (Vassilikos).

The present study is prepared by the Consulting Engineering Firms "ROGAN & Associates S.A. and Dion. Toumazis & Associates" for the Cyprus Ports Authority.

The wave disturbance study takes as input the prevailing wave pattern and provides as output the annual percentage of time during which the port, or individual sections of it can be operational. The wave heights in sections of the harbor basin are determined under various incident wind-generated wave conditions and degrees of absorption of the solid boundaries.

This study concerns the expansion of the Port of Vasilikos in Cyprus to the East. It is prepared within the framework of the project titled: "UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS," assigned by the Cyprus Ports Authority to the consortium of companies consisting of Dion. Toumazis and Associates and Rogan and Associates S.A.

2.2. OBJECTIVE

The scope of the preset study is to support the design process of the proposed port expansion works in attaining the necessary tranquility of the sea surface in the harbor basin.

The numerical simulations are carried out using the advanced numerical model of high precision, the Maris HMS, which employs equations of mild slope hyperbolic approximation. This model, developed by Scientia Maris, is capable of simulating the propagation of complex nonlinear wave phenomena by simulating the entirety of physical phenomena occurring within and around the port. This includes shoaling, diffraction, refraction, reflection, and energy dissipation due to bottom friction and breaking. This model has been published and presented in numerous publications in international scientific journals and proceedings of international conferences. It has been applied in a multitude of approved studies related to wave and coastal engineering.

2.3. AVAILABLE DATA

The data considered in this study includes:

- Satellite imagery obtained from the internet and the Google Earth application.
- Digital topographic and bathymetric data delivered from the topographic and bathymetric survey.
- Wave data spanning from 1993 to 2021 sourced from the Copernicus Marine Service database (https://marine.copernicus.eu/).
- Bathymetric data from Navionics sources (navionics.com).

2.4. WORKING GROUP

The present Wave Disturbance Study was conducted by the Consulting Engineers of ROGAN AND ASSOCIATES S.A.

The working team for this study comprises:

Dr. Christos Solomonidis, Civil Engineer – Port Engineer
George Fotis, M.Sc., Survey Engineer – Port Engineer
Polyvios Sotirakopoulos, M.Sc., Civil Engineer – Port Engineer
Achilles Stamatiadis, M.Sc., Civil Engineer – Port Engineer
Apostolos Kalpias, M.Sc., Civil Engineer – Port Engineer

3. DESCRIPTION OF EXISTING PORT INFRASTRUCTURE AND FUTURE EXPANSION

3.1. EXISTING PORT INFRASTRUCTURE

Vassilikos Port is located at the eastern side of Vassiliko Bay (see Figure 3.1). It is currently operated by Vassiliko Cement Works under a concession agreement with the Cyprus Ports Authority for a period of 50 years, i.e. until 2032. The port is capable to handle dry and liquid bulk cargoes.

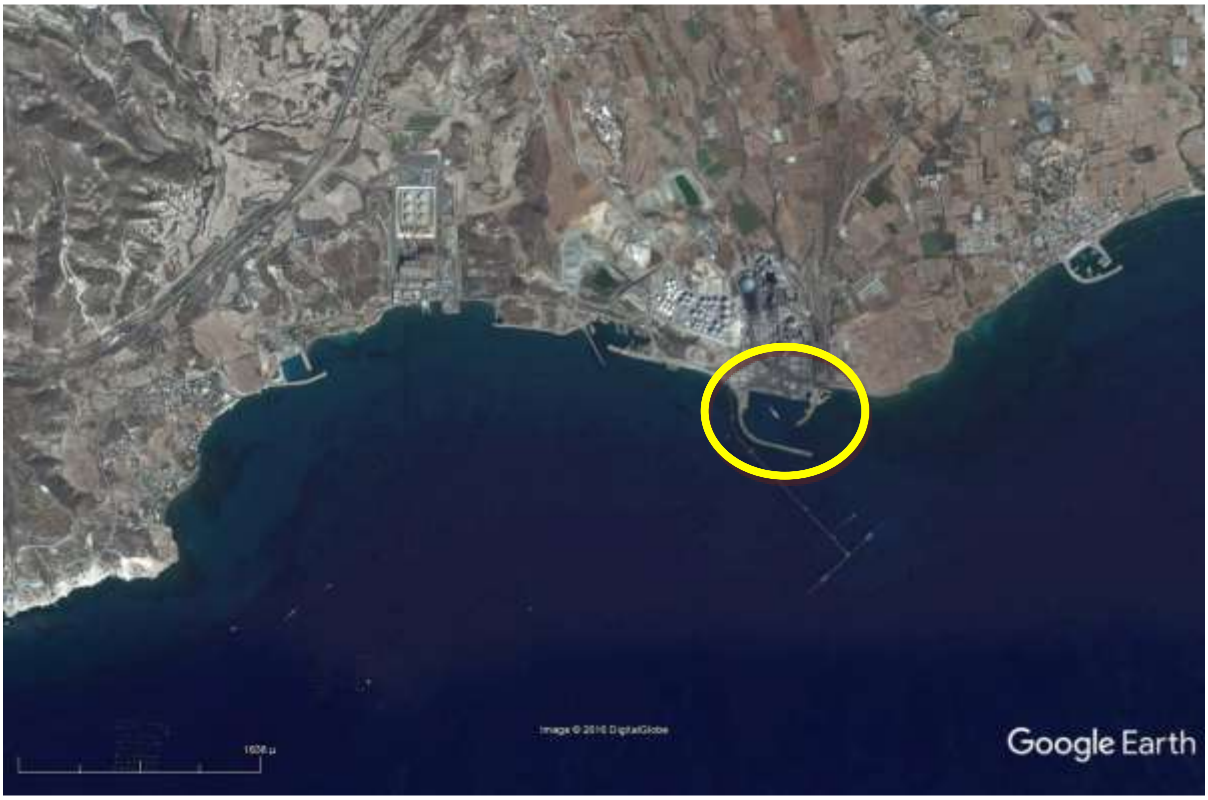


Figure 3.1. Location of Vassilikos Port (indicated with yellow circle).

The port is protected by two breakwaters, the southern (windward) and the eastern (leeside). The port entrance is orientated eastwards (see Figure 3.2). There are two main quays, the northern of 360m length and the western of 125m. It has a turning circle of 280m diameter, and the water depth is about 9m.

The main activity within the port of Vassilikos is the import and export of cement and bulk aggregate cargoes. Vassilikos Cement Works has primary operating rights within the port and has a fixed loading elevator structure on the main quayside within the port. In year 2014 Vassilikos Port handled about 244 ships and 1.630.000 tons of dry bulk cargo were imported/exported (Cyprus Ports Authority data).
The port has a roll on/roll off (Ro/Ro) ramp located at the extreme western end of the quayside and can be used by vessels fitted with a stern door ramp berthed at the west berth.

Fuel oil (e.g. Jet fuel) is imported over the west berth in Vassilikos Port in small vessels.

Figure 3.2. Existing Port Infrastructure of Vassiliko.

3.2. FUTURE EXPANSION

The Cyprus Ports Authority (CPA) appointed the joint venture of Rogan & Associates S.A. and Dion. Toumazis & Associates as consultants for the preparation of the Environmental Impact Assessment Study (EIA) for the expansion of Limassol Port Terminal 2 (Vassilikos).

The main works are:

- Extension of the existing main breakwater by approximately 720m
- Construction of a new leeside breakwater
- Deepening of the sea bed so that the water depth in the new basin and the approach channel is 15m below Chart Datum (CD)

4. METHODOLOGY OF WAVE STUDY

The methodology employed in the current study is based on the following four distinct stages:

- The first stage involves the collection and evaluation of available data aiming to identify meteorological, marine, and geomorphological conditions in the study area. Specifically, the following are identified and assessed:
  - Bathymetry of the study area
  - Open-sea wave climate from the European Copernicus Marine Service database

- In the second stage, a computational framework representing the geomorphology of the area of interest is created. Utilizing the wave characteristics in the deep waters obtained from the previous stage, numerical simulations are conducted using an appropriate high-precision nonlinear wave model to simulate wave penetration and disturbance for the existing condition (Do Nothing Scenario).

- In the third stage, a new set of simulations is developed in alignment with the second stage. This includes the incorporation of new port structures and coastal interventions of the proposed arrangement (Arrangements: W1, W2).

- Finally, in the fourth stage, a comparison between the results of the third and fourth stages (Arrangements DN and W1, W2) is conducted to evaluate the impact of the new projects on the port basin of the Port of Vasilikos. The aim is to select the optimal alternative solution for redevelopment projects.

It's worth noting, as previously mentioned, that the numerical simulations of wave disturbance are conducted using the advanced high-precision numerical model Maris HMS developed by Scientia Maris. This model can simulate the propagation of complex nonlinear waves by emulating the entirety of natural phenomena occurring within and around the port.

The above methodology of this wave study is summarized in the flowchart depicted in Figure 4.1.

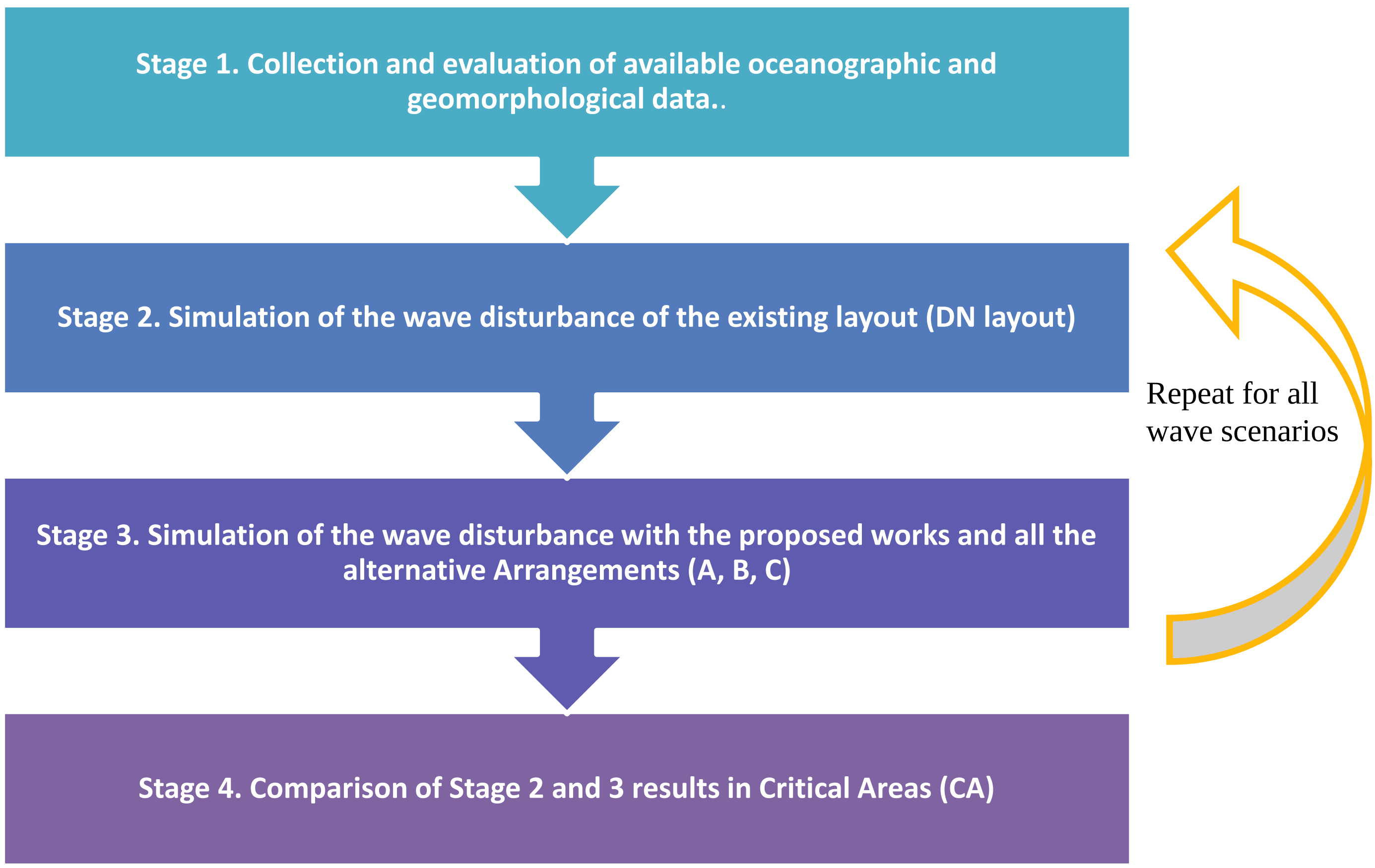


Figure 4.1 Methodology of wave Study

5. WAVE CLIMATE

5.1. WAVE CONDITIONS IN THE OPEN SEA OF THE STUDY AREA

Taking into account the orientation of the Port of Vasilikos, the waves that affect the new installation have the following incident directions:

- Southwest
- South
- Southeast
- East

To determine the wave characteristics of the study area, available wave data from the study 'Coastal Zone Management for Cyprus: Nearshore Wave Climate Analysis by Xenia Loizidou and John Dekker (Delft Hydraulics), March 1994' were utilized. The table below presents the annual probabilities of wave occurrence for specific wave height ranges and specific directions at the depth contour of -20m."

Table 5-1 Annual probabilities of wave occurrence for specific wave height ranges and specific directions at the isobath of -20m (Delft Hydraulics).

Observed Wave Height (m)	Wave Direction (deg.N)												
	-15.: 15.	15.: 45.	45.: 75.	75.: 105.	105.: 135.	135.: 165.	165.: 195.	195.: 225.	225.: 255.	255.: 285.	285.: 315.	315.: 345.	Total
< .25	3.19	2.30	2.97	2.78	.88	.60	1.11	2.09	9.65	8.30	6.78	5.99	46.65
.25: .75	.29	.51	2.25	3.75	1.08	1.05	1.00	3.49	15.03	5.97	2.32	.58	37.32
.75: 1.25	.	.	.18	1.86	.61	.69	.76	1.95	5.15	.28	.06	.	11.54
1.25: 1.75	.	.	.02	.48	.27	.21	.12	.80	1.13	.	.	.	3.03
1.75: 2.25	.	.	.	.17	.10	.03	.11	.31	.27	.	.	.	.99
2.25: 2.75	.	.	.	.04	.03	.04	.03	.15	.06	.	.	.	.36
2.75: 3.25	.	.	.	.01	.	.	.01	.04	.01	.	.	.	.08
3.25: 3.75	.	.	.	.	.	.	.01	.	.	.	.	.	.02
3.75: 4.25	.	.	.	.	.	.	.	.01	.	.	.	.	.01
4.25: 4.75	.	.	.	.	.	.	.	.01	.	.	.	.	.01
4.75: 5.75	.	.	.	.	.	.	.	.01	.	.	.	.	.01
5.75: 6.75	.	.	.	.	.	.	.	.	.	.	.	.	.
6.75: 7.75	.	.	.	.	.	.	.	.	.	.	.	.	.
7.75: 8.75	.	.	.	.	.	.	.	.	.	.	.	.	.
8.75: 9.75	.	.	.	.	.	.	.	.	.	.	.	.	.
9.75:10.75	.	.	.	.	.	.	.	.	.	.	.	.	.
10.75:12.75	.	.	.	.	.	.	.	.	.	.	.	.	.
12.75:14.75	.	.	.	.	.	.	.	.	.	.	.	.	.
> 14.75	.	.	.	.	.	.	.	.	.	.	.	.	.
Total	3.48	2.81	5.41	9.09	2.96	2.62	3.16	8.87	31.32	14.56	9.16	6.58	100.00

5.2. WAVE INPUT DATA INTO THE NUMERICAL MODEL

Taking into consideration the aforementioned data and the directions that can cause disturbance within the port, Table 5-2 presents the wave characteristics provided as input data into the numerical simulation model. It is noted that a conservative approach is applied in selecting wave heights. From the ranges of wave heights categorized, the upper limit is chosen each time (e.g., from the range 4.75-5.75, a wave height of 5.75m is selected for simulation) For the SSW waves, which have the highest wave heights and the highest frequency of occurrence, a wave condition with wave height, Hs = 2.75m period Tp = 6.63sec, was additionally examined in order to test the wave conditions both at the dry bulk's berthing position, during moderate wave phenomena.

Table 5-2 Wave input data into the numerical model

	Hs (m)	Tp (sec)	Dir (°)
1	3.25	7.21	90
2	2.75	6.63	135
3	3.75	7.74	180
4	5.75	9.59	210
5	2.75	6.63	210
6	3.25	7.21	240

6. METHODOLOGY APPLIED AND SCIENTIFIC BACKGROUND OF NUMERICAL MODELS

The mathematical background of the advanced wave model Maris HMS by Scientia Maris is used in this wave disturbance study. This model has been published and presented in numerous publications in international scientific journals and proceedings of international conferences, and has been applied in a multitude of approved studies concerning wave and coastal engineering

6.1. SIMULATION PHENOMENA AND APPLICATION AREAS

In this study, the mathematical wave propagation model, Maris HMS (nonlinear Hyperbolic Mild-Slope), developed by Scientia Maris, is used. It represents an advanced nonlinear model of mild-slope equations that simulate the spatiotemporal propagation of complex waves in coastal areas and harbors. It accurately simulates all the intricate phenomena occurring in a coastal domain, including:

- Propagation of complex nonlinear waves
- Shoaling
- Diffraction
- Refraction
- Partial or total reflection
- Energy dissipation due to bottom friction and breaking

This model serves as a valuable tool for conducting wave disturbance studies in enclosed marine areas (such as bays, harbors) and simulating phenomena like resonance and seiching within a port. Furthermore, it can be applied in coastal zones where wave reflection significantly impacts coastal engineering studies. The variables computed by this model include wave height, period, direction, as well as the elevation of the free water surface and radiation stresses.

6.2. BASIC MODEL FUNCTIONS

This mathematical model is based on mild-slope equations initially formulated by Booij (1972) and later expanded by Booij (1981) by adding energy diffusion terms. Further development was achieved by Massel (1993) and Suh et al. (1997) to incorporate the effects of sudden changes in the seabed. These mild-slope equations are elliptic partial differential equations with complex variables. Solving them requires significant computational time, especially for large coastal areas. Therefore, various approximate methodologies have been proposed for their solution.

This specific model is based on mild-slope equations, hyperbolic form (Copeland, 1985; Karambas et al., 2010, 2013). The equations are written as follows:

$$\zeta_t + \frac{c}{c_g}\nabla\frac{c_g}{c}\boldsymbol{Q_w} = 0$$

$$\boldsymbol{U_{w,t}} + \frac{c^2}{d}\nabla\zeta = v_h\nabla^2\boldsymbol{U_w}$$

Here, ζ represents the free surface elevation due to waves, $\mathbf{Q_w} = \mathbf{U_w}h_w = (Q_w, P_w)$, $h_w = d + \zeta$ (where d is the water depth), $\mathbf{U_w} \equiv (U_\mathrm{w}, V_\mathrm{w})$, U_w and V_w are the depth-averaged horizontal velocities, c is the wave celerity, $c_g$is the group celerity, and v_h is the turbulent eddy viscosity coefficient that incorporates energy diffusion due to breaking and partial or total reflection.

The energy loss due to wave breaking at the shore or over breakwaters is introduced into the model through the simulation of Reynolds stresses, with the turbulent eddy viscosity coefficient v_h in the right-hand side of the momentum equations. The turbulent eddy viscosity coefficient v_h is calculated as follows (Battjes, 1975):

$$v_h = 2h\left(\frac{D}{\rho}\right)^{1/3}$$

Where D is the energy loss due to the breaking of random waves.

$$D = \frac{1}{4}Q_b f_s \rho g H_m^2$$

where f_s is the mean spectral frequency, H_m is the maximum possible wave height (=γ·h, with γ a constant, γ≈0.6), and Q_b is a coefficient related to the probability of wave breaking. Following the assumption of Rayleigh distribution, the coefficient Q_b is given by the solution of the following equation:

$$\frac{1 - Q_b}{\ln Q_b} = \left(\frac{H_{rms}}{H_m}\right)^2$$

Where *Hrms* is the root mean square wave height (calculated in the program as H_{rms}=2(<2ζ2>)1/2 , where the brackets ⟨⟩ denote the mean temporal value).
It is evident that the maximum value of *Qb* is unity (all waves are breaking), and when H_{rms}<<H_m, τότε Q_b<<1 (non-breaking waves). The above equation for the loss *D* can describe the loss of random wave energy in any complex bathymetry, including the elongated bars of the breaker zone (longshore bars).

The loss of energy due to bottom friction is simulated by linear terms on the right-hand side of the momentum equations. The linear friction coefficient *fb* is related to the wave friction coefficient *fw* by the equation:

$$f_b\sigma = \frac{\frac{1}{2} f_w \sqrt{U_w^2 + V_w^2}}{d}$$

In the above equations, phase velocity, group velocity, and wave number are variables directly dependent on the selected dispersion relationship. Widely used internationally, mild-slope mathematical models adopt a linear dispersion relationship, even in intermediate and deep waters, significantly compromising result accuracy due to nonlinearity impacting wave characteristics, especially wave height, which is crucial for applications.

Conversely, the advanced Maris HMS model (Chondros et al., 2021; 2019, Metallinos et al., 2019) outperforms comparable models circulating globally, offering more precise outcomes. This is achieved by embracing the philosophy of an innovative methodology proposed by Chondros and Memos (2014) for computing parameters k and C appearing in fundamental equations. This methodology resolves higher-order spatiotemporal nonlinear Stokes 2nd and 5th order theories, Cnoidal, and Solitary.

Specifically, to account for the propagation of nonlinear waves, the Maris HMS model follows an analytical approach to compute dispersion relationships, thus incorporating nonlinearity at any water depth. Initially, the Ursell parameter is calculated: Ur=(HL^2)∕h^3 (where H is wave height, and L is wave length), and the parameter expressing frequency dispersion, s=H/L, in each cell of the computational domain. Subsequently, considering these parameters and the applicable domains of various wave propagation theories proposed by Hedges (1995), nonlinear dispersion is computed in relation to Stokes 2nd or 5th order waves, Cnoidal theory, or solitary wave theory as follows:

Areas of wave propagation theory application.			**Dispersion relationship**
$s < 0.04$	$Ur < 40$	Stokes 1st	$\omega^2 = gk\tanh(kh)$
$s > 0.04$	$Ur < 40$	Stokes higher	$\omega^2 = gk(1+\varepsilon^2 D)\tanh(kh)$
$s > 0.00$	$40 < Ur < 4000$	Cnoidal	$\omega^2 = gk^2 h\left(1 + H/mh(2 - m - 3E/K)\right)$, where K, E are the complete elliptic functions of the first and second kind, respectively. The parameter m is the modulus of the elliptic functions.

			Alternatively, the modified Cnoidal equation is used herein: $\omega^2 = gk^2\mathrm{h}(1+f(m)H/h)$, Bell et al. (2004) assumed a value of 0.4 for $f(m)$
s > 0.00	Ur > 4000	Solitary	$\omega^2 = gk^2h(1+H/h)$

The radiation stresses are calculated using the following relationships (Copeland 1985):

$$\frac{S_{xx}}{\rho} = h^2 < U_w^2 > A_r - h^2 < \left(\frac{\partial U_w}{\partial x} + \frac{\partial V_w}{\partial y}\right)^2 > B_r + \frac{\partial}{\partial x} < \left[U_w\left(\frac{\partial U_w}{\partial x} + \frac{\partial V_w}{\partial y}\right)\right] > D_r + h^2\frac{\partial}{\partial y} < \left[V_w\left(\frac{\partial U_w}{\partial x} + \frac{\partial V_w}{\partial y}\right)\right] > D_r + \frac{1}{2}g < \zeta^2 >$$

$$\frac{S_{yy}}{\rho} = h^2 < V_w^2 > A_r - h^2 < \left(\frac{\partial U_w}{\partial x} + \frac{\partial V_w}{\partial y}\right)^2 > B_r + \frac{\partial}{\partial y} < \left[V_w\left(\frac{\partial U_w}{\partial x} + \frac{\partial V_w}{\partial y}\right)\right] > D_r + h^2\frac{\partial}{\partial x} < \left[U_w\left(\frac{\partial U_w}{\partial x} + \frac{\partial V_w}{\partial y}\right)\right] > D_r + \frac{1}{2}g < \zeta^2 >$$

$$\frac{S_{yy}}{\rho} = h^2 < U_w V_w > A_r$$

Where the symbols <> denote integration over the wave period and

$$A_r = \frac{k}{4sinh^2kd}(sinh2kd + 2kd)$$

$$B_r = \frac{1}{4ksinh^2kd}(sinh2kd - 2kd)$$

$$D_r = \frac{d}{4sinh^2kd}(\frac{1}{2kd}sinh2kd - cosh2kd)$$

It's worth noting that computing and incorporating nonlinear velocities in the above-mentioned manner make the model highly accurate without dramatically increasing the required computational load and time.

6.3. NUMERIC APPLICATION

The method used to solve the basic equations of the model is that of finite differences applied to a Cartesian grid with constant spatial and temporal steps that satisfy the Courant criterion. The algorithm solves the equations, initially assuming linear velocities until the entire numerical field stabilizes, meaning the wave height in each grid cell does not differ by more than 0.5% from the immediately preceding time step. Once the first stage of stabilization is achieved, velocities are recalculated, incorporating non-linearity, and the field is re-solved until stabilization is reached.

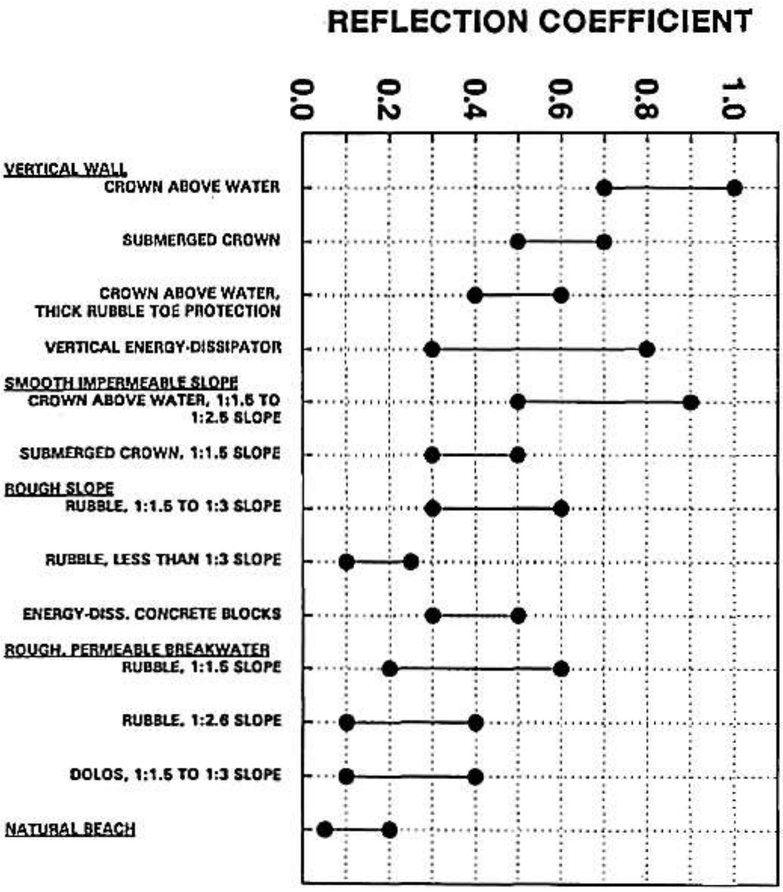
To generate wave disturbance within the study area, the method of internal generation is employed:

$$\zeta = 2\frac{H_o}{2}\cos(ky\sin\theta - \omega t)c\frac{\Delta t}{\Delta x}\cos\theta$$

At boundaries where total reflection is expected (e.g., vertical faces or seawalls), the condition is applied:

$$\frac{\partial\zeta}{\partial n} = 0$$

Finally, the Maris HMS model takes as input a two-dimensional file that specifies, near the solid boundaries of the study area, the turbulent eddy viscosity coefficient v_h simulating energy diffusion due to partial or total wave reflection. Proper estimation of the reflection coefficients **r** (defined as the ratio of incident to reflected waves $= H_i/H_r$)) and the corresponding eddy viscosity coefficients v_h in each segment of the solid boundary is crucial for the model's effectiveness. Typical coefficients for wave periods less than 20 s are provided in the following figure (Thompson et al., 1996).



6.4. REQUIRED INPUT DATA AND RESULTS

The required input data for the model to be applied are as follows:

- The bathymetry of the study area is provided as a two-dimensional numerical grid where each cell represents either a depth value or a dry cell.
- Selection of boundary conditions at the boundaries of the numerical field (damping).
- Determination of wave characteristics in the wave generator of the numerical field, height, period, and direction.
- Definition of coordinates for the starting and ending points of the wave generator.
- Simulation or not of seabed friction and bottom friction.
- Map of the spatial distribution of the turbulent diffusion coefficient and bottom friction.

The results of the mathematical model are provided in the form of two-dimensional files containing wave height at all points of the numerical grid.

7. NUMERICAL SIMULATION OF WAVE DISTURBANCE

EXISTING CONDITION

The following subsections present the results and corresponding commentary of the numerical simulations regarding wave penetration in the harbor basin of the Port of Vasiliko for the existing condition scenario (Arrangement DN).

7.1. INPUT DATA TO THE NUMERICAL MODEL: EXISTING CONDITION

7.1.1. BATHYMETRY

For the existing condition scenario, bathymetric data resulting from the bathymetric survey conducted within the scope of this project, along with open-source bathymetric databases (Navionics) for the broader study area, were utilized. Combining these sources, the bathymetric grid BATH_DN was generated.

The bathymetric grid inputted into the numerical simulation model covers an area of approximately 3.75 km x 6.2 km. A small spatial step (dx = dy = 2.5 m) was chosen to compute results with high precision.

7.1.2. DEFINING REFLECTION COEFFICIENTS

The MARIS HMS wave propagation simulation model utilizes, in addition to the bathymetric file, a second two-dimensional file specifying near the solid boundaries (4 grid cells) of the study area, the turbulent diffusion coefficients v_h, artificially simulating the energy diffusion of incident waves at the front. These coefficients are calculated from an initial set of simulations applying the model based on the wave period T, wave height H, and a constant depth d at the project site. Accurately estimating the reflection coefficients r (defined as the ratio of incident wave height to reflected $= H_i/H_r$) and the corresponding v_h coefficients at each segment of the solid boundary is crucial for the model's effectiveness.

In this study, the following reflection coefficients are considered for various types of solid boundaries, and the corresponding turbulent diffusion coefficients are estimated:

- Vertical walls - Quay walls, r = 1.0
- Natural Rock Armor, r = 0.5 - 0.60
- Vertical walls – Energy- Dissipator, r = 0.40

In the existing conditions of the port of Vasiliko natural rock armor exists in the windward and leeward breakwaters on the windward and leeward sides of them. Also the existing vertical quay walls have been designed in order to dissipate the energy of the incoming wave and decrease the wave height that may occur due to consecutive reflections.

7.1.3. WAVE INPUT DATA

The waves were simulated as selected in Chapter 5.2. The following table presents the wave characteristics provided as input data into the numerical simulation model.

Table 7-1 Wave input data into the numerical model

	Hs (m)	Tp (sec)	Dir (°)
1	3.25	7.21	90
2	2.75	6.63	135
3	3.75	7.74	180
4	5.75	9.59	210
5	2.75	6.63	210
6	3.25	7.21	240

8. INVESTIGATION OF EXISTING PORT BASIN'S WAVE DISTURBANCE

The first scenario investigated is the existing port layout, which is, without any extension of the windward breakwater. This case is the "**Do Nothing**" scenario (**DN** hereafter).

As mentioned in Chapter 2, the port is protected by two breakwaters, the southern (windward) and the eastern (leeside). The port entrance is orientated eastwards (see Figure 3.2). There are two main quays, the northern of 360m length and the western of 125m. It has a turning circle of 280m diameter, and the water depth is about 9m.

The **DN layout** is depicted in the following figure.

8.1. Numerical Simulation of Wave Penetration with Scientia Maris HMS Model

The wave disturbance inside the port basin is simulated by applying the **Scientia Maris HMS**. **HMS** is based on an efficient numerical solution of the so-called "mild-slope" wave equation, which governs the motion of time harmonic water waves of infinitesimal height (linear waves) on a gently sloping bathymetry with arbitrary water depth.

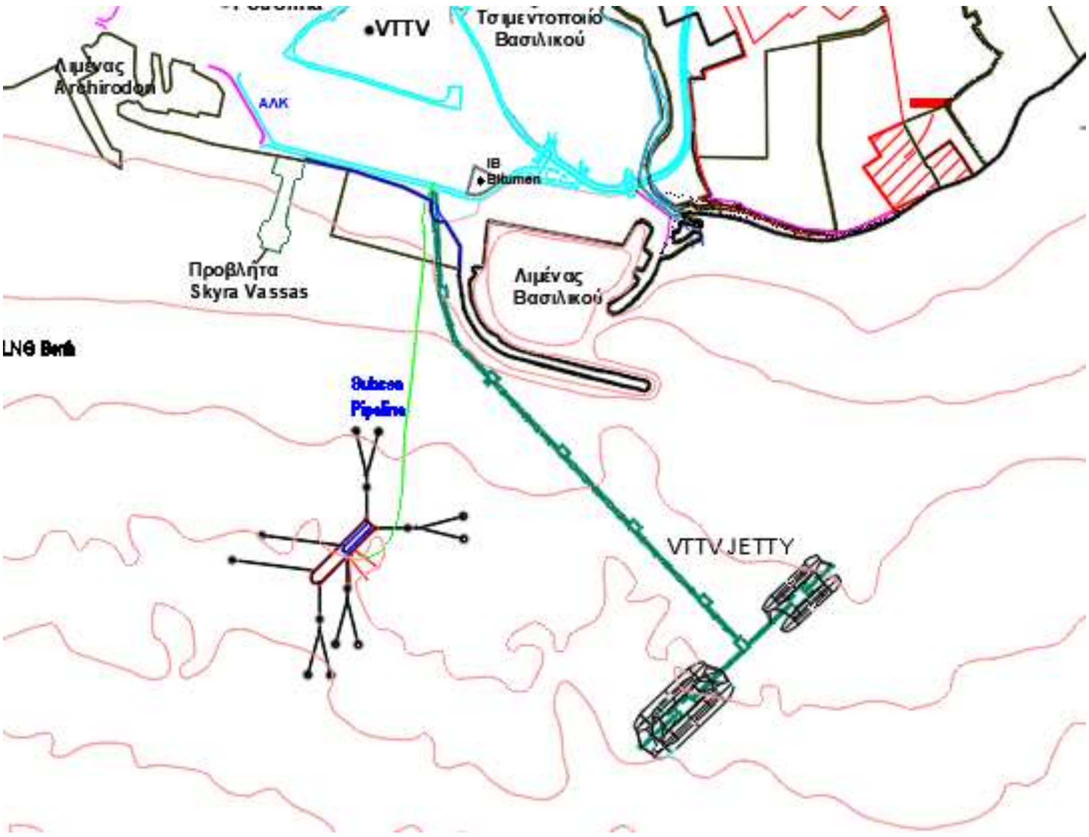


Figure 8.1. Layout of alternative DN.

8.2. Input Data

Under the framework of the present study, the consultants were provided with topographic and bathymetric surveys in the area of Vassilikos, both by the Cyprus Ports Authority and by the Department of Lands and Surveys. The two sets of data were in close agreement, and the ones provided by CPA were the governing ones.

The specific data are used for construction of numerical grids representing the sea bottom inside the port basin and in the vicinity of the port. The following bathymetric grid was constructed, **BATH_DN,** (see Appendix) covering an area of approximately 6.2km x 3.75 km, with equal spatial steps dx = dy=2.5 m in two horizontal axes x- and y-.

The breakwaters and revetments were assumed to have 0.6 reflection coefficient. while the rocky shorelines were set to have reflection coefficient equal to 0.6. Sponge layers were used at the offshore boundaries to absorb waves traveling outside the model domain. Because the model's offshore boundaries were closed, using the sponge layers allowed the model to dissipate waves which would travel away from the model domain without letting them to reflect from the boundaries. The sponge layer is a numerical analog to wave absorber in wave tank.

8.3. Results of Numerical Simulations for DN Layout

Drawings (**WV_DN_1** up to **WV_DN_6**, see **Appendix**) for each incoming wave case and for each alternative were created, depicting the wave height distribution all over the examined area. Drawings **WV_DN_1** illustrate the wave propagation and port penetration from E inside the port basin for waves propagating from SE **WV_DN_2** illustrates the wave propagation. Drawings **WV_DN_3** represents the wave from the South its propagation and port penetration, drawings **WV_DN_4,5** presents in the same manner the SSW wave. Finally, the drawings **WV_DN_6** illustrate the wave field for incoming waves with WSW direction.

General observations and comments on the results:

- A partial reflection of incoming waves is taking place on the windward breakwater.
- There is wave penetration into the port basin especially for waves coming from S, E, SSW and SE directions.
- The eastern side of the proposed dry bulk pier is exposed to S, SSE and ESE incident waves.
- For waves travelling from WSW, the poRt basin is well protected. Consequently, further simulations for all the examined alternatives, will not be executed for this direction.
- As waves approach the shoreline, the wave heights are decreasing due to depth induced wave breaking heights. The mean wave direction tend to be vertical to the shoreline due to diffraction effects.

The basic conclusion arising from the investigation on the **DN alternative** (current situation, without any extension of the windward breakwater) has as follows:

Taking into consideration the numerical results, the east side of the proposed pier (i.e. the quay wall at -13m) will be exposed to wave disturbance, preventing the port operations for 18.67% of the year (or 1 in 5 days). Therefore the extension of the breakwater is of crucial importance.

9. ALTERNATIVE LAYOUTS OF THE OUTER WORKS

Apart from the **DN** scenario, two (2) alternative layouts of the outer works, i.e. the extension of the windward breakwater, and the construction of a new leeside breakwater, are investigated with numerical simulations, namely A and B.

It has to be mentioned that each alternative will include the following proposed works:

- Dredging of an area close to 300.000 sq.m. to -15m CD in order to create the required navigational depths for the maximum LNGC vessel that may visit the area ships. This area includes the approach channel and the maneuvering area inside the port basin. The dredging area outside the port (navigational channel) may be slightly different for each layout according to the design of the port entrance.
- Demolition of the leeside breakwater and construction of a new dry bulk cargo pier with an approximate length of 230m and width of 125m.

However, the major changes between the alternative scenarios (options) correspond to the length and shape of the windward and leeside breakwaters. The following options (Table 2) are considered in the present study, and the drawings are given in the following figures:

Table 2. Length of windward and leeside breakwaters extension for each option.

Alternative	Length of windward breakwater extension (m)	Length of leeside breakwater extension (m)
DN	-	-
A	1155	275
B	1240	275

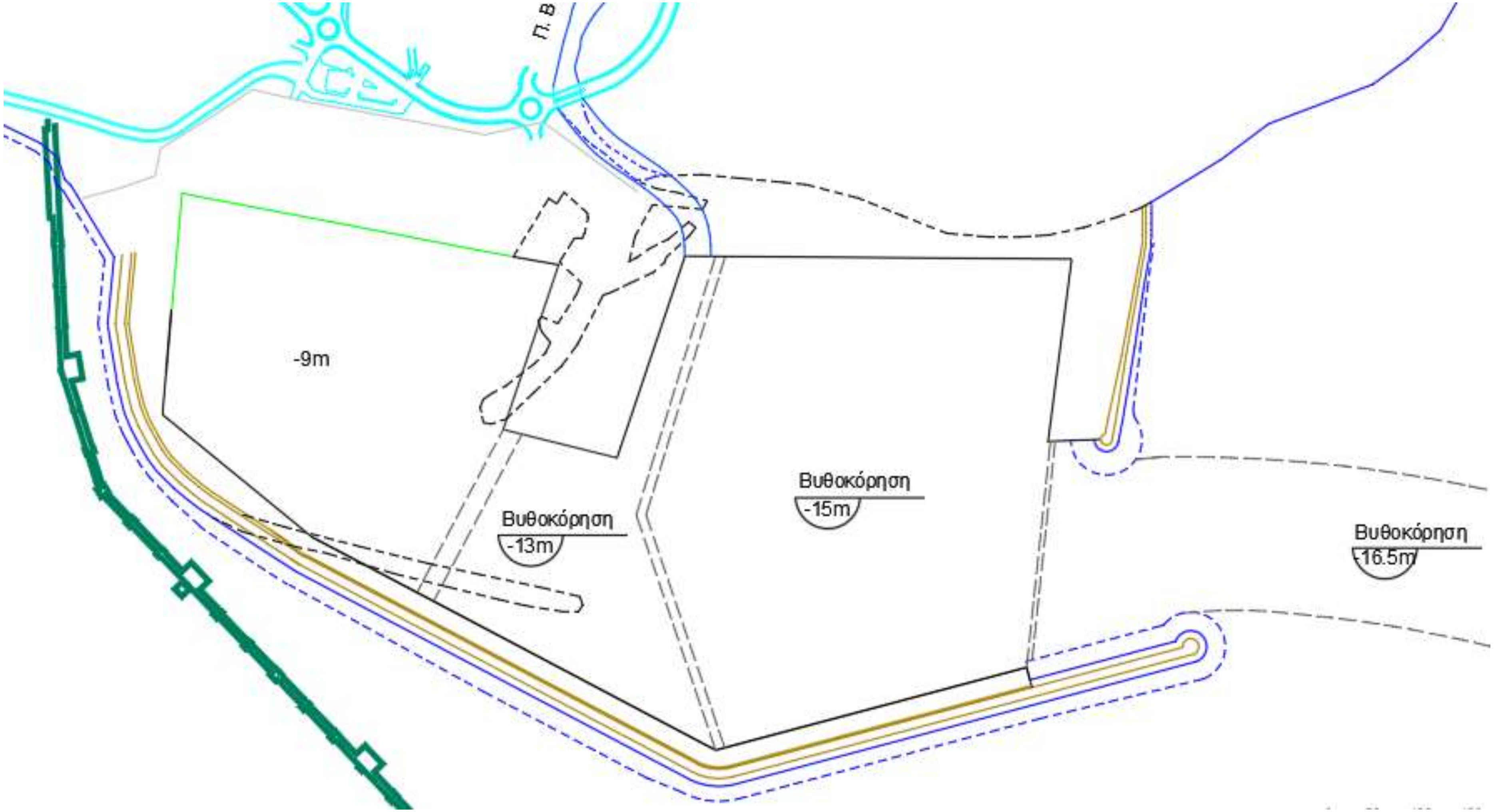


Figure 9.1. Layout of alternative A

Figure 9.2. Layout of alternative B.

10.NUMERICAL SIMULATION OF ALTERNATIVE LAYOUTS

In the following paragraphs the summarized results of the numerical simulations are shown, in terms of idle times (% per year) of the Port as determined for inspection area 1. It is noted that this area is critical for port operations (dry bulk loading / unloading), whereas for inspection area 2, the acceptable wave height limit is higher (1.5m) thus not critical for the selection of the optimal outer works layout

10.1. Alternative A

Drawings (**WV_A_1** up to **WV_A_6,** see **Appendix**) for each incoming wave case and for each alternative were created, depicting the wave height distribution all over the examined area. Drawings **WV_A_1** illustrate the wave propagation and port penetration from E inside the port basin for waves propagating from SE **WV_A_2** illustrates the wave propagation. Drawings **WV_A_3** represents the wave from the South its propagation and port penetration, drawings **WV_A_4** presents in the same manner the SSW wave. Finally, the drawings **WV_A_5** illustrate the wave field for incoming waves with WSW direction.

10.2. Alternative B

Drawings (**WV_B_1** up to **WV_B_6**, see **Appendix**) for each incoming wave case and for each alternative were created, depicting the wave height distribution all over the examined area. Drawings **WV_B_1** illustrate the wave propagation and port penetration from E inside the port basin for waves propagating from SE **WV_B_2** illustrates the wave propagation. Drawings **WV_B_3** represents the wave from the South its propagation and port penetration, drawings **WV_B_4,5** presents in the same manner the SSW wave. Finally, the drawings **WV_B_6** illustrate the wave field for incoming waves with WSW direction.

10.3. Alternative C

As for alternative C there is no major change corresponding to the first alternative A. The changes tha happen in the Alternative C focus on the energy dissipation quaywalls, instead of fully reflective , at the corner of the quawall inside of the windward breakwater as well as in the east and the south view of the new pier built in the port basin as shown in the following figure.

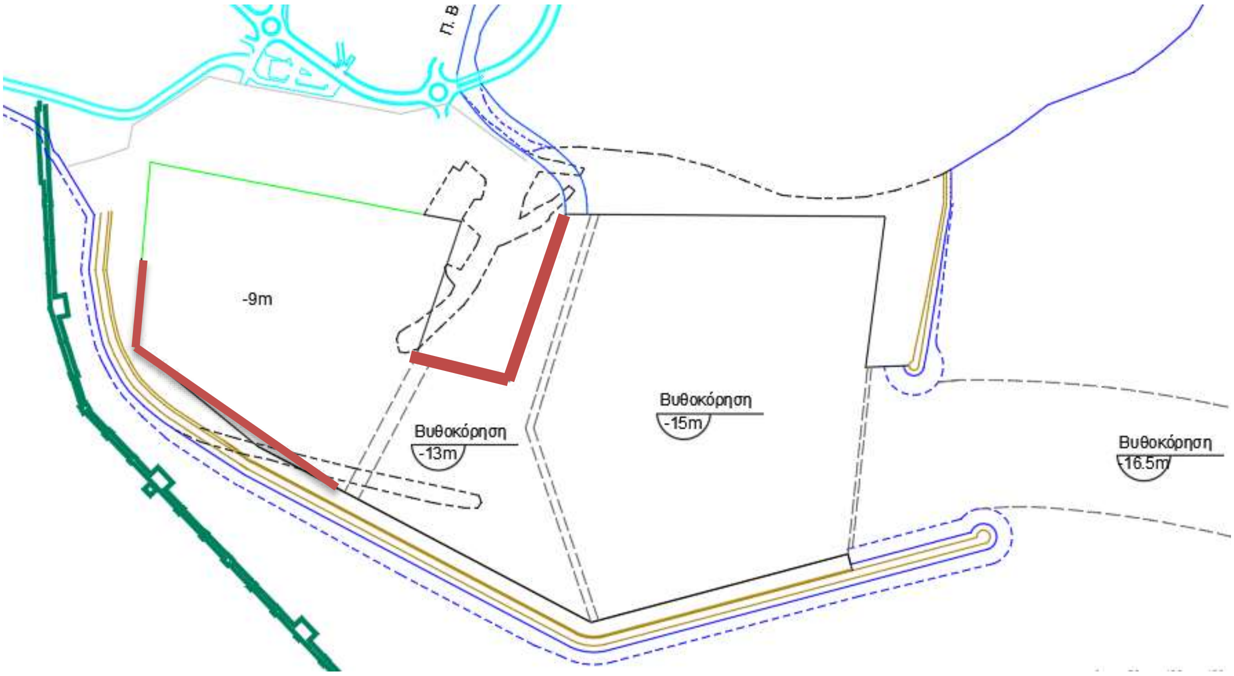


Figure 10.1 Alternative C with energy dissipation Quaywalls

Drawings (**WV_C_1** up to **WV_C_6**, see **Appendix**) for each incoming wave case and for each alternative were created, depicting the wave height distribution all over the examined area. Drawings **WV_C_1** illustrate the wave propagation and port penetration from E inside the port basin for waves propagating from SE **WV_C_2** illustrates the wave propagation. Drawings **WV_C_3** represents the wave from the South its propagation and port penetration, drawings **WV_C_4,5** presents in the same manner the SSW wave. Finally, the drawings **WV_C_6** illustrate the wave field for incoming waves with WSW direction.

10.4. Comments on the Results

As it is obvious from the above results, there is wave penetration into the port basin for waves coming from E and SE directions, for all the examined alternatives. These propagating waves reflect on the eastern side of the proposed dry bulk pier and create wave disturbance inside the basin.

Hence, a solution based on less reflective structures would be advantageous. Non-conventional vertical structures, i.e. absorbing quay walls can represent an alternative, by absorbing incoming wave energy. Examples of such structrures include but are not limited to quays with MONOBAR blocks, quays with perforated caisson (Jarlan) etc.
In order to highlight the advantageous performance of such absorbing quays, further numerical simulations have been carried out in the alternative C, where the eastern side of the dry bulk pier has been simulated as an absorbing quaywall (assuming a reflection coefficient equal to 0.4, instead of 1.0 indicating a total reflection).

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A comparison of the results incorporating abosorbing quay walls with that incorporate totally reflective quay walls, illustrate the reduction of the wave disturbance inside the port basin. Therefore, the present study highlights the use of such quays at the eastern side of the dry bulk pier and the west side of the the quay of the windward breakwater in the basin of the -13meters.

11. CONCLUSIONS – SELECTION OF OPTIMUM ALTERNATIVE

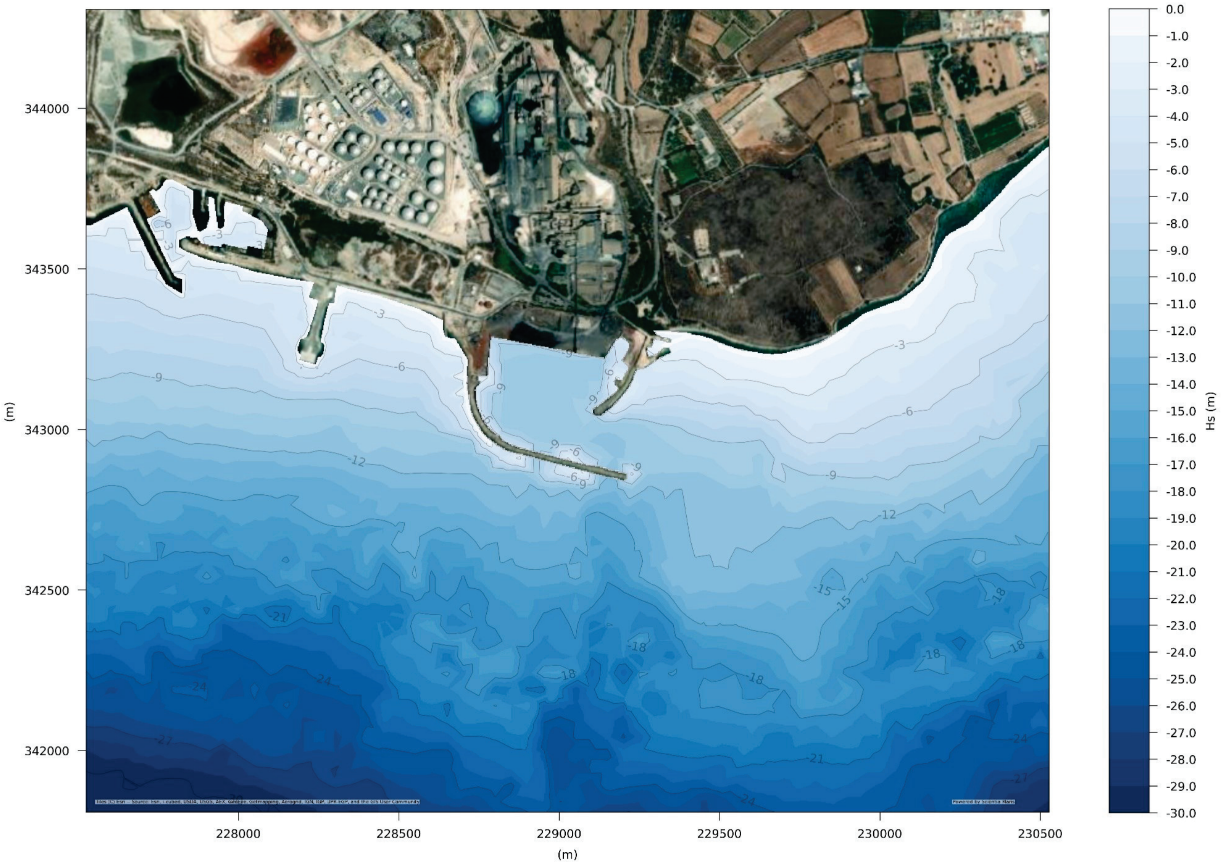
The basic conclusion arising from the investigation on the **DN** alternative (current situation, without any extension of the windward breakwater) has as follows:

- Taking into consideration the numerical results, the east side of the proposed pier will be exposed to wave disturbance, preventing the port operations for 18.67% of the year (or 1 in 5 days). Therefore, the extension of the breakwater is of crucial importance.
- Wave heights decrease towards the shallows once they reach the shoreline east of the harbour due to the breaking effect. The mean direction of wave propagation (shown by arrows) tends to become perpendicular to the shoreline as we move towards the shallows, due to the refraction effect
- For extreme West-South-West incoming waves, the existing infrastructure is not sufficient to provide wave tranuility in the port basin

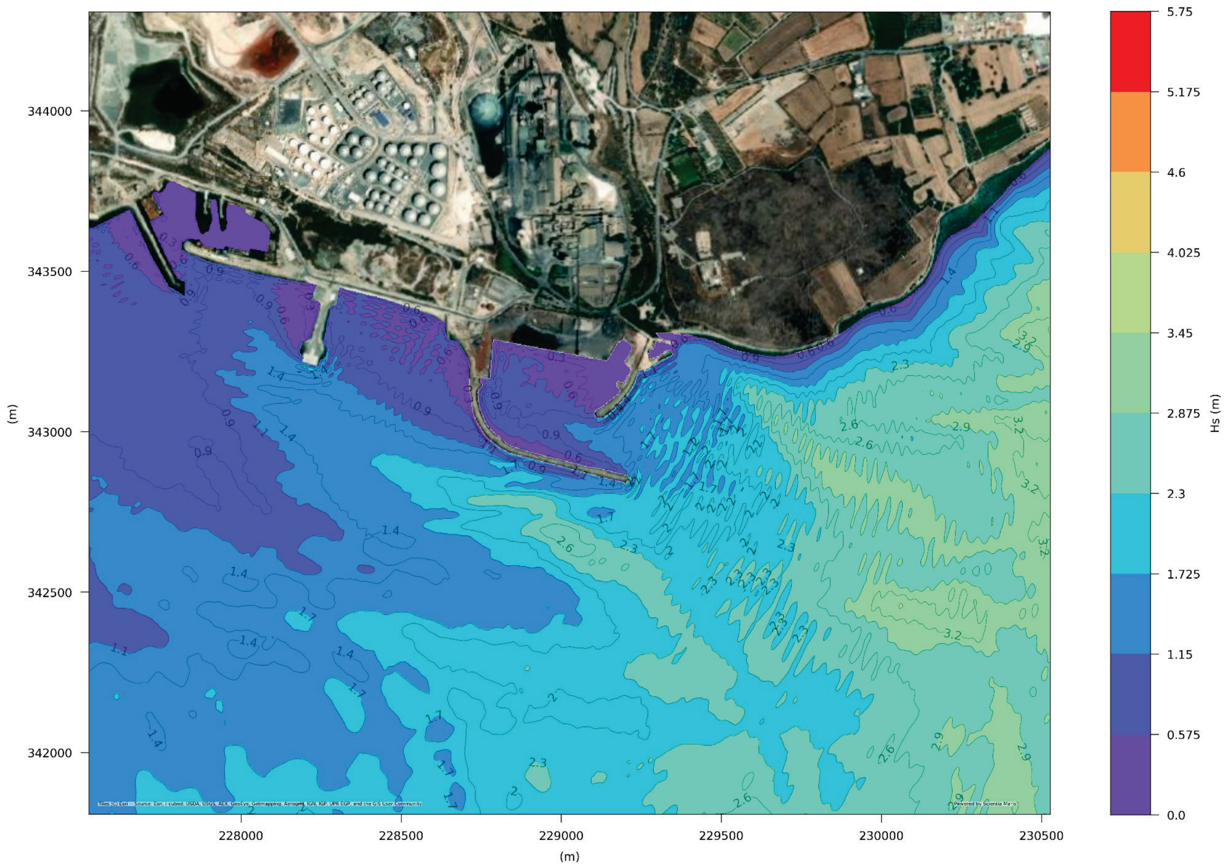
The basic conclusions that can be drawn from the investigation of the three alternative scenarios (A, B, and C) are summarized as follows:

- There is wave propagation on the eastern shelf mainly for East-South-East, South-South-East, South and South-South-West waves. The eastern vertical front of the proposed pier is exposed to the above incoming waves.
- Regardless extension length of breakwater, waves incoming from ESE directions will prevent the operations of the eastern berth for an annual rate of 1.73%. These propagating waves reflect on the eastern side of the proposed dry bulk pier and create wave disturbance inside the basin. A comparison of the results incorporating abosorbing quay walls with the respective that incorporate totally reflective quay walls, illustrate the reduction of the wave disturbance inside the port basin. Therefore, the present study highlights the use of such quays at the eastern side of the dry bulk pier.
- Option C does not provide any additional improvement in the operational time of the port compared to option B despite the fact that there is a reduction in wave height inside the port basin.
- Options A and B provide similar results regarding the down time of the harbor operations. However, option B provides safer approach in extreme weather conditions.
- **According to the wave disturbance results, Alternative B' is selected as it provides the minimum wave disturbance in the Port's basin and quaywalls and the possibility of an all-weather operation for all vessels.**

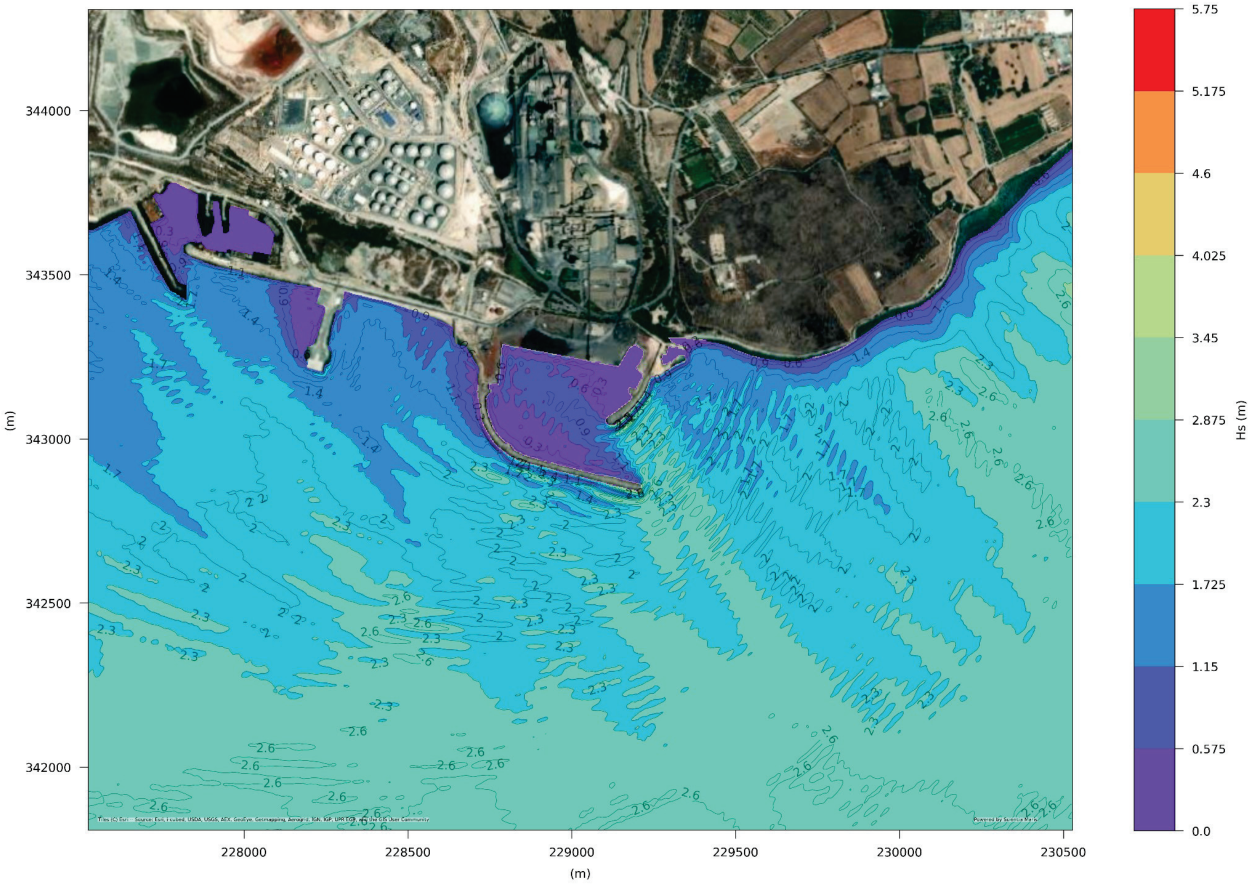
APPENDIX:



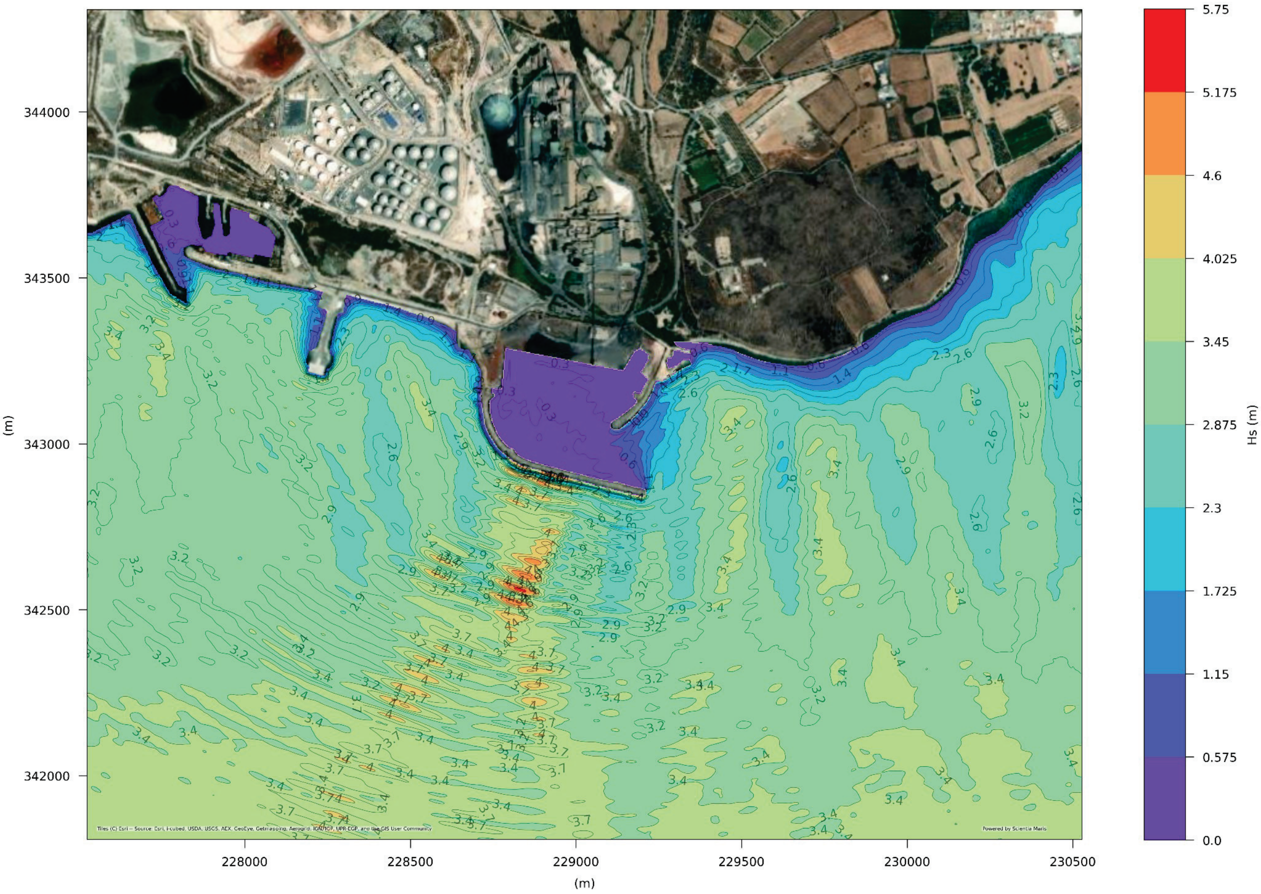
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **BATH_DN**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: GRID OF EQUAL SPATIAL STEPS DX=DY=2.5M REPRESENTING BATHYMETRY OF **DN ALTERNATIVE** DO NOTHING ALTERNATIVE (CURRENT SITUATION)	**FIGURE TITLE:** BATHYMETRY
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



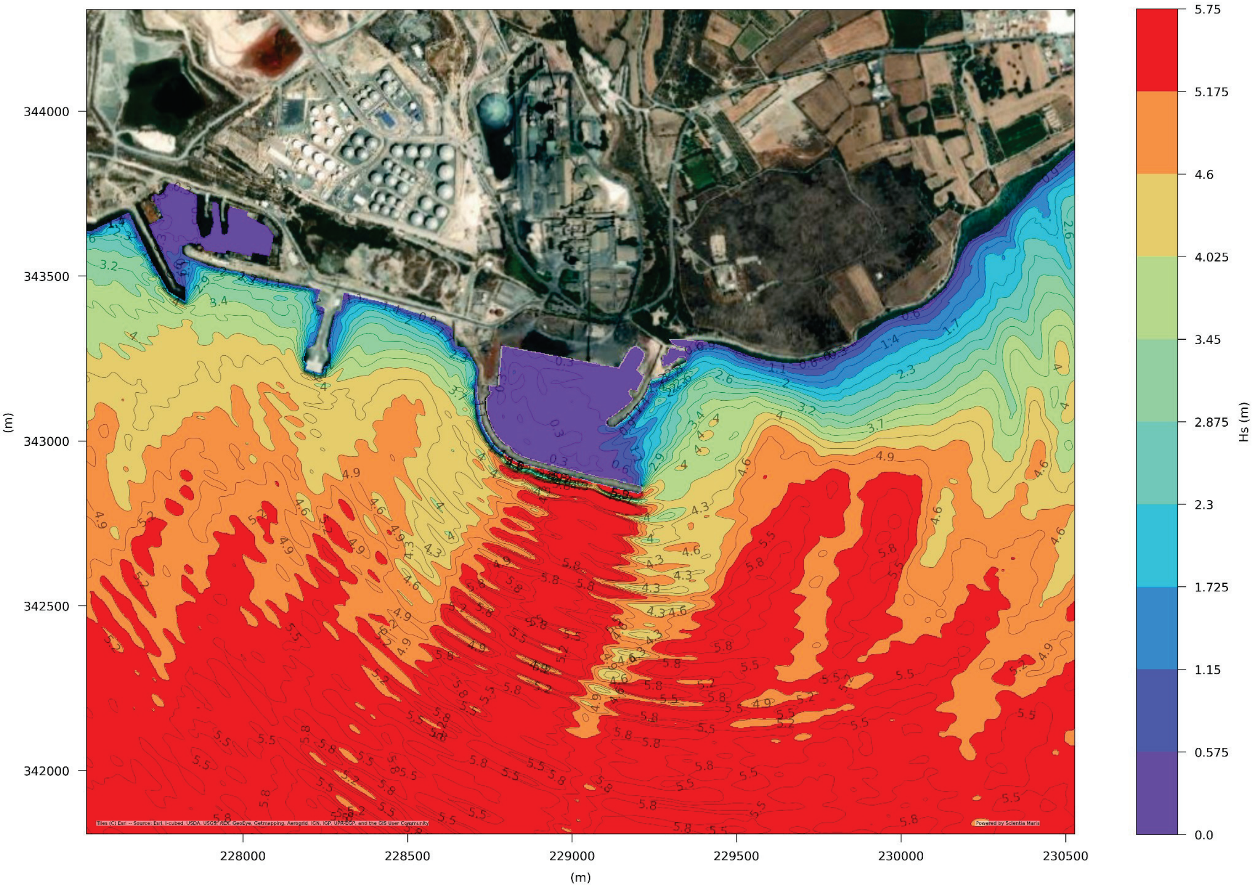
CONSULTANT:	PROJECT TITLE:	FIGURE NUMBER:
ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**WV_DN_1**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=3,25 m, Tp=7,21 sec, θ°= 90 DEGREES** DO NOTHING ALTERNATIVE (CURRENT SITUATION)	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



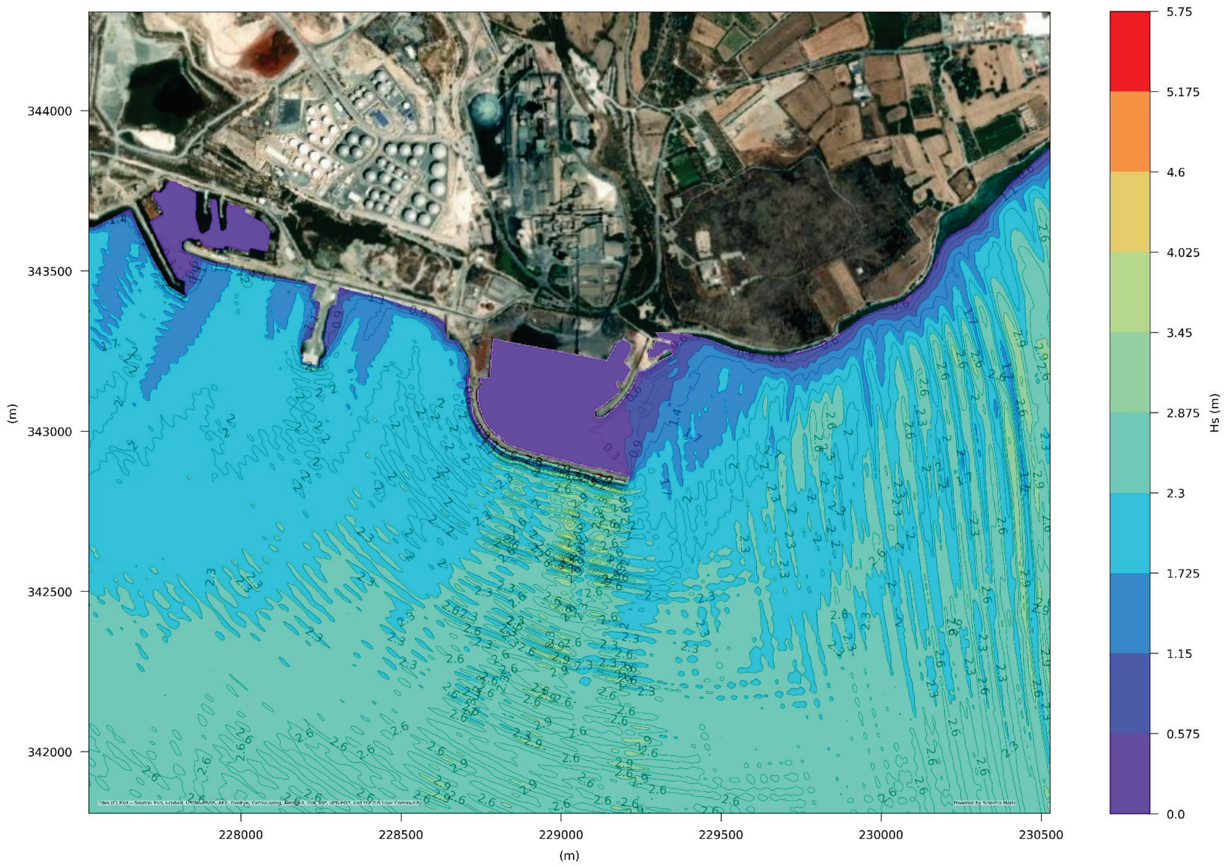
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_DN_2**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=2,75 m, Tp=6,63 sec, θ°= 135 DEGREES** DO NOTHING ALTERNATIVE (CURRENT SITUATION)	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



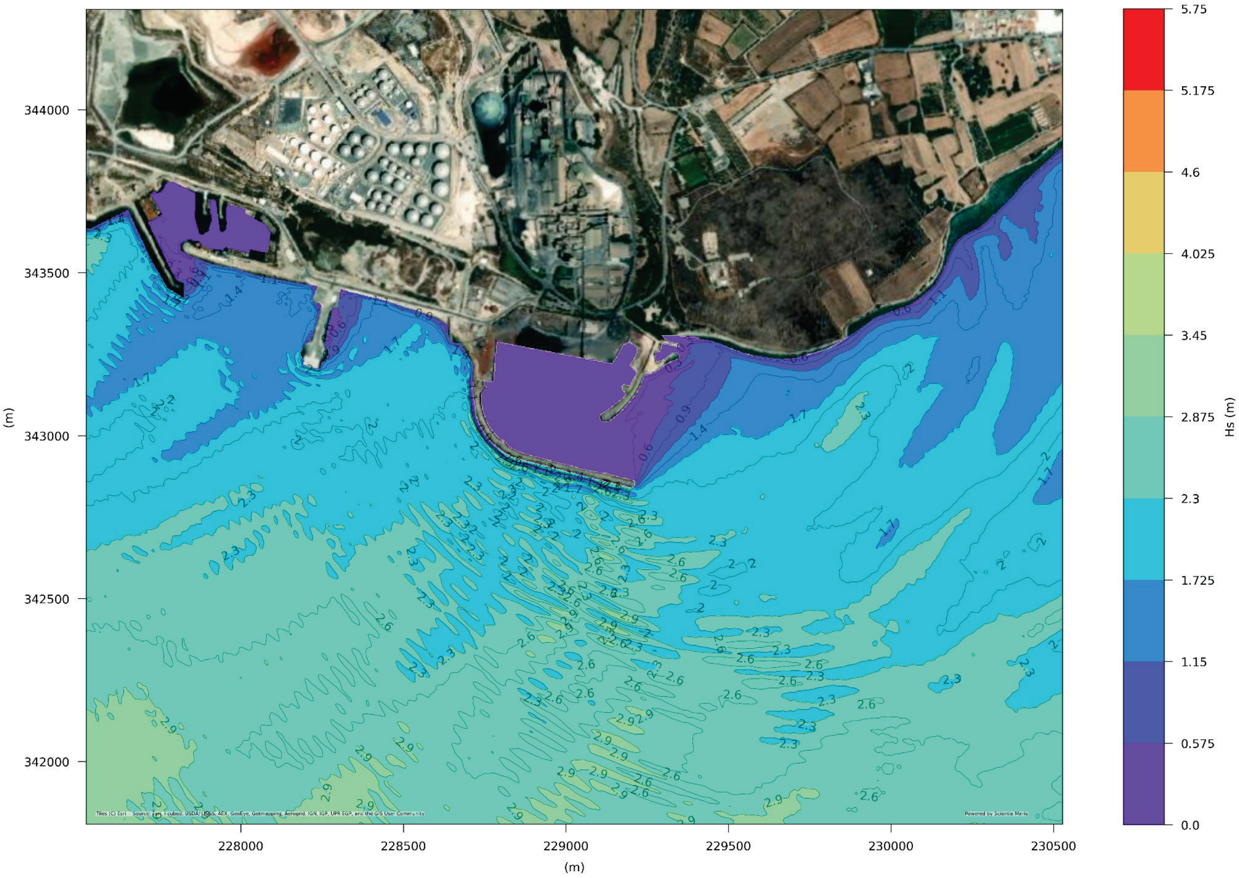
CONSULTANT:	PROJECT TITLE:	**FIGURE NUMBER:**
ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**WV_DN_3**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS:	**FIGURE TITLE:** WAVE FIELD
CLIENT:	**Hs=3,75 m, Tp=7,74 sec, θ°= 180 DEGREES** DO NOTHING ALTERNATIVE (CURRENT SITUATION)	**DATE:** DECEMBER 2023



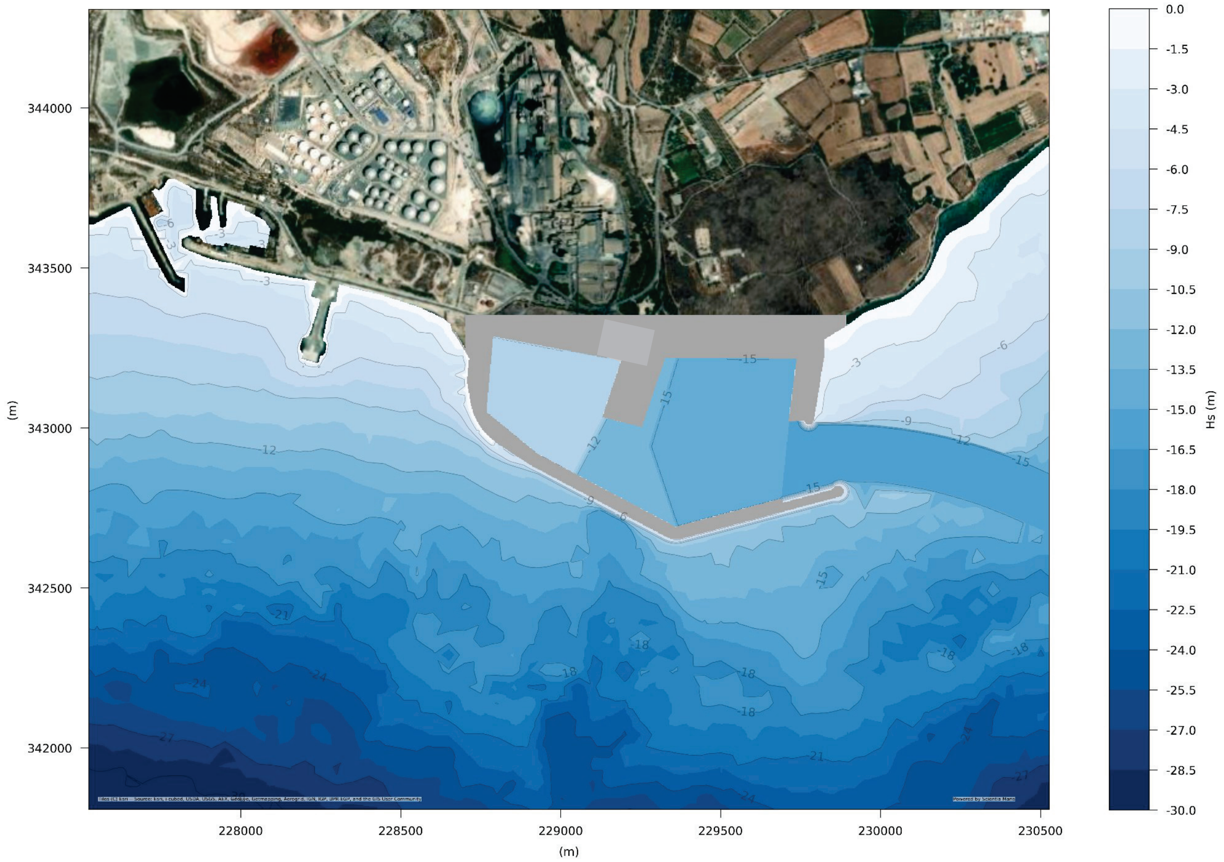
CONSULTANT:	PROJECT TITLE:	FIGURE NUMBER:
ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**WV_DN_4**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS:	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου	**Hs=5,75 m, Tp=9,59 sec, θ°=210 DEGREES** DO NOTHING ALTERNATIVE (CURRENT SITUATION)	**DATE:** DECEMBER 2023



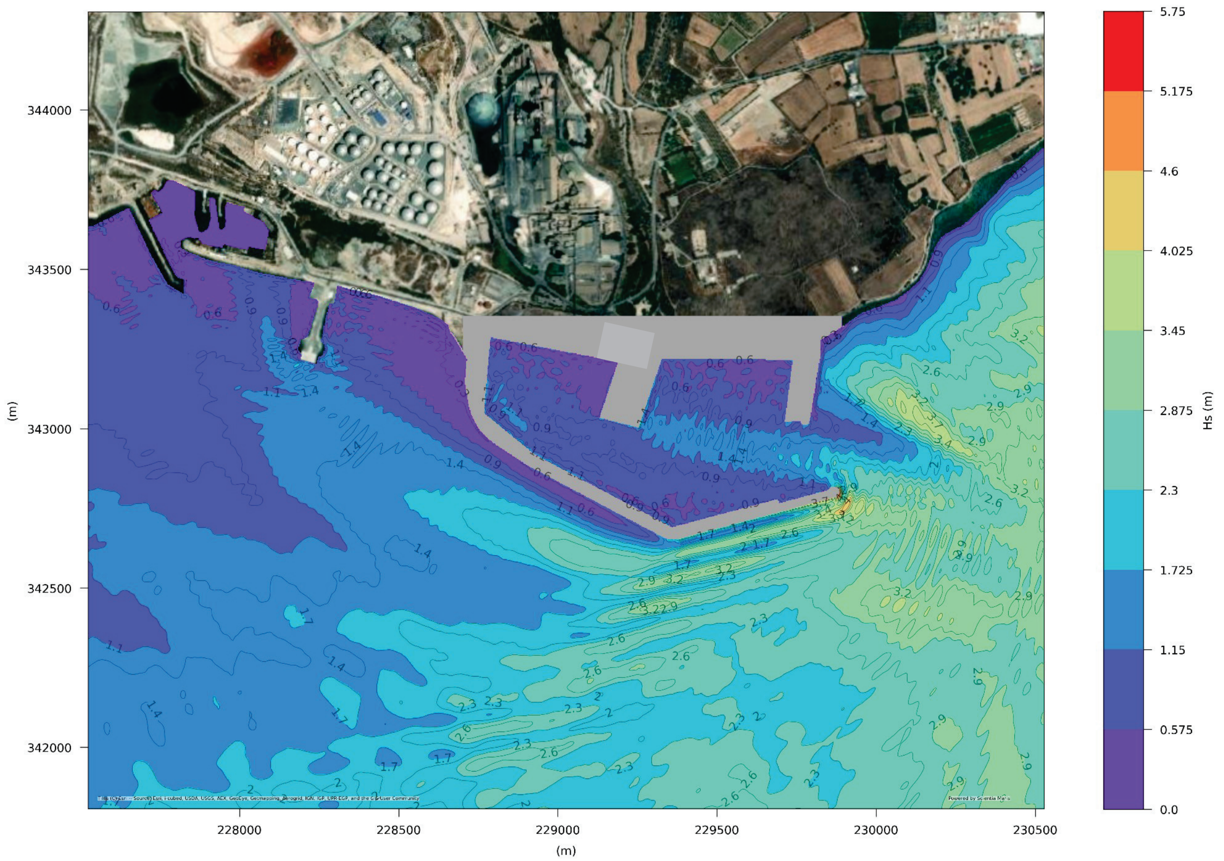
CONSULTANT:	PROJECT TITLE:	FIGURE NUMBER:
ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**WV_DN_5**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=2,75 m, Tp=6,63 sec, θ°=210 DEGREES** DO NOTHING ALTERNATIVE (CURRENT SITUATION)	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



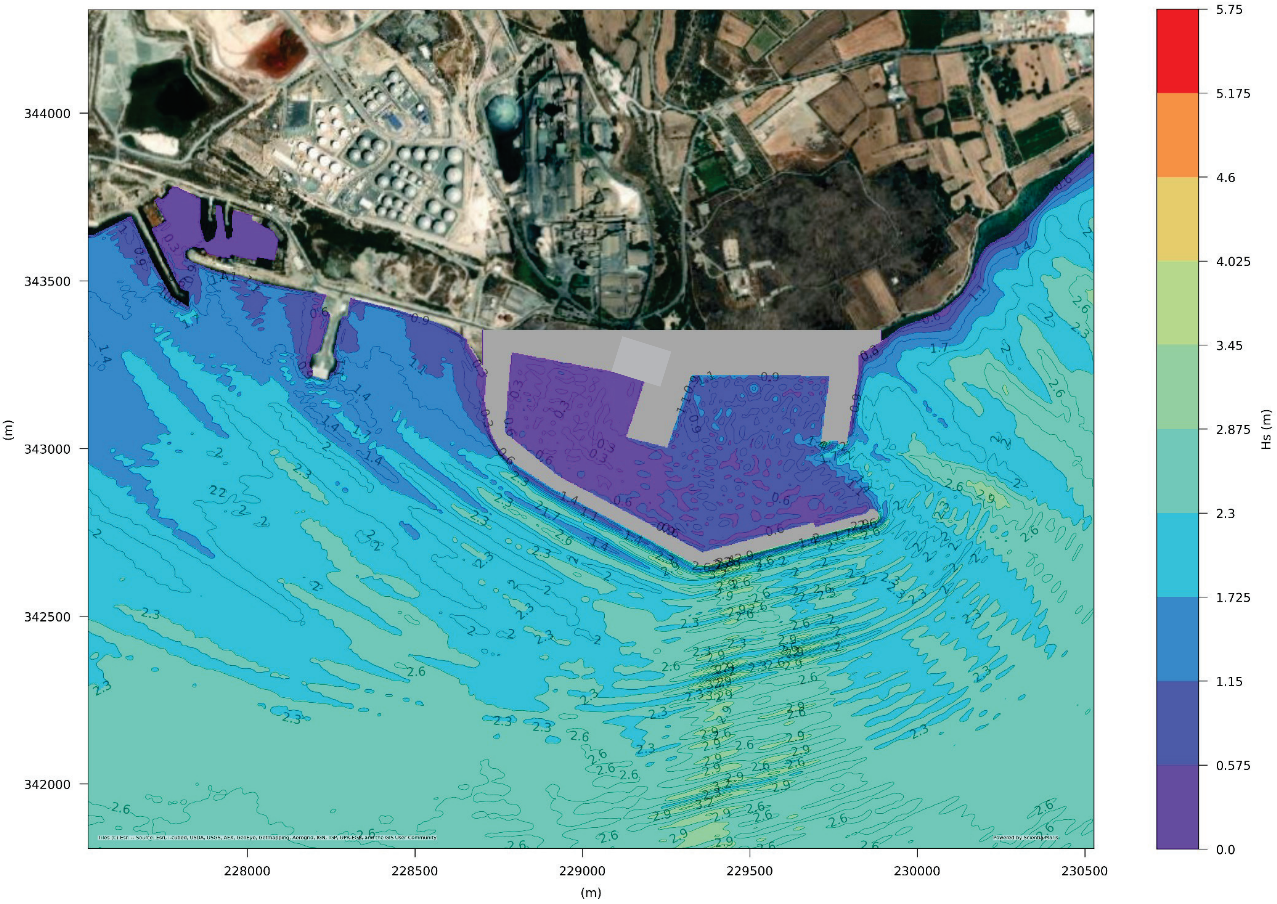
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_DN_6**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=3,25 m, Tp=7,21 sec, θº= 240 DEGREES** ΠΡΟΤΕΙΝΟΜΕΝΩΝ ΕΡΓΩΝ ΧΩΡΙΣ ΕΠΕΚΤΑΣΗ	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



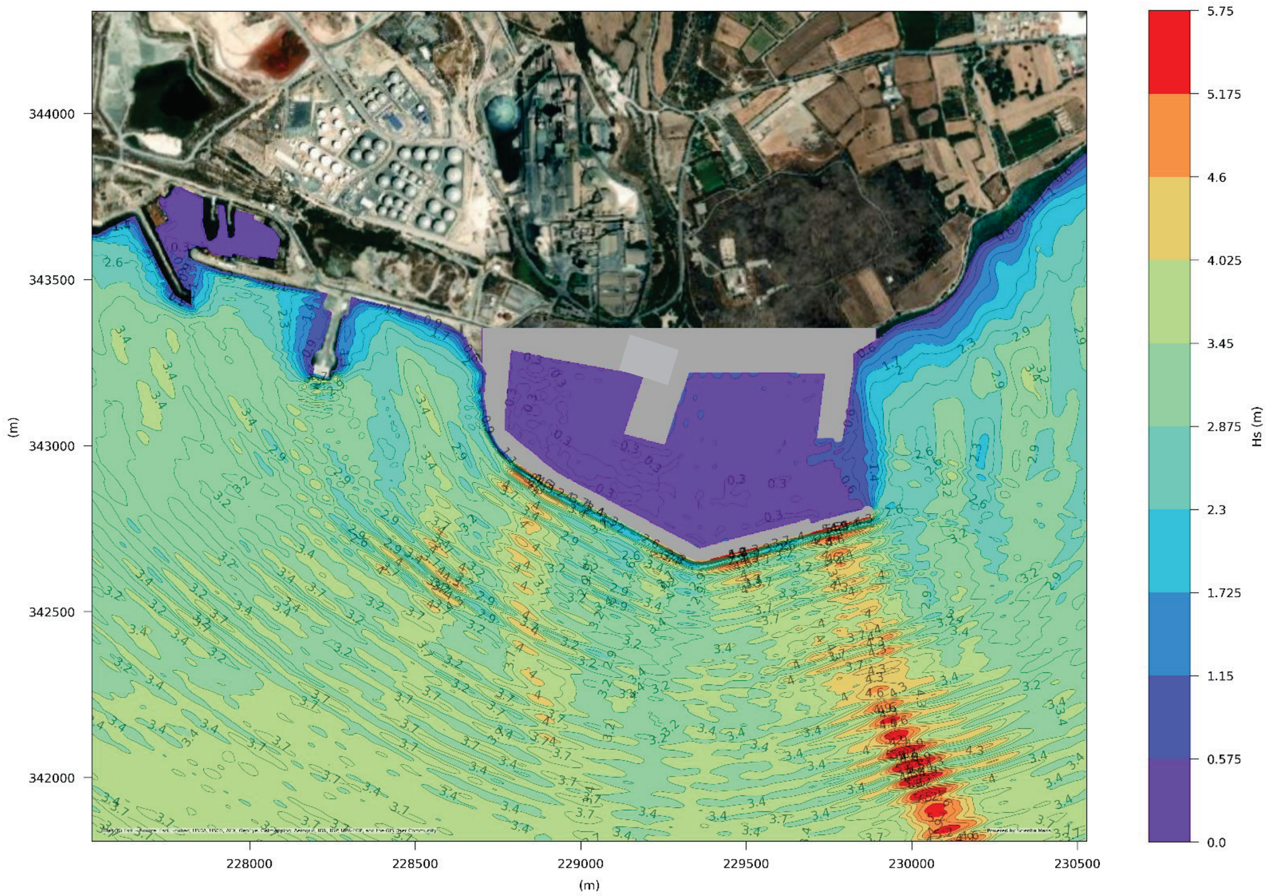
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **BATH_A**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: GRID OF EQUAL SPATIAL STEPS DX=DY=2.5M REPRESENTING BATHYMETRY OF **A ALTERNATIVE**	**FIGURE TITLE:** BATHYMETRY
CLIENT: Αρχή Λιμένων Κύπρου	PROPOSED CIVIL WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY-DISSIPATION QUAYWALLS	**DATE:** DECEMBER 2023



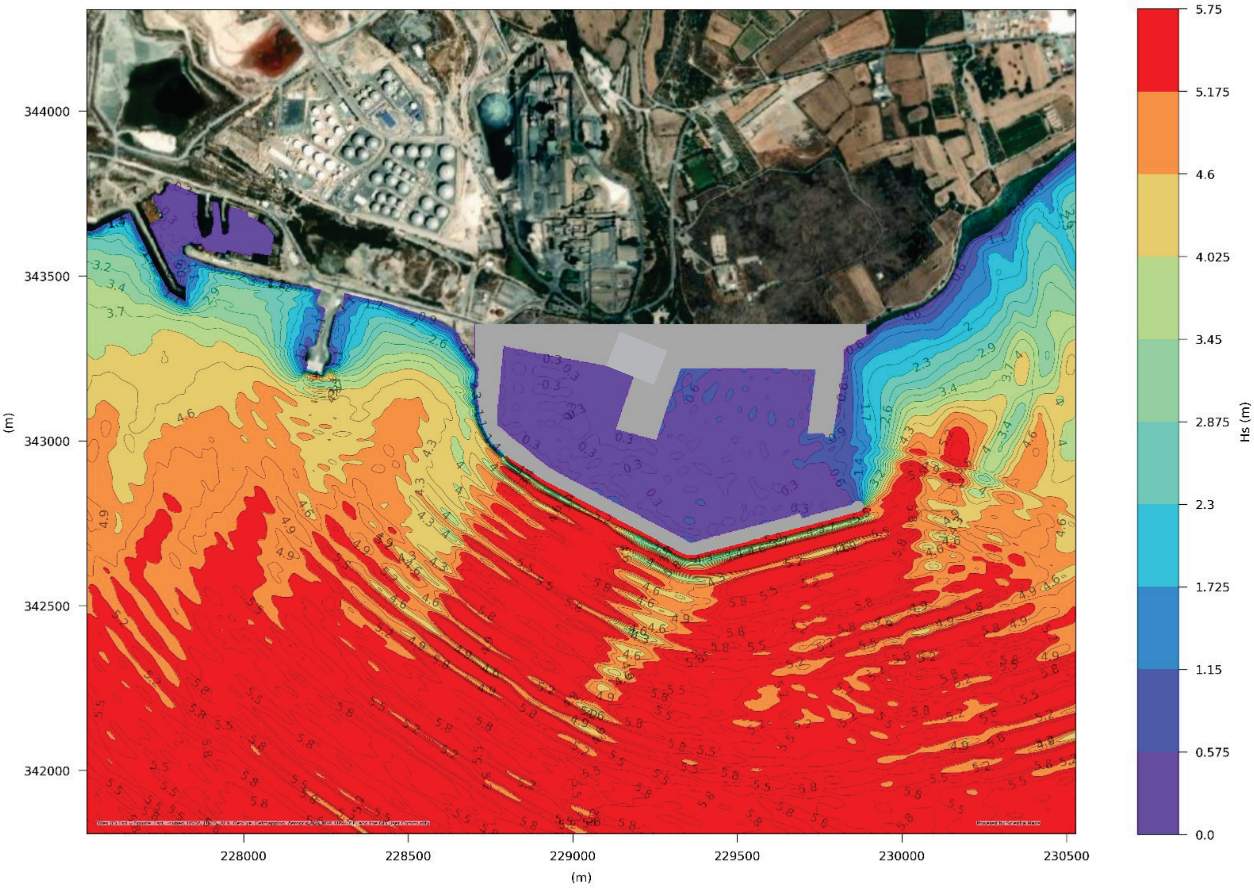
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_A_1**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=3,25 m, Tp=7,21 sec, θ^{o}= 90 DEGREES** PROPOSED CIVIL WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY-DISSIPATION QUAYWALLS	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



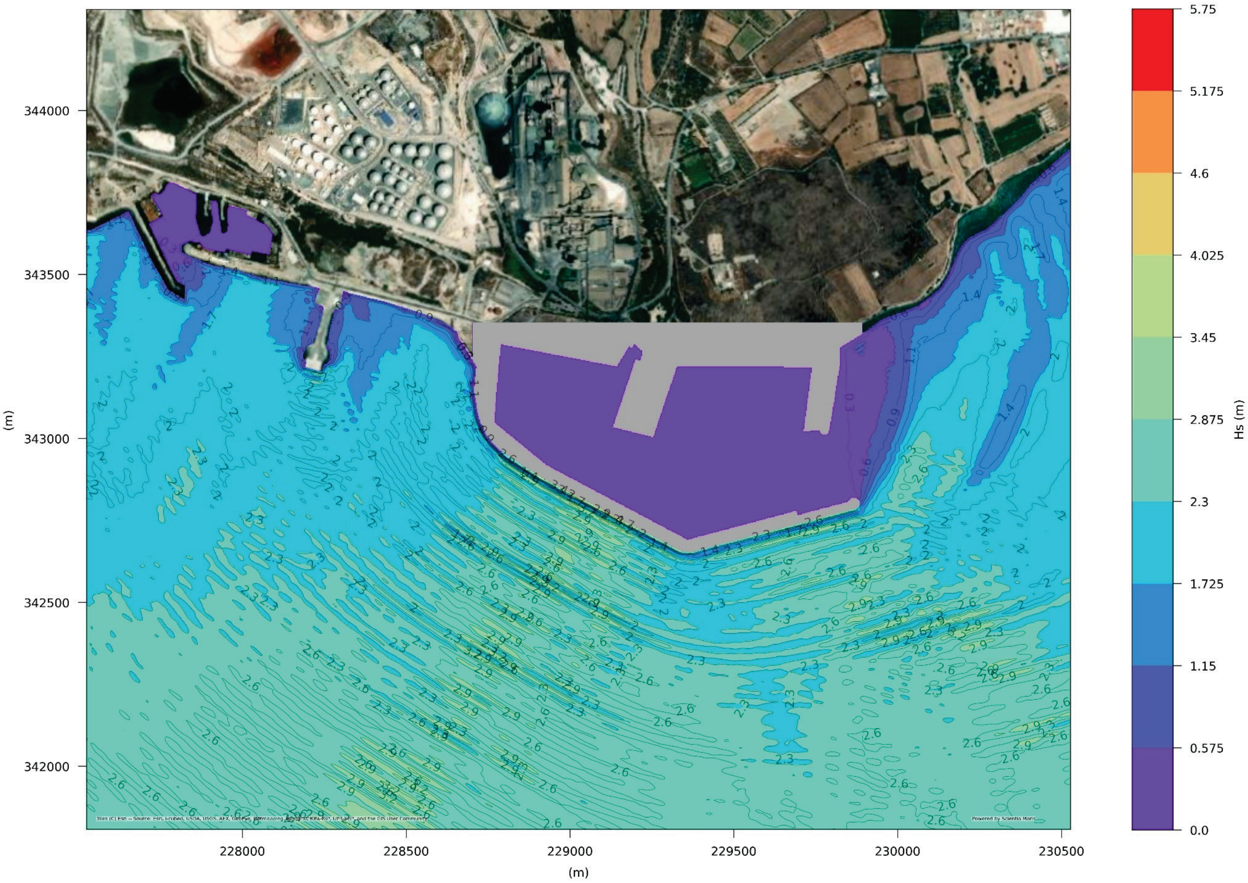
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_A_2**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=2,75 m, Tp=6,63 sec, θ°= 135 DEGREES** PROPOSED CIVIL WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY-DISSIPATION QUAYWALLS	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



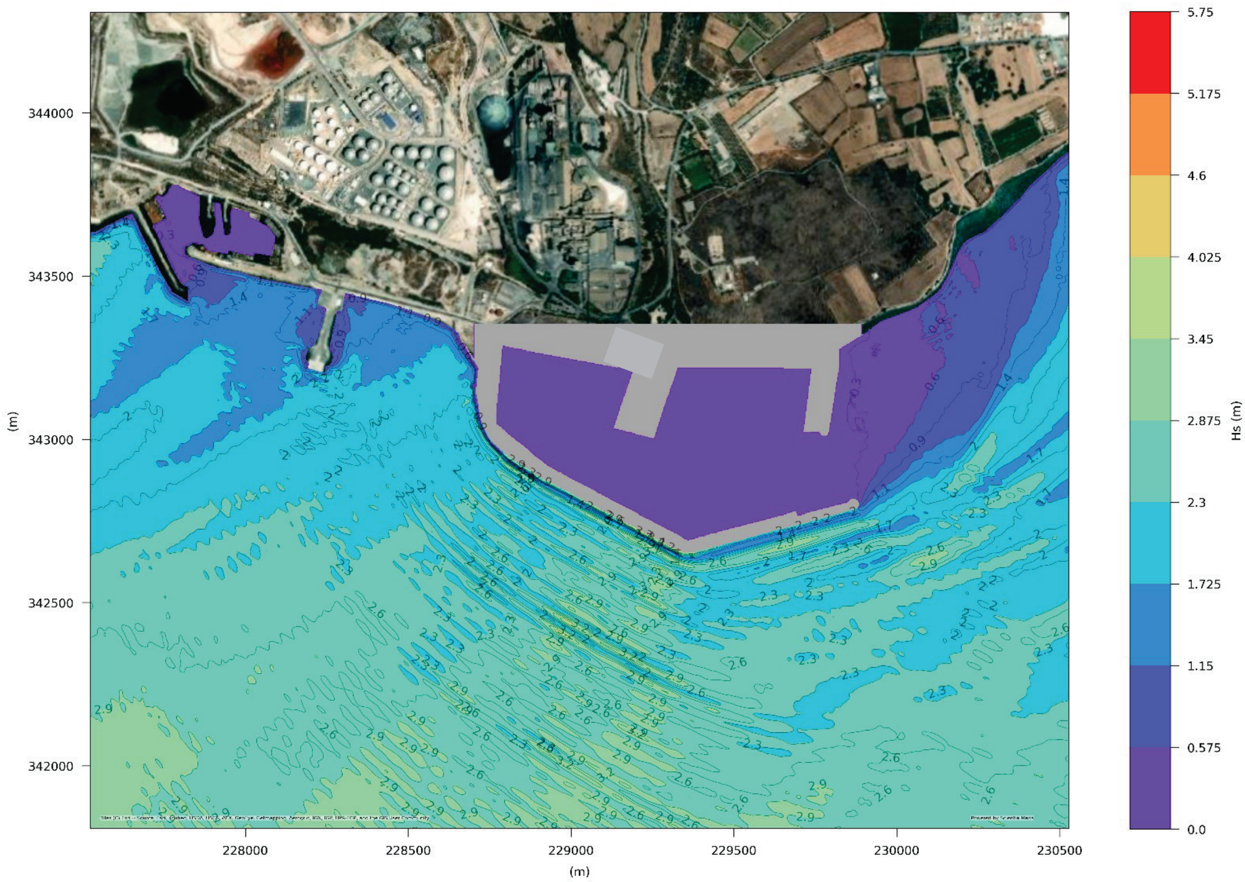
CONSULTANT:	PROJECT TITLE:	FIGURE NUMBER:
ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**WV_A_3**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=3,75 m, Tp=7,74 sec, θ^{o}= 180 DEGREES** PROPOSED CIVIL WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY-DISSIPATION QUAYWALLS	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



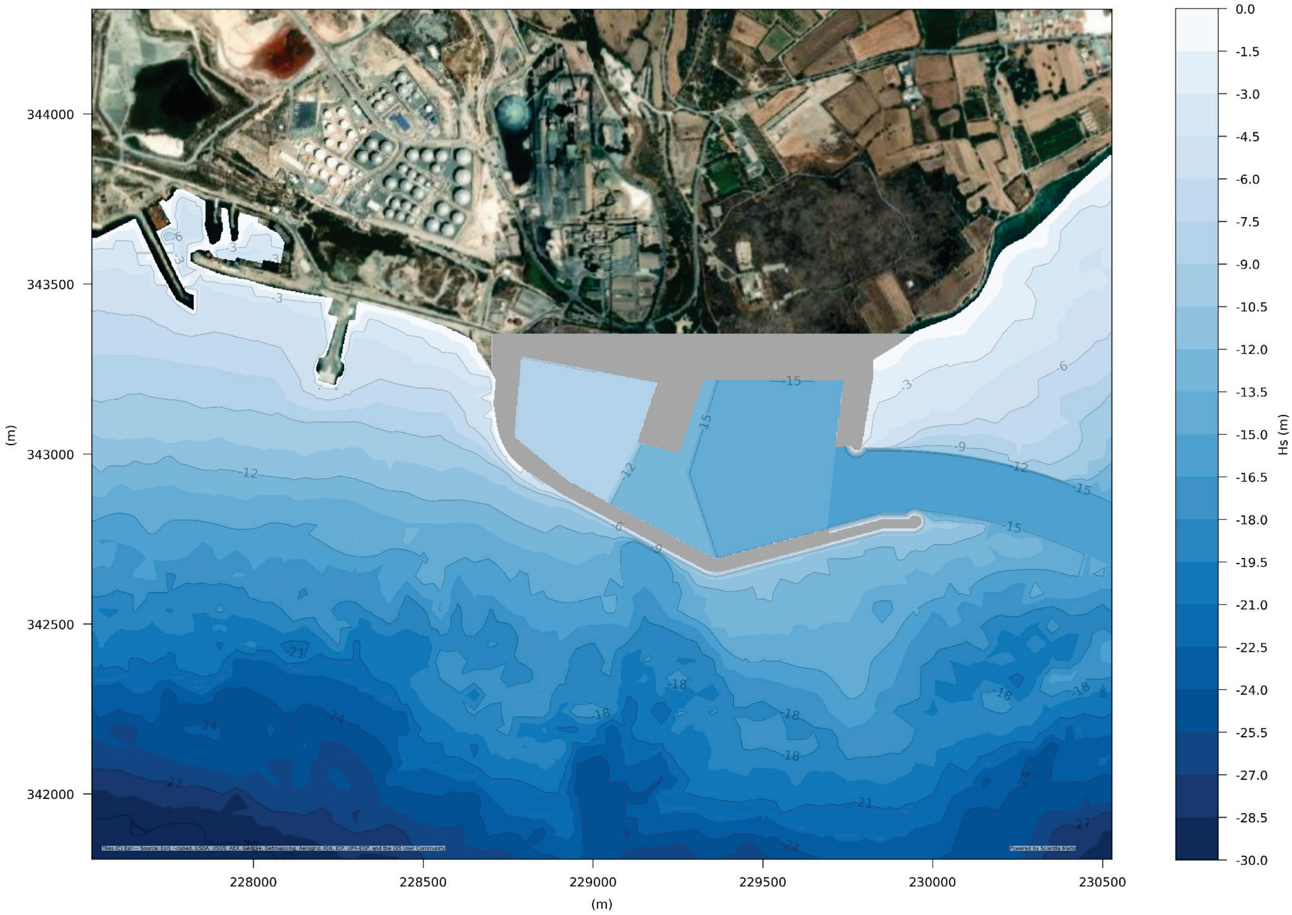
CONSULTANT:	PROJECT TITLE:	FIGURE NUMBER:
ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**WV_A_4**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=5,75 m, Tp=9,59 sec, θ°= 210 DEGREES** PROPOSED CIVIL WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY-DISSIPATION QUAYWALLS	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



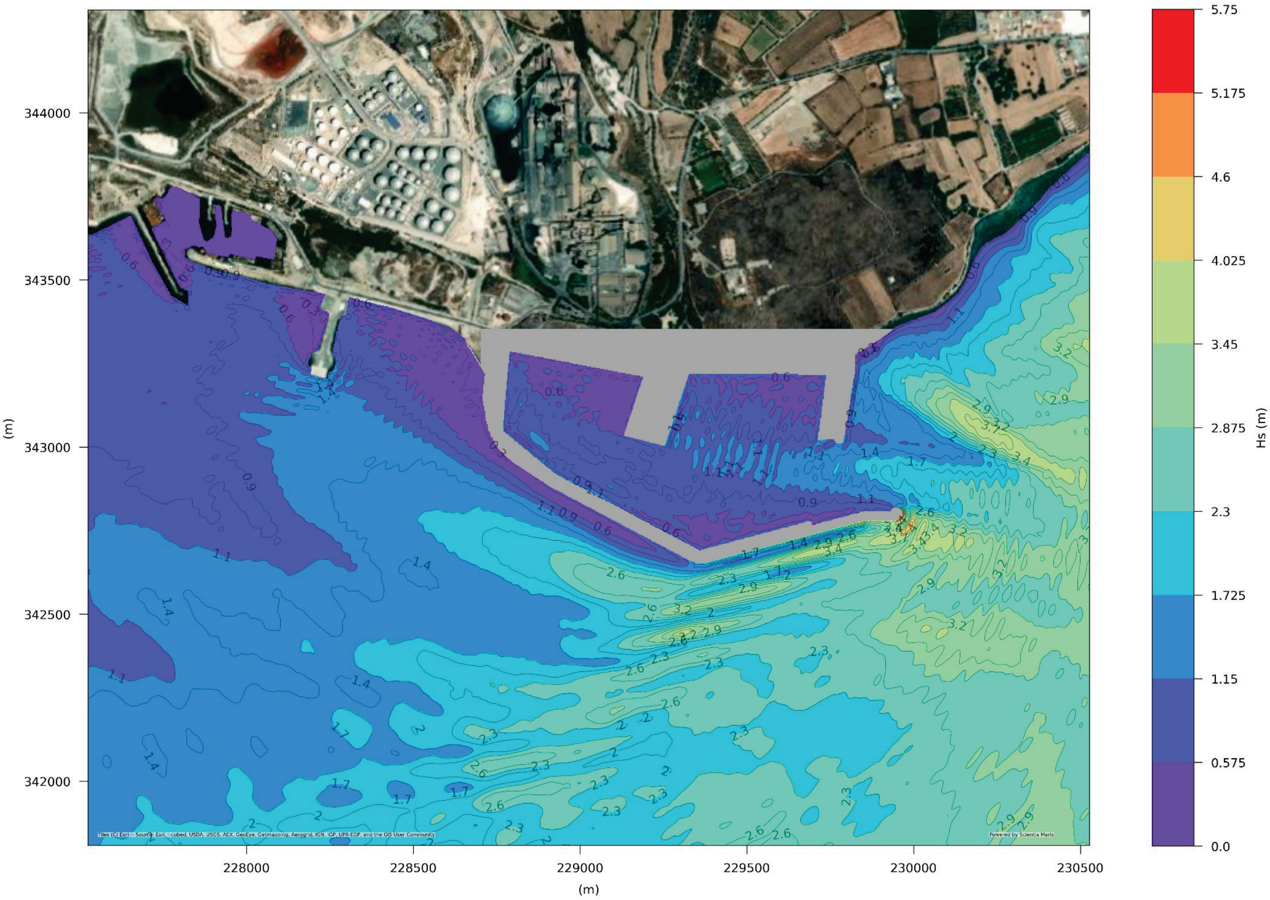
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_A_5**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=2,75 m, Tp=6,63 sec, θº= 210 DEGREES** PROPOSED CIVIL WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY-DISSIPATION QUAYWALLS	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



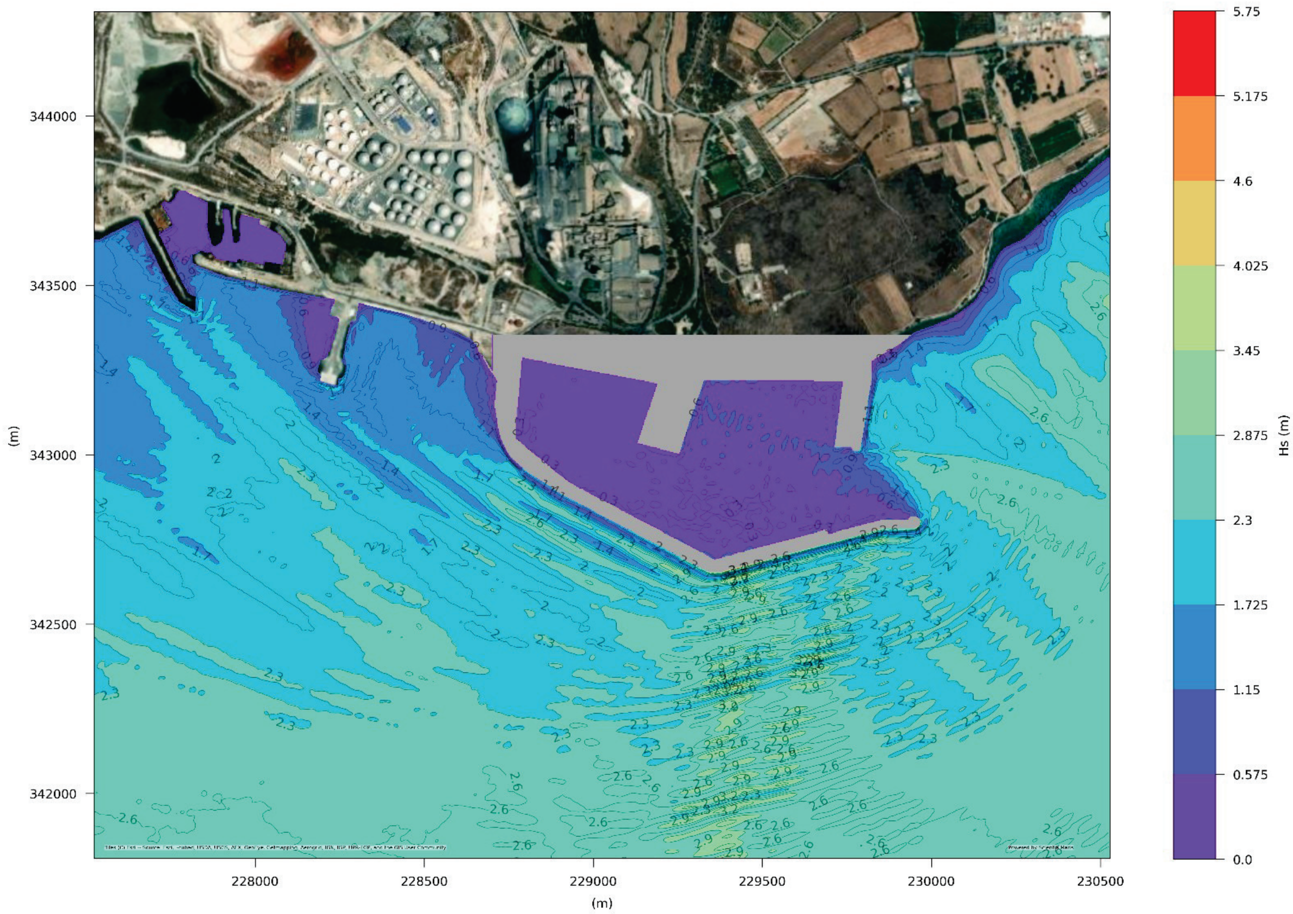
CONSULTANT:	PROJECT TITLE:	FIGURE NUMBER:
ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**WV_A_6**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS:	**FIGURE TITLE:** WAVE FIELD
CLIENT:	**Hs=3,25 m, Tp=7,21 sec, θ°= 240 DEGREES** PROPOSED CIVIL WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY-DISSIPATION QUAYWALLS	**DATE:** DECEMBER 2023



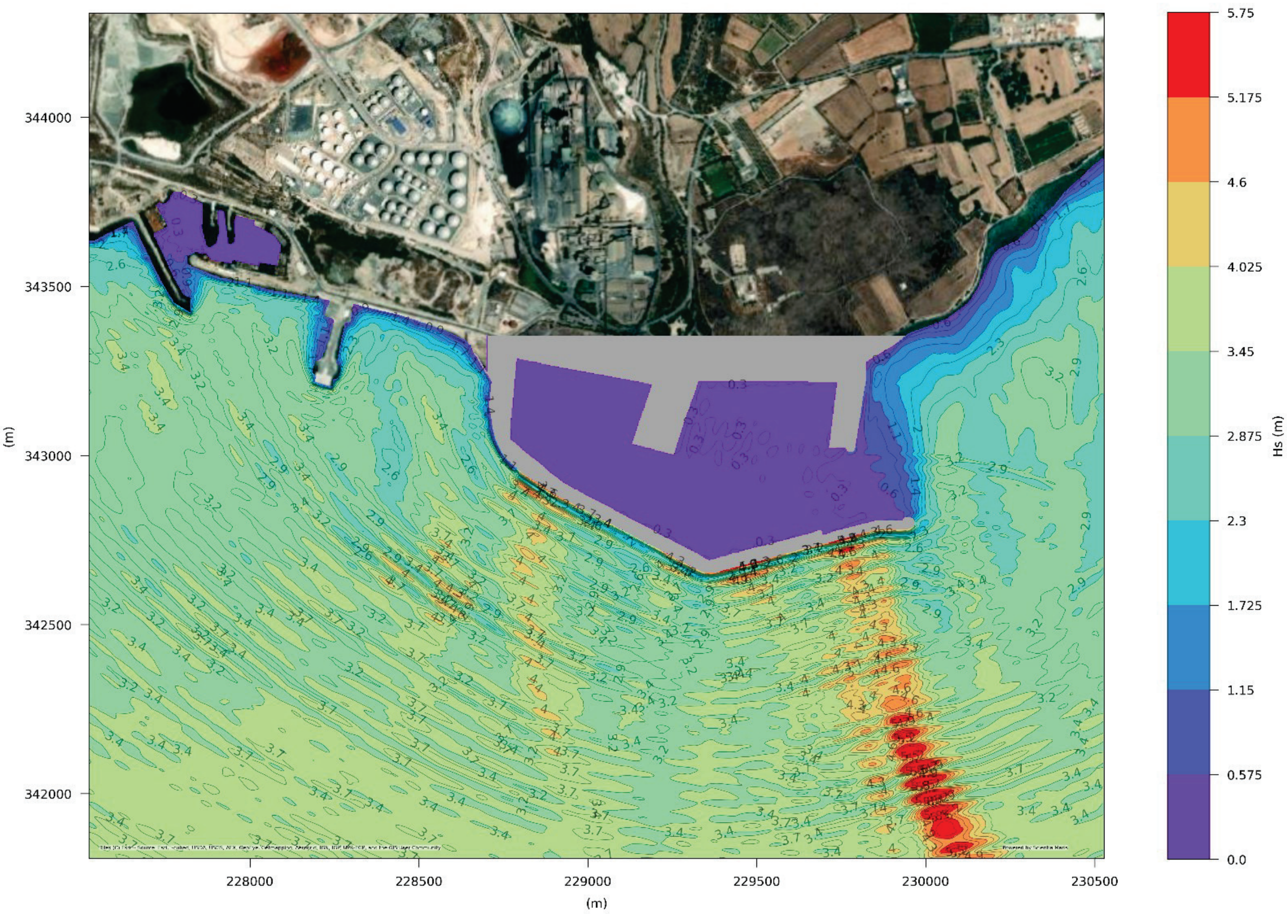
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **BATH_B**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: GRID OF EQUAL SPATIAL STEPS DX=DY=2.5M REPRESENTING BATHYMETRY OF **B ALTERNATIVE**	**FIGURE TITLE:** BATHYMETRY
CLIENT:	PROPOSED WORKS WITH THE EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY DISSIPATION QUAYWALLS	**DATE:** DECEMBER 2023



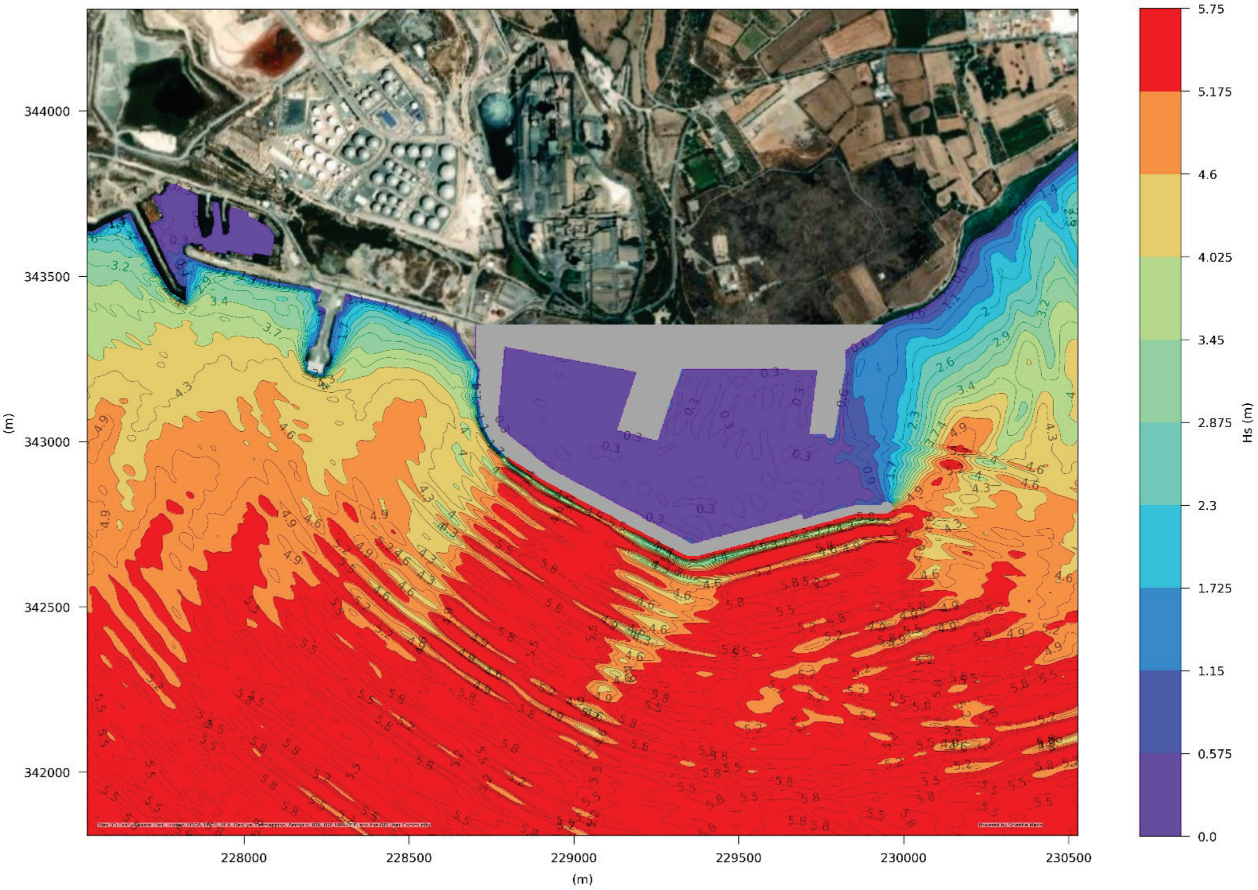
CONSULTANT:	PROJECT TITLE:	FIGURE NUMBER:
ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**WV_B_1**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=3,25 m, Tp=7,21 sec, θ°= 90 DEGREES** PROPOSED WORKS WITH THE EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY DISSIPATION QUAYWALLS	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



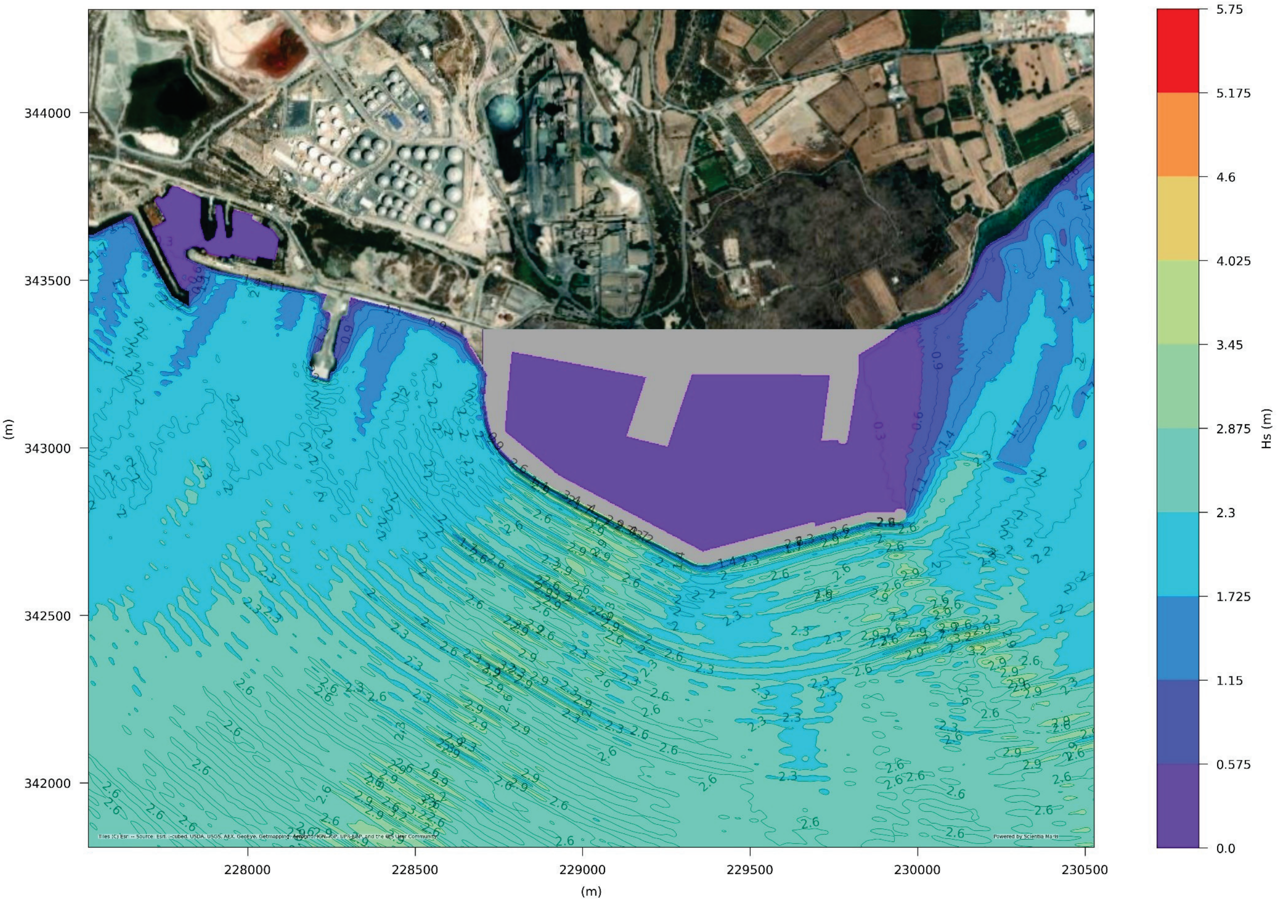
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_B_2**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=2,75 m, Tp=6,63 sec, θ°= 135 DEGREES** PROPOSED WORKS WITH THE EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY DISSIPATION QUAYWALLS	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



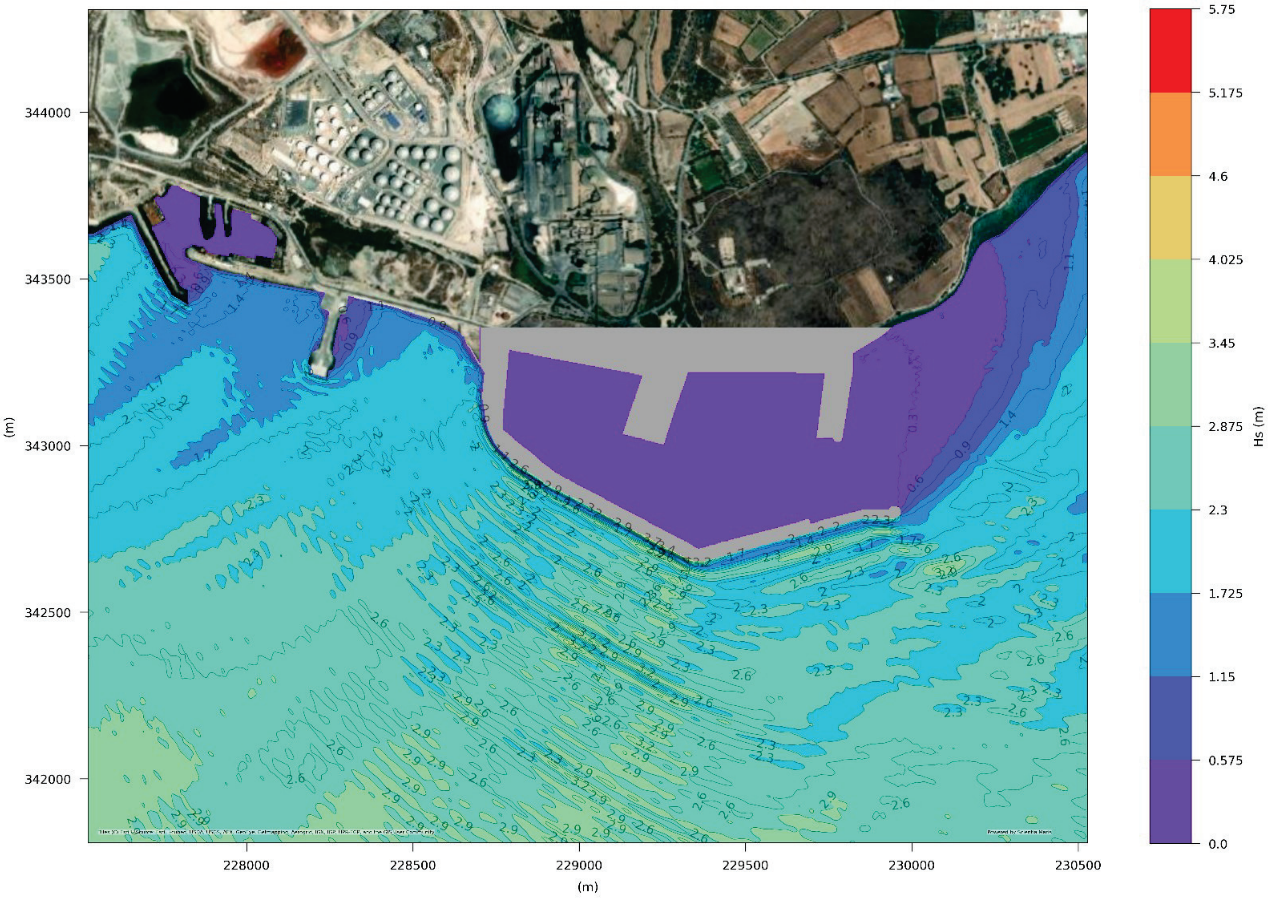
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_B_3**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS:	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου	**Hs=3,75 m, Tp=7,74 sec, θ°= 180 DEGREES** PROPOSED WORKS WITH THE EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY DISSIPATION QUAYWALLS	**DATE:** DECEMBER 2023



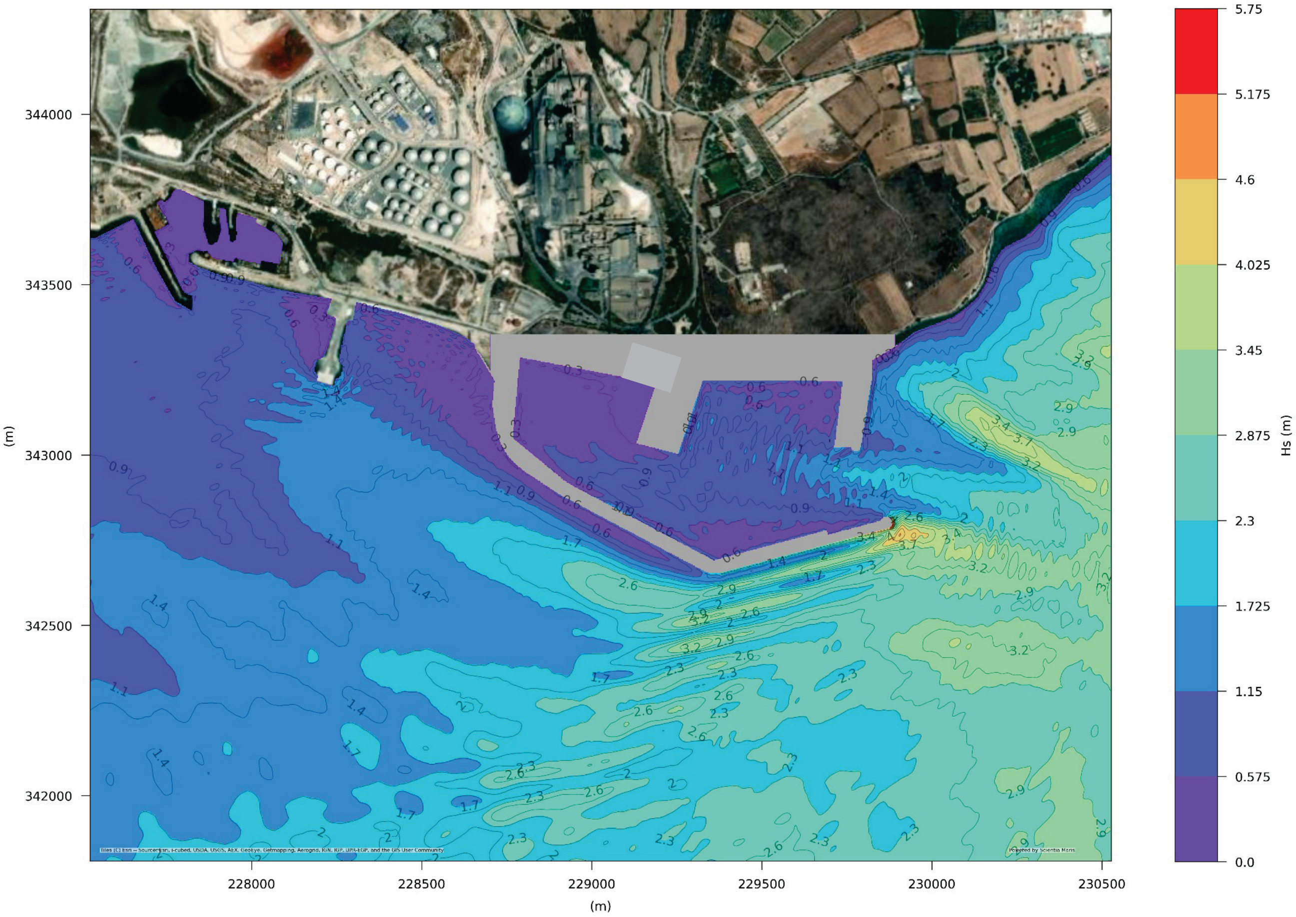
CONSULTANT:	PROJECT TITLE:	**FIGURE NUMBER:**
ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**WV_B_4**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS:	**FIGURE TITLE:** WAVE FIELD
CLIENT:	**Hs=5,75 m, Tp=9,59 sec, θ°= 210 DEGREES** PROPOSED WORKS WITH THE EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY DISSIPATION QUAYWALLS	**DATE:** DECEMBER 2023



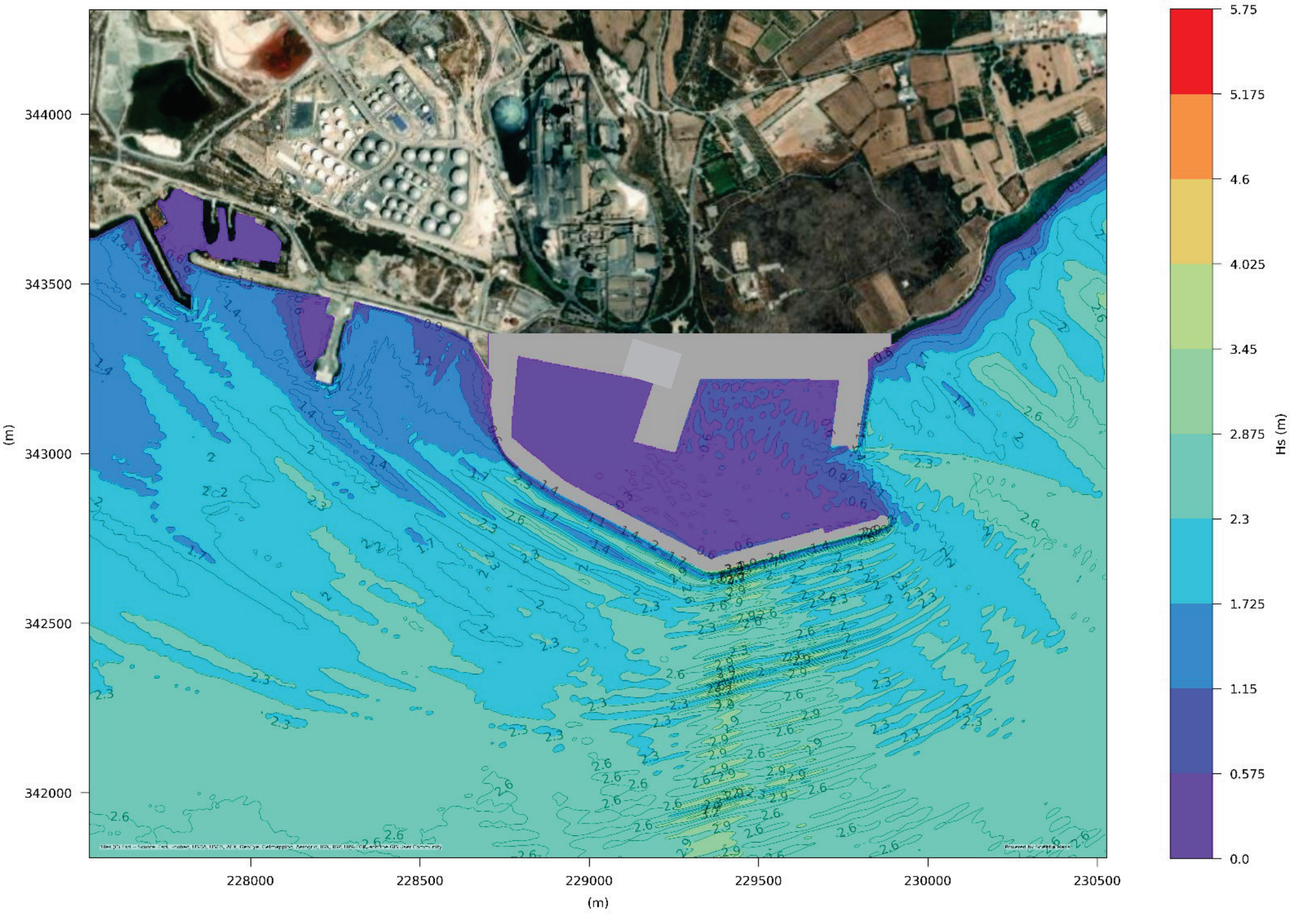
CONSULTANT:	PROJECT TITLE:	FIGURE NUMBER:
ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**WV_B_5**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=2,75 m, Tp=6,63 sec, θ°= 210 DEGREES** PROPOSED WORKS WITH THE EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY DISSIPATION QUAYWALLS	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



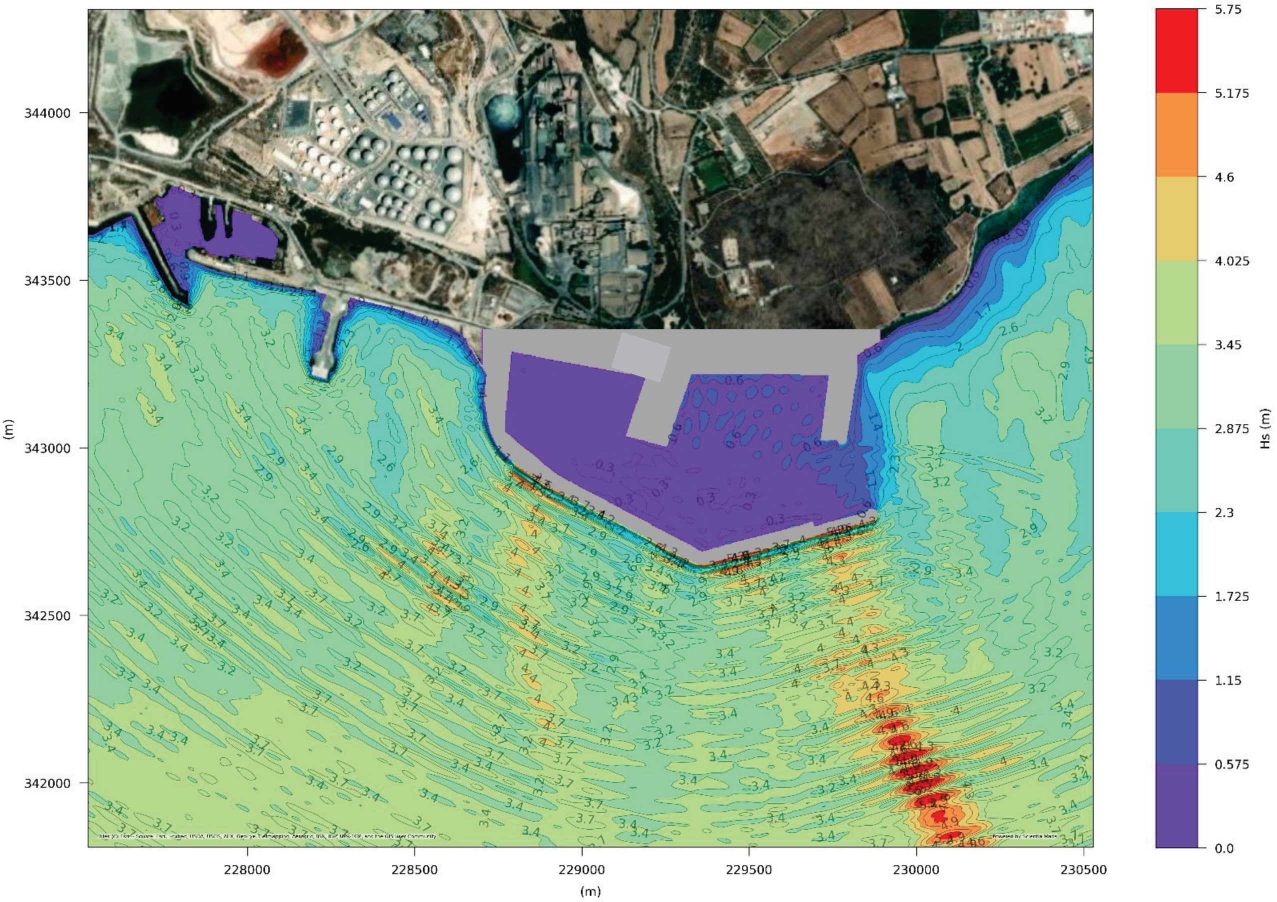
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_B_6**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=3,25 m, Tp=7,21 sec, θ°= 240 DEGREES** PROPOSED WORKS WITH THE EXTENSION OF THE WINDWARD BREAKWATER AND WITHOUT ENERGY DISSIPATION QUAYWALLS	**FIGURE TITLE:** WAVE FIELD
CLIENT:		**DATE:** DECEMBER 2023



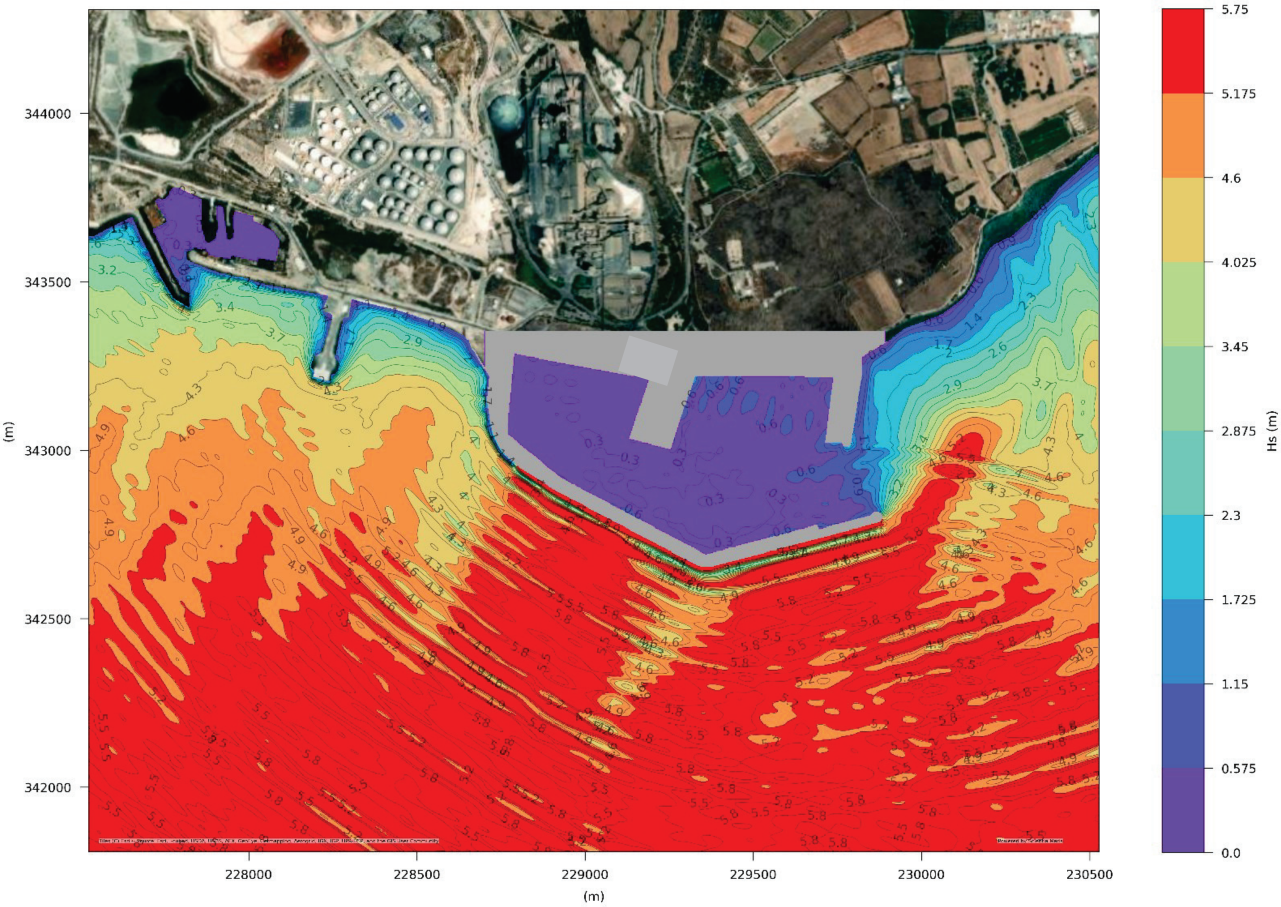
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_C_1**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS:	**FIGURE TITLE:** WAVE FIELD
CLIENT:	**Hs=3,25 m, Tp=7,21 sec, θ°= 90 DEGREES** PROPOSED WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER BUT WITH ENERGY DISSIPATION QUAYWALLS	**DATE:** DECEMBER 2023



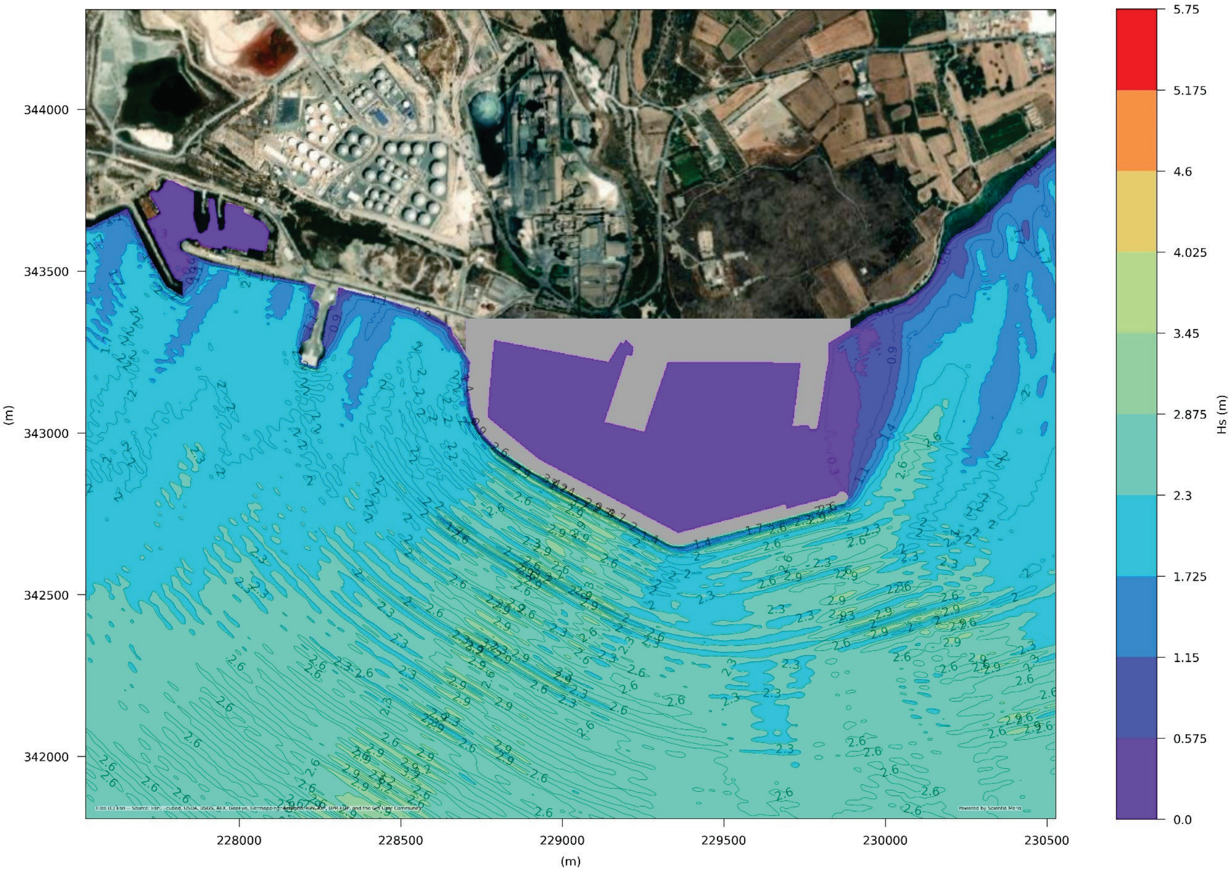
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_C_2**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS:	**FIGURE TITLE:** WAVE FIELD
CLIENT:	**Hs=2,75 m, Tp=6,63 sec, θ°= 135 DEGREES** PROPOSED WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER BUT WITH ENERGY DISSIPATION QUAYWALLS	**DATE:** DECEMBER 2023



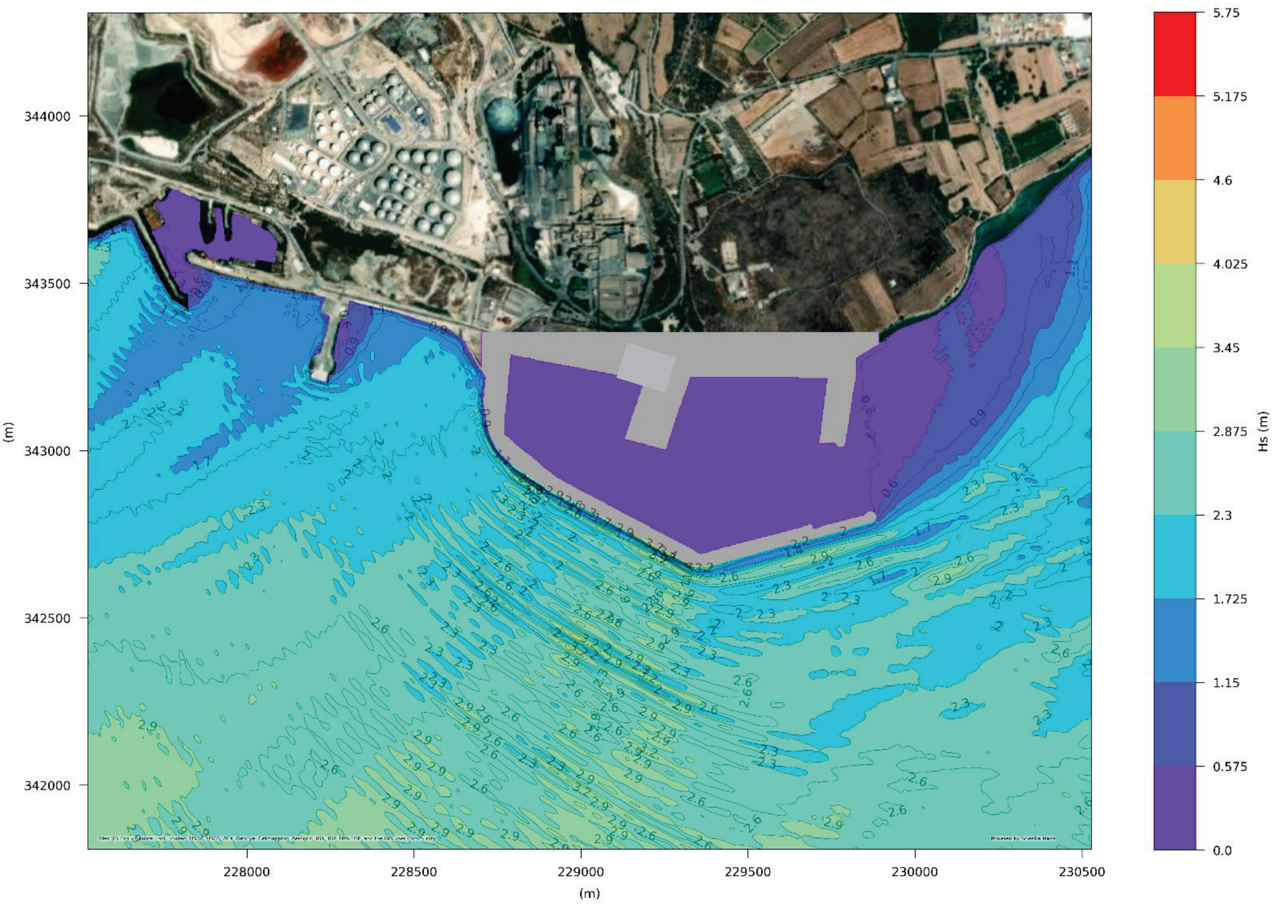
CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_C_3**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS: **Hs=3,75 m, Tp=7,74 sec, θ°= 180 DEGREES** PROPOSED WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER BUT WITH ENERGY DISSIPATION QUAYWALLS	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου		**DATE:** DECEMBER 2023



CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_C_4**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS:	**FIGURE TITLE:** WAVE FIELD
CLIENT:	**Hs=5,75 m, Tp=9,59 sec, θ°= 210 DEGREES** PROPOSED WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER BUT WITH ENERGY DISSIPATION QUAYWALLS	**DATE:** DECEMBER 2023



CONSULTANT: ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	PROJECT TITLE: UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**FIGURE NUMBER:** **WV_C_5**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS:	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου	**Hs=2,75 m, Tp=6,63 sec, θ^o= 210 DEGREES** PROPOSED WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER BUT WITH ENERGY DISSIPATION QUAYWALLS	**DATE:** DECEMBER 2023



CONSULTANT:	PROJECT TITLE:	FIGURE NUMBER:
ROGAN ASSOCIATES CONSULTING ENGINEERS - ARCHITECTS	UPDATED ENVIRONMENTAL IMPACT ASSESSMENT STUDY (EIAS) FOR THE EXPANSION OF THE PORT OF VASILIKOS.	**WV_C_5**
MODEL APPLIED: scientia maris	FIGURE DESCRIPTION: SPATIAL DISTRIBUTION OF WAVE HEIGHTS FOR INCOMING WAVE CHARACTERISTICS:	**FIGURE TITLE:** WAVE FIELD
CLIENT: Αρχή Λιμένων Κύπρου	**Hs=3,25 m, Tp=7,21 sec, θ°= 240 DEGREES** PROPOSED WORKS WITHOUT EXTENSION OF THE WINDWARD BREAKWATER BUT WITH ENERGY DISSIPATION QUAYWALLS	**DATE:** DECEMBER 2023