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ΕΛΕΥΘΕΡΙΑ Σ. ΒΑΒΑΔΑΚΗ

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Συνεπιβλέποντες:

Frank Molkenthin (BTU)

Klaus Peter Holz (BTU)

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National Technical University of Athens
&
Brandenburgische Technische Universität Cottbus

INTER-DEPARTMENT PROGRAM OF POST-GRADUATE STUDIES IN WATER RESOURCES SCIENCE AND TECHNOLOGY

MANAGEMENT OF COASTAL REGIONS USING HYDROINFORMATIC SYSTEMS

NUMERICAL SIMULATION CASE STUDY ON DESIGN OPTIONS FOR PLEASURE-BOAT HARBOURS AT SANDY COASTS

ELEFTHERIA S. VAVADAKI

Supervised by:

Vasiliki Tsoukala (NTUA)

Co-supervisors:

Frank Molkenthin (BTU)

Klaus Peter Holz (BTU)

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Last but not least, I owe my gratitude to my family; my parents, siblings, nieces and nephews for their constant and essential support during all the years of my studies. Besides all, I would not be able to live this dream without the financial support of my parents.

I will conclude with an expression of the ancient greek tragedian Sophocles :

What we ask with insistence, is achievable (Sophocles, 497-406 BC)

With systematic work, patience and insistence everything is achievable. The willingness and passion for work can manage to overcome the difficulties and not to give up.

IT WAS A HARD YEAR

THANKS FOR THE PATIENCE AND THE SUPPORT

TO DAVID

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Abstract

Sandy coasts are subject to intensive sediment transport. Building pleasure boat harbours along such coastlines is a challenge and some options for design are to be investigated.

Background for this investigation is the discussion about touristic development of the German Baltic Sea coast ongoing since 20 years already. Of urgent interest is a new harbour place at the coast of Prerow which is located in between the nearest marinas; Rostock and HiddenSee.

Three kind of harbour design have been thought of: Inshore, Onshore and Offshore. Intention of this study was to investigate and compare the three options for harbour design using data of the area of Prerow.

A step by step procedure was followed both at Wave and Hydrodynamic mathematical models (Mike21, DHI) in order to “transfer” the boundaries from the Ruegen Overal model to the local one; Prerow. At this downscaling procedure, comparison with measured data at 3 gauging stations was done in order to calibrate the model. After validating the model, the final Prerow model has been created. At that local Prerow model 4 harbours variants were designed (two Offshores).

Extreme events have been identified and simulated with Spectral Wave model FM, Flow model FM and Sand transport model FM for all the harbour variants.

The results of the Spectral Wave Prerow model have been used in order to check whether the design criteria of the harbours have been covered. The H_{mo} was checked nearby the entrance of the harbours as well as at mooring places according to the Coastal Engineering Manual (CEM).

Results from the Flow model on the currents and on the total water depth have been discussed. The total water depth after the simulation procedure was used in order to check if the harbours remain accessible for the boats.

From the Sand Transport model the bed level at the beginning and at the end of the simulation was compared for all occasions. The goal was to acquire an initial feeling about the tendency of accumulation and erosion nearby the harbours.

Conclusions were drawn for the best performance of the 3 variants with respect to:
a. Accessibility of the harbours at extreme conditions in terms of bathymetry
b. Safety in the harbours during extreme events (mooring).

A general conclusion was that the harbours are affected more from the North wind than the West. The proposed harbours are the Inshore and the Offshore A (0.5km from the coast) as they applied the best performances for the criteria checked. The choice between the two will depend on further more detailed studies.

Extended Greek Abstract

<u>Στόχος της εργασίας</u>

Οι αμμώδεις ακτές εκτίθενται σε έντονη στερεομεταφορά καθιστώντας δύσκολο τον σχεδιασμό λιμένων για σκάφη αναψυχής. Στην παρούσα εργασία γίνεται έρευνα για τον σχεδιασμό λιμένα για σκάφη αναψυχής (μαρίνα) στην ακτή Zingst-Darss που βρίσκεται στο ανατολικό τμήμα της Γερμανικής ακτής και συγκεκριμένα στη Βαλτική.

Ερευνήθηκαν τρία είδη λιμένων ως προς την θέση σχεδιασμού:

I. <u>Εσωτερικός</u>: το λιμάνι βρίσκεται μέσα στην πόλη και η είσοδος από τη θάλασσα γίνεται μέσω ενός καναλιού ναυσιπλοΐας προστατευόμενο από κυματοθραύστες (βλ. εικ.1)

Εικόνα 1: Παράδειγμα εσωτερικού λιμένα αναψυχής (Αναφορά: Harbor of Kolberg, Poland)

II. <u>Παράκτιος</u>: το λιμάνι βρίσκεται στην ακτογραμμή. Προσβασιμότητα δίνεται κατευθείαν από την ακτή (βλ. εικ. 2).

Εικόνα 2: Παράδειγμα παράκτιου λιμένα αναψυχής (Αναφορά: Hafen Kühlungbornb&o Ingenieure Dipl.-Ing. Bernd Opfermann, November 2007)

III. <u>Υπεράκτιος</u>: το λιμάνι βρίσκεται στην ανοικτή θάλασσα. Είναι τεχνητό και προστατευμένο από όλες τις πλευρές. Προσβασιμότητα δίνεται με γέφυρα ανοικτής κατασκευής που επιτρέπει τη διέλευση του ιζήματος από το λιμάνι έως την ακτή (βλ. εικ.3)

Εικόνα 3: Παράδειγμα υπεράκτιου λιμένα αναψυχής (Αναφορά: Harbor planning at Heringsdorf, Ostesee-Zeitung.de, grafiker: Karsten Gläser)

Ο μοντέρνος σχεδιασμός του υπεράκτιου λιμένα αναψυχής παρουσιάζει υδροδυναμικά και γεωμορφολογικά πλεονεκτήματα έναντι των συμβατικών σχεδιασμών. Αποφεύγεται η εμφάνιση εμποδίων κατά την είσοδο ή την αγκυροβόληση των σκαφών σε περιοχές ρηχών νερών και έντονης στερεομεταφοράς ενώ ωθείται επίσης και η αύξηση του τουρισμού. Οι υπεράκτιοι λιμένες για σκάφη αναψυχής (island harbours) μπορούν επίσης να προσφέρουν υπηρεσίες θαλασσίων σπορ, καταστημάτων και χώρων στάθμευσης μετατρέποντάς το λιμάνι σε ένα πολύβουο κέντρο για θαλάσσιες και μη δραστηριότητες. Επιπρόσθετα, το κόστος ανέγερσης και συντήρησης τέτοιου είδους κατασκευών συνήθως καθίσταται χαμηλότερο από τις συμβατικές λύσεις κοντά στις οποίες παρουσιάζεται σημαντική μετακίνησης ιζήματος και απαιτείται συνεχής βυθοκόρηση.

Στην εικόνα 4 παρουσιάζονται οι διατάξεις των λιμένων που εξετάστηκαν κοντά στην περιοχής μελέτης. Δυο σενάρια (Α και Β) προσομοιώθηκαν για την περίπτωση του υπεράκτιου λιμένα στο 0.5 km και 1 km από την ακτή αντίστοιχα. Όλοι οι λιμένες σχεδιάστηκαν για την εξυπηρέτηση 300 σκαφών ολικού μήκους 10 m (LOA), πλάτους 3 m (beam) και βύθισμα 2.1 m (draft).

Εικόνα 4: Θέσεις υπό εξέταση λιμένων αναψυχής

Τα συμπεράσματα δόθηκαν ως προς την καλύτερη επίδοση των τριών εναλλακτικών διατάξεων σε σχέση με:

I. Την προσβασιμότητα στο λιμάνι σε έντονες καιρικές συνθήκες από την πλευρά της βαθυμετρίας
II. Την ασφάλεια σε επιλεγμένες θέσεις αγκυροβόλησης κατά τη διάρκεια έντονων καιρικών συνθηκών

Υπόβαθρο της εργασίας και κατάστρωση του μοντέλου

Αρχικά έγινε έρευνα στα υπάρχοντα υπολογιστικά μοντέλα της αγοράς που χρησιμοποιούνται για την προσομοίωση παράκτιων ζωνών, με απώτερο σκοπό την επιλογή ενός από τα πιο κατάλληλα για την εργασία αυτή και συγκεκριμένα το Mike21 του Danish Hydraulic Institute (http://mikebydhi.com/). Έπειτα, ερευνήθηκε η σημασία των μεταδεδομένων και ειδικότερα έγινε αναφορά στο Ευρωπαϊκό πλαίσιο που αναπτύσσεται για τη διατήρηση των θαλάσσιων δεδομένων (http://www.coastalwiki.org/coastalwiki/Main_Pagehttp://www.seadatanet.org/). Έγινε συνοπτική περιγραφή των Γερμανικών οργανισμών για τα θαλάσσια μεταδεδομένα και ακολούθησε η συλλογή των δεδομένων που αφορούν τη συγκεκριμένη περιοχή μελέτης (http://www.coastalwiki.org/coastalwiki/NOKIS_-_Information_Infrastructure_for_the_North_and_Baltic_Sea). Τέλος, έγινε μια πρώτη προσέγγιση για την πρόβλεψη της εξέλιξης της ακτογραμμής του Darsser-Ort με το στατιστικό πρόγραμμα Shev με στόχο την αντίληψη της περιοχής από μια γενικότερη άποψη (Doukakis Eustratios, 2007) . Έτσι, έγινε αντιληπτή η αλλαγή του συστήματος κατά τη διάρκεια των τελευταίων δεκαετιών από μια ολική κλίμακα βοηθώντας στην περαιτέρω κατανόηση της εξέλιξης της ακτογραμμής στο μέλλον.

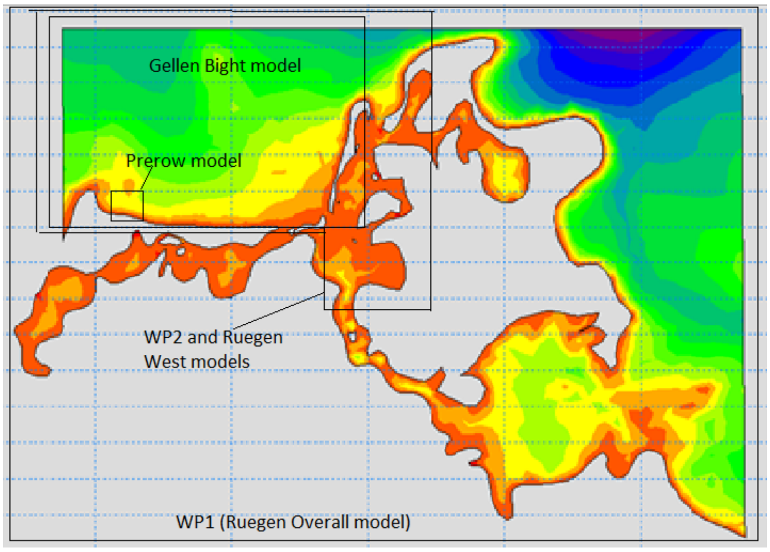
Η περιοχή μελέτης είναι το Prerow που περίπου ισαπέχει από τους δυο πλησιέστερους λιμένες αναψυχής στο Rostock και Hiddensee όπως παρουσιάζεται στην εικόνα 5.

Εικόνα 5: Προτεινόμενη θέση Prerow (Αναφορά:
http://www.portbooker.com/de/liegeplatz/deutschland)

Ο σχεδιασμός ενός νέου λιμένα αναψυχής (μαρίνα) στην περιοχή αυτή κρίνεται αναγκαίος καθώς η απόσταση ανάμεσα στους δυο προαναφερόμενους είναι μεγαλύτερη από 60 ναυτικά μίλια και είναι δύσκολο να καλυφθεί ειδικά όταν επιβιβάζονται παιδιά ή άτομα μεγάλης ηλικίας. Η κατάσταση δυσχεραίνει ακόμη περισσότερο όταν κατά τη διάρκεια του ταξιδιού επικρατούν έντονες καιρικές συνθήκες χωρίς να μεσολαβεί χώρος στάθμευσης για επείγουσες περιπτώσεις.

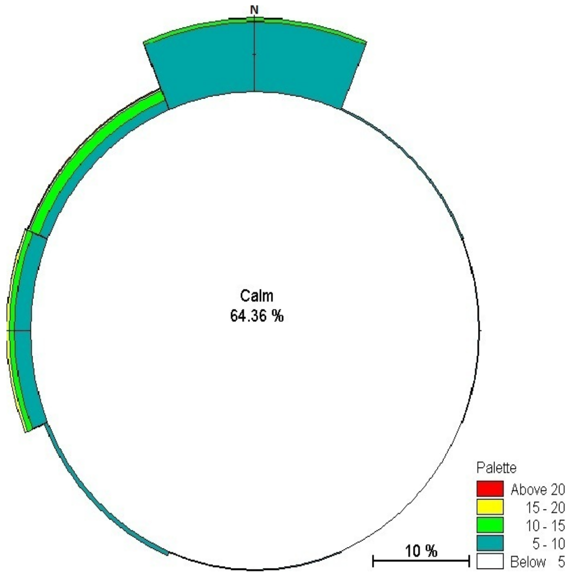
Τα δεδομένα της στάθμης θαλάσσης που χρησιμοποιήθηκαν προήλθαν από σταθμούς μετρήσεων που βρίσκονται μακριά από την περιοχή μελέτης. Έτσι, ακολουθήθηκε μια βήμα προς βήμα μεθοδολογία ώστε να μεταφερθούν τα όρια από το μεγάλο μοντέλο (Ruegen overall) στο τοπικό (Prerow), όπου βρίσκεται και η περιοχή μελέτης. Το ενδιάμεσο μοντέλο (Ruegen West) βαθμονομήθηκε και επικυρώθηκε με μετρήσεις σε ενδιάμεσους σταθμούς (gauging stations). Έτσι στο τελικό μοντέλο του Prerow σχεδιάστηκαν τρεις διαφορετικές διατάξεις μαρίνων.

Στην εικόνα 6 παρουσιάζονται τα μοντέλα που χρησιμοποιήθηκαν ώστε να μεταφερθούν οι οριακές συνθήκες από το Ruegen Overall model στο Ruegen West model, στο Gellen Bight model και τέλος στο τοπικό Prerow model.



Εικόνα 6: Μεταφορά οριακών συνθηκών

Από τα ανεμολογικά δεδομένα που παρήχθησαν δημιουργήθηκε το ανεμολογικό ροδόγραμμα (βλ. εικ. 7) και παρατηρήθηκε πως οι επικρατέστεροι άνεμοι είναι ο Δυτικός και ο Βόρειος.



Εικόνα 7: Ανεμολογικό ροδόγραμμα

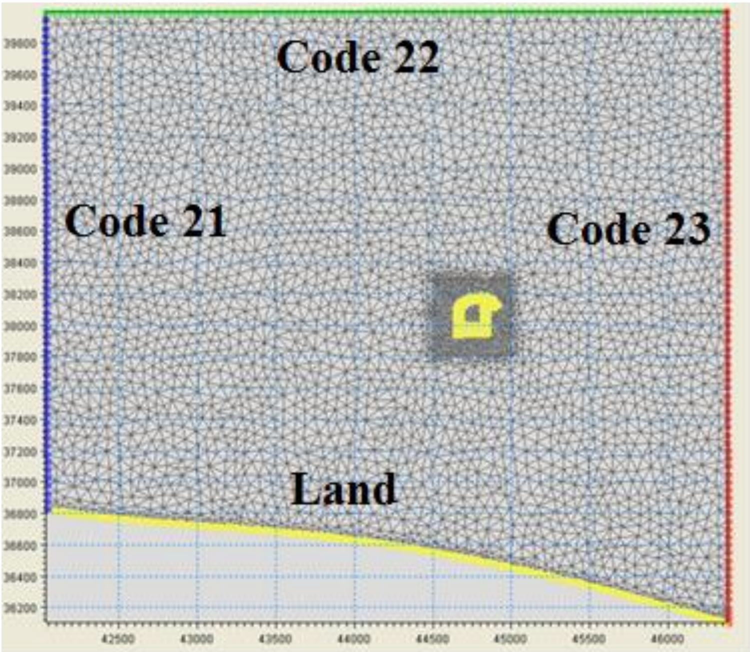
<u>Προσομοίωση</u>

Τρία γεγονότα προσομοιώθηκαν (δυο με το Δυτικό σενάριο και ένα με το Βόρειο) σύμφωνα με την ταχύτητα των επικρατέστερων ανέμων με την υπόθεση ότι είναι τα αντιπροσωπευτικότερα του έτους 1997. Οι λιμένες αναψυχής παρατηρήθηκε πως είναι πιο ευάλωτοι στον Βόρειο άνεμο οι παράγοντες προσομοίωσης και τα αποτελέσματα του οποίου παρουσιάζονται στη συνέχεια.

Κυματικό μοντέλο Spectral Wave FM

Η προσομόιωση καθορίστηκε από τους επόμενους παράγοντες:

- Περίοδος προσομοίωσης: 24.10.1997-28.10.1997 (108 χρονικά βήματα)
- Άνεμος (ταχύτητα - διεύθυνση): μετρήσεις κοντά στο Prerow (Zingst)
- Στάθμη νερού: μεταβαλλόμενη σε χρόνο και χώρο (αποτέλεσμα του Gellen Bight μοντέλου)
- Αρχικές συνθήκες: πραγματική προσομοίωση άρχισε στις 23.10.1997
- Οριακές συνθήκες Code22 (βλ. εικ. 8): Ανοικτό όριο με χαρακτηριστικά H_s,T_p,MWD,DSD μεταβαλλόμενα στο χρόνο και κατά μήκος του ορίου (αποτέλεσμα του Gellen Bight Wave model)
- Οριακές συνθήκες Codes 21 and 23 (βλ. εικ. 8): πλευρικά (lateral) χρησιμοποιήθηκαν στα Ανατολικά και Δυτικά όρια
- Παραγόμενα αποτελέσματα: 3 είδη αποτελεσμάτων για κάθε είδους διάταξη
    - ✓ Σημαντικό ύψος κύματος στην είσοδο των λιμένων και τις θέσεις αγκυροβόλησης
    - ✓ Τάσεις ακτινοβολίας για όλο τον τομέα (χρησιμοποιήθηκαν στο υδροδυναμικό μοντέλο)
    - ✓ Κυματικές δυνάμεις (ύψος, περίοδος, διεύθυνση κυματισμών) μεταβαλλόμενες σε χρόνο και σταθερές στο τομέα (χρησιμοποιήθηκαν στο μοντέλο στερεομεταφοράς)



Εικόνα 8: Καθορισμός οριακών συνθηκών

Υδροδυναμικό μοντέλο (Flow model FM)

Η προσομοίωση καθορίστηκε από τους επόμενους παράγοντες:

- Περίοδος προσομοίωσης: 24.10.1997-28.10.1997 (108 χρονικά βήματα)
- Άνεμος (ταχύτητα - διεύθυνση): μετρήσεις κοντά στο Prerow (Zingst)
- Τάσεις ακτινοβολίας: μεταβαλλόμενες στο χρόνο και χώρο (υπολογίστηκαν από το Spectral Wave model)
- Αρχικές συνθήκες: πραγματική προσομοίωση άρχισε στις 23.10.1997
- Οριακές συνθήκες: Καθορισμένη στάθμη (specified level) – μεταβαλλόμενη στο χρόνο και κατά μήκος του ορίου (αποτέλεσμα του μοντέλου Gellen Bight)
- Αποτελέσματα: για όλη την περιοχή μελέτης
    - ✓ Ολικό βάθος νερού
    - ✓ Ταχύτητα κυματογενούς ρεύματος

Μοντέλο στερεομεταφοράς (Sand Transport FM)

Η προσομόιωση καθορίστηκε από τους επόμενους παράγοντες:

- Τύπος μοντέλου : κύμα και ρεύμα
- Διάμετρος κόκκου : 0.2mm
- Δυνάμεις: κυματικές συνθήκες μεταβαλλόμενες σε χρόνο και σταθερές στον τομέα (αποτέλεσμα του μοντέλου Spectral Wave)
- Οριακές συνθήκες: μηδενική μεταβολή της ροής ιζήματος για εκροή και μηδενική μεταβολή πυθμένα για εισροή

Σχολιασμός αποτελεσμάτων

Από το φασματικό κυματικό μοντέλο (Spectral Wave FM) του Mike21 ελέγχθηκαν τα κριτήρια σχεδιασμού σύμφωνα με το σημαντικό ύψος κύματος στην είσοδο των λιμένων και στα σημεία αγκυροβόλησης. Παράλληλα, υπολογίστηκαν και οι τάσεις ακτινοβολίας οι οποίες χρησιμοποιήθηκαν στη συνέχεια στο υδροδυναμικό μοντέλο (Flow model FM) για τον υπολογισμό των κυματογενών ρευμάτων και του ολικού βάθους στην περιοχή.

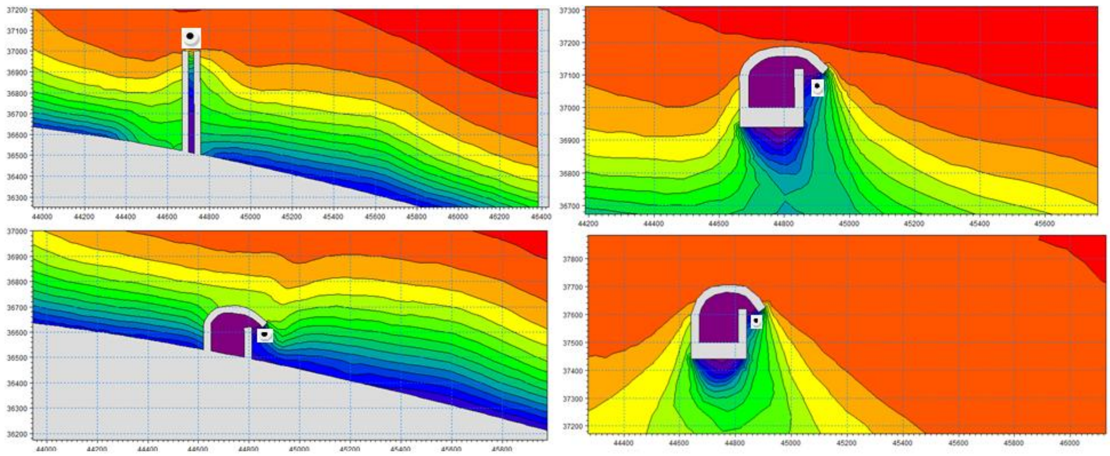
Στον πίνακα 1 παρουσιάζεται η μέγιστη τιμή του σημαντικού ύψους κύματος που παρατηρήθηκε για τα τρία σενάρια προσομοίωσης σε περιοχές κοντά στην είσοδο των λιμένων.

Πίνακας 1: Μέγιστα ύψη κύματος κατά τη διάρκεια της προσομοίωσης

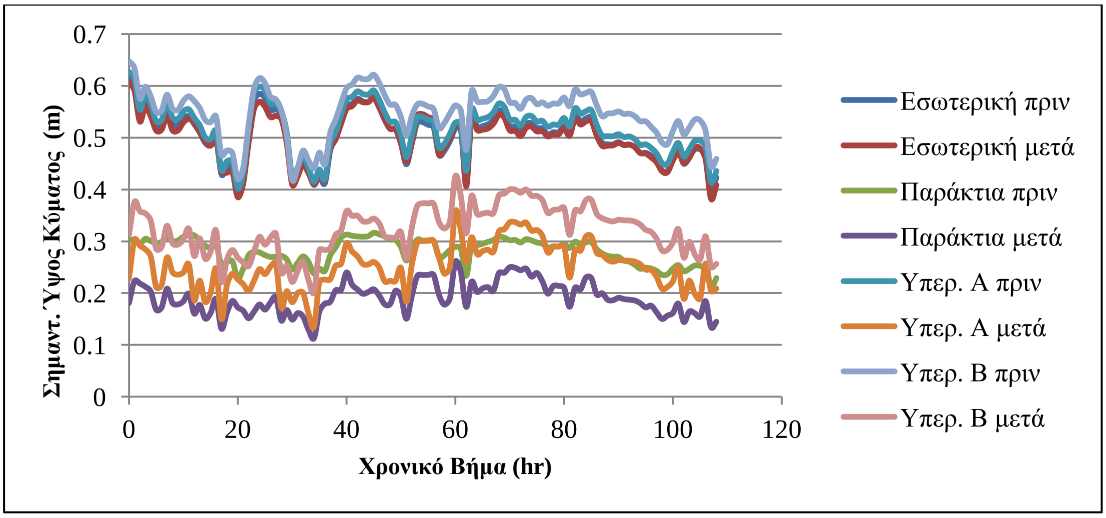
H_{mo} (m)			
Διατάξεις	**Βόρειος (μέσης εντάσεως)**	**Δυτικός (μέσης εντάσεως)**	**Δυτικός (μεγίστης εντάσεως**
Εσωτερική	0.48-0.56(m)	0.32-0.4(m)	0.32-0.4(m)
Παράκτια	0.12-0.36(m)	0-0.24(m)	0-0.24(m)
Υπεράκτια Α	0.04-0.52(m)	0-0.32(m)	0-0.32(m)
Υπεράκτια Β	0.04-0.52(m)	0-0.32(m)	0-0.32(m)

Από τον πίνακα 1 παρατηρήθηκε ότι οι μέγιστες τιμές όταν επικρατέστερος άνεμος είναι ο Βόρειος είναι αρκετά υψηλότερες από εκείνες του Δυτικού. Επιπλέον, οι τιμές του Δυτικού ανέμου είναι περίπου οι ίδιες είτε ο άνεμος πνέει με μέσης ή υψηλής εντάσεως ταχύτητες γεγονός που αποδεικνύει πως οι διατάξεις των λιμένων που σχεδιάστηκαν δεν είναι τόσο ευάλωτες στον Δυτικό άνεμο όσο στον Βόρειο.Το μέγεθος των Δυτικών ανέμων οφείλεται στην προστασία της περιοχής μελέτης από την παρουσία του Darsser-Ort που λειτουργεί ως φυσικό εμπόδιο.

Στην εικόνα 10 παρουσιάζονται οι χρονοσειρές του σημαντικού ύψους κύματος για το Βόρειο άνεμο πριν και μετά το σχεδιασμό των μαρίνων σε σημεία κοντά στην είσοδο των λιμένων όπως παρουσιάζονται στην εικόνα 9.



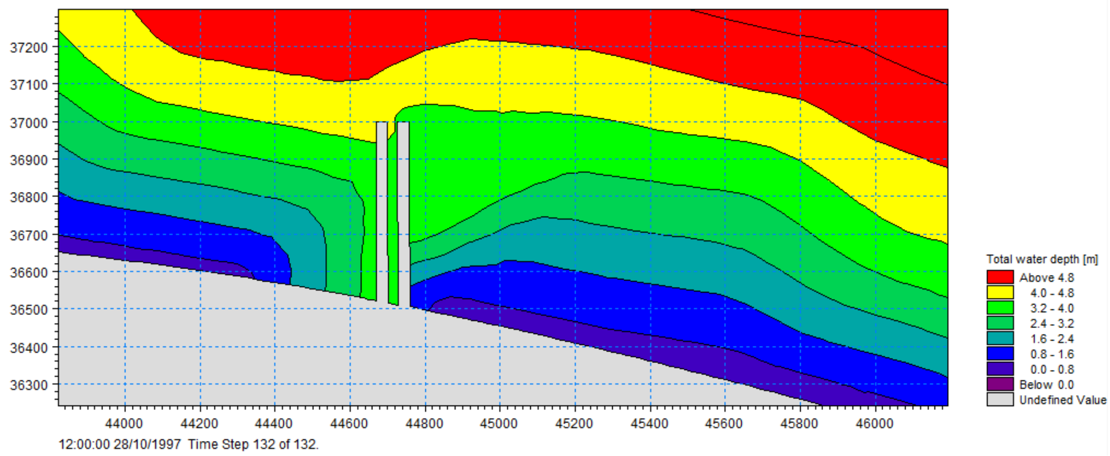
Εικόνα 9: Σημεία κοντά στην είσοδο των λιμένων



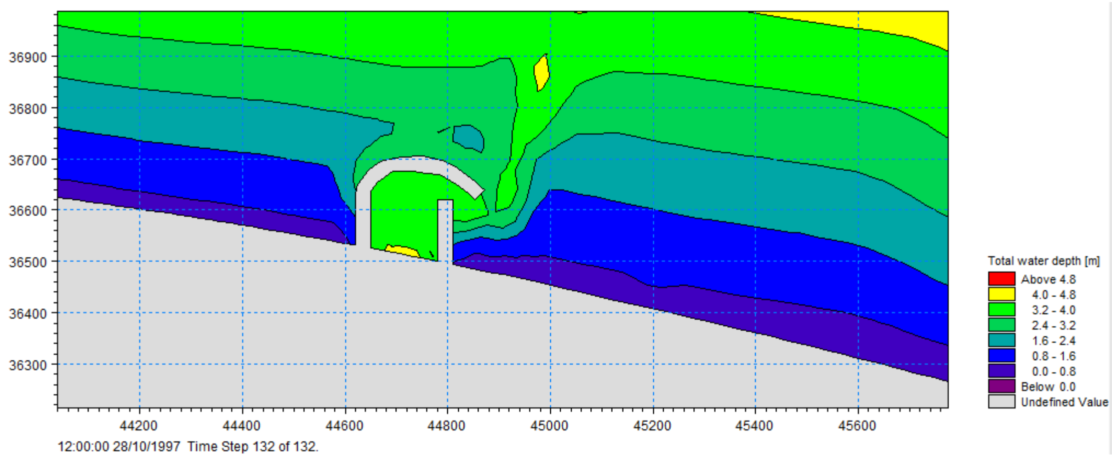
Εικόνα 10: Χρονοσειρές σημαντικού ύψους κύματος των σημείων στην είσοδο των λιμένων

Το σημαντικό ύψος κύματος μετά τον σχεδιασμό των λιμένων είναι χαμηλότερο από 0.6 m για περισσότερο από το 90% του χρόνου προσομοίωσης, όπως απαιτείται από το CEM. Τα κριτήρια καλύπτονται επίσης και για τις θέσεις αγκυροβόλησης (σημαντικό ύψος κύματος χαμηλότερο από 0.3 m για περισσότερο από το 90% του χρόνου). Επιπρόσθετα, παρατηρείται ότι μετά το σχεδιασμό των λιμένων οι αρχικές τιμές του σημαντικού ύψους κύματος μειώθηκαν κατά 50%.

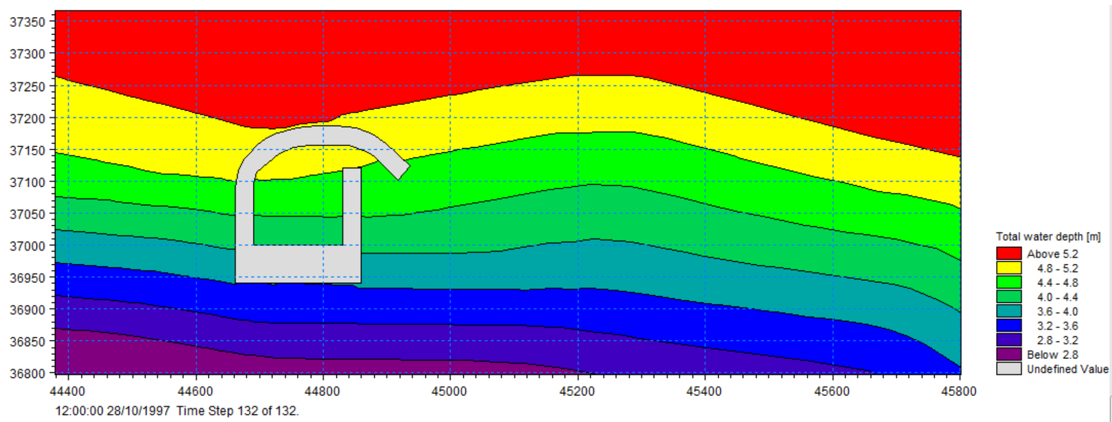
Το υδροδυναμικό μοντέλο έδωσε τα επικρατέστερα κυματογενή ρεύματα και το ολικό βάθος μετά από την προσομοίωση. Το αρχικό ολικό βάθος σχεδιάστηκε να είναι μεγαλύτερο από 3.2 m για την ασφαλή είσοδο –έξοδο και αγκυροβόληση των υπό μελέτη σκαφών. Για το λόγο αυτό, το ολικό βάθος ελέγχθηκε μετά την προσομοίωση. Στις εικόνες 11,12,13 και 14 παρουσιάζεται το ολικό βάθος μετά την προσομοίωση του Βόρειου ανέμου.



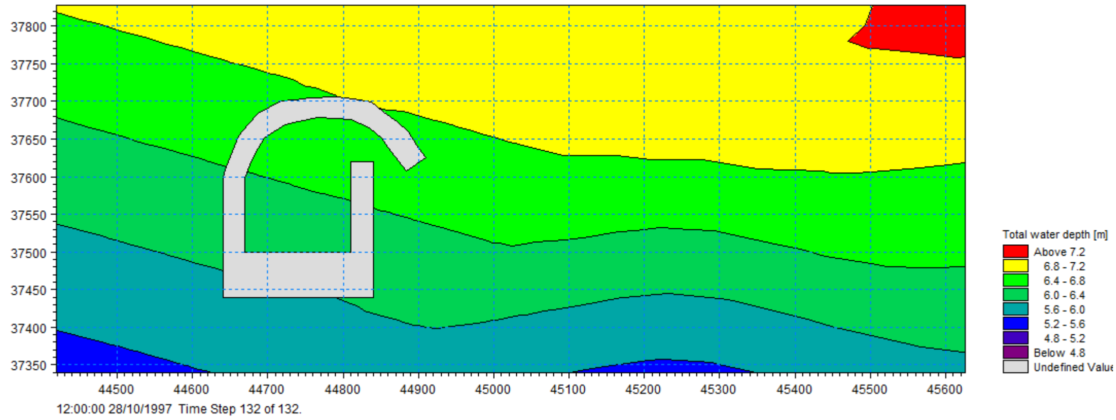
Εικόνα 11: Ολικό βάθος για εσωτερικό λιμένα αναψυχής



Εικόνα 12: Ολικό βάθος για παράκτιο λιμένα αναψυχής



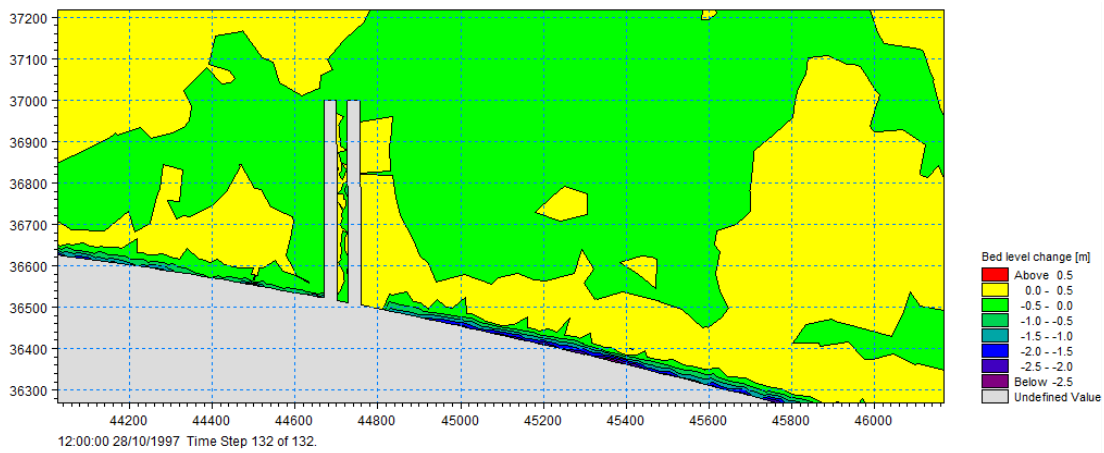
Εικόνα 13: Ολικό βάθος για υπεράκτιο Α λιμένα αναψυχής



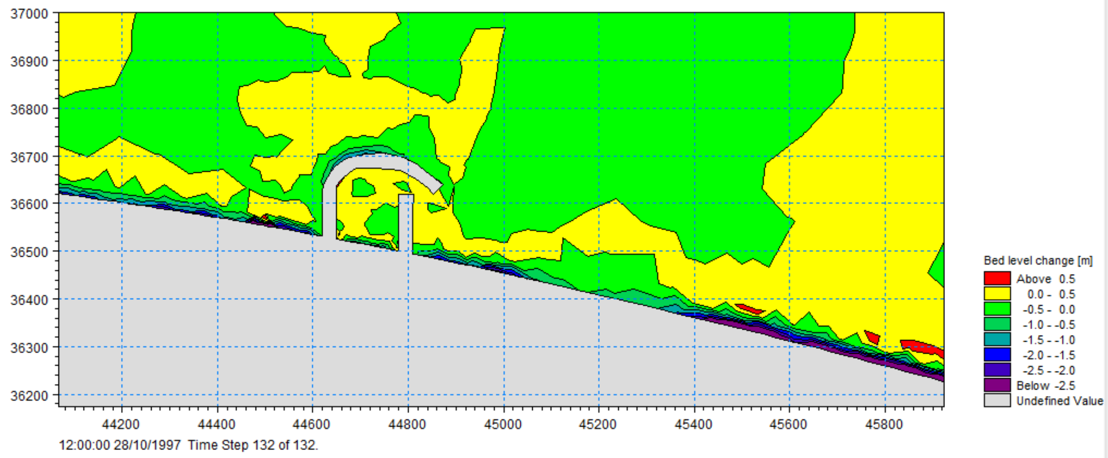
Εικόνα 14: Ολικό βάθος για υπεράκτιο Β λιμένα αναψυχής

Παρατηρήθηκε ότι μετά την προσομοίωση όπου ο επικρατέστερος άνεμος είναι ο Βόρειος, η παράκτια διάταξη έχει ολικό βάθος λιγότερο από 3.2 m κοντά στην είσοδο. Ως αποτέλεσμα, δημιουργείται πρόβλημα στη διέλευση των υπό μελέτη σκαφών. Τα υπόλοιπα είδη λιμένων δεν παρουσιάζουν ιδιαίτερα προβλήματα.

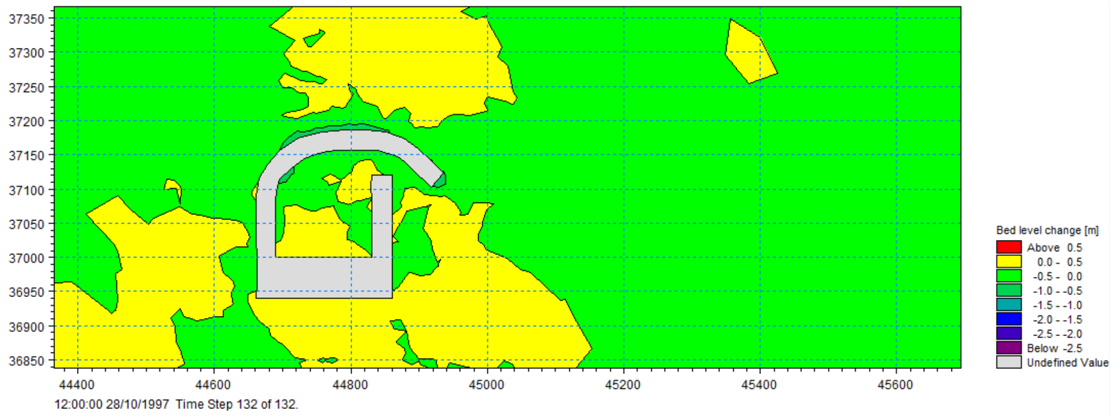
Το μοντέλο στερεομεταφοράς (Sand Transport module) χρησιμοποιήθηκε για την προσομοίωση της κίνησης των ιζημάτων και τα αποτελέσματα που προέκυψαν από αυτό λήφθηκαν υπόψη μόνο ποιοτικά, λόγω έλλειψης δεδομένων για βαθμονόμηση και επικύρωση. Ως εκ τούτου, εντοπίστηκαν οι πιθανές θέσεις απόθεσης ιζήματος ή διάβρωσης τόσο εντός των λιμένων όσο και στην ευρύτερη περιοχή μελέτης. Στις εικόνες 15,16,17 και 18 παρουσιάζονται οι πιθανές περιοχές απόθεσης και διάβρωσης όπως προέκυψαν μετά την προσομοίωση με επικρατέστερο τον Βόρειο άνεμο.



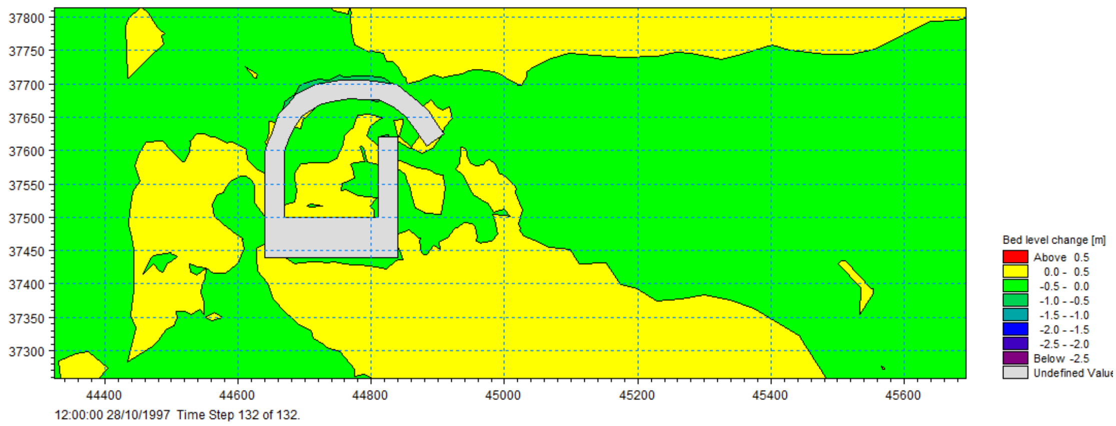
Εικόνα 15: Αλλαγή πυθμένα για εσωτερικό λιμένα αναψυχής



Εικόνα 16: Αλλαγή πυθμένα για παράκτιο λιμένα αναψυχής



Εικόνα 17: Αλλαγή πυθμένα για υπεράκτιο Α λιμένα αναψυχής



Εικόνα 18: Αλλαγή πυθμένα για υπεράκτιο Β λιμένα αναψυχής

Ο εσωτερικός λιμένας παρουσιάζει τάση για διάβρωση στο δυτικά του δυτικού κυματοθραύστη και τάση για συσσώρευση ιζήματος στην ανατολική πλευρά του ανατολικού κυματοθραύστη. Παραπέρα, σημαντική τάση για διάβρωση παρατηρείται κατά μήκος της ακτογραμμής. Στις υπόλοιπες διατάξεις μαρίνων, επικρατεί η τάση για διάβρωση στο Βόρειο μέρος εξωτερικά της κατασκευής και συσσώρευση ιζήματος κοντά στην είσοδο.

Συμπεράσματα

Λαμβάνοντας υπόψη τα αποτελέσματα των μοντέλων οι προτεινόμενοι λιμένες για σκάφη αναψυχής είναι ο εσωτερικός και υπεράκτιος Α. Και οι δυο περιπτώσεις καλύπτουν τα κριτήρια που ελέχθησαν σε όλα στα στάδια της εργασίας. Η τελική επιλογή θα βασίζεται σε περαιτέρω πιο λεπτομερείς έρευνες (π.χ βέλτιστη πρόσβαση των σκαφών στις μαρίνες) καθώς και σε περιβαλλοντικές, οικονομικές και κοινωνικοπολιτικές μελέτες.

Η περίπτωση της παράκτιας διάταξης απορρίφθηκε καθότι το ολικό βάθος μετά την προσομοίωση ήταν λιγότερο από το απαιτούμενο για τα υπό μελέτη σκάφη καθιστώντας αδύνατη την είσοδο και την έξοδό τους. Επιπλέον, μέσα στην λιμενολεκάνη υπάρχει τάση για συσσώρευση ιζήματος στη Βόρεια πλευρά δημιουργώντας ερωτήματα για την ασφαλή αγκυροβόληση των σκαφών.

Οι δυο περιπτώσεις των υπεράκτιων διατάξεων καλύπτουν τα κριτήρια που ελέχθησαν ενώ παράλληλα δεν παρουσιάζουν σημαντικές διαφορές μεταξύ τους. Έτσι, η περίπτωση της πλησιέστερης στην ακτή (υπεράκτια Α) επιλέχθηκε και εκείνη της υπεράκτιας Β απορρίφθηκε.

Προτάσεις για περαιτέρω έρευνα

Μια πλήρης μελέτη στερεομεταφοράς κοντά στο Prerow κρίνεται αναγκαία ώστε να καθοριστούν τα πιο κρίσιμα γεγονότα που επηρεάζουν σημαντικά την περιοχή. Παράλληλα, σταθμοί μετρήσεων (Gauging stations) κοντά στο Prerow θα βοηθήσουν σε μελλοντικές μελέτες και μοντέλα προσομοίωσης ικανά να βαθμονομηθούν και να επικυρωθούν διασφαλίζοντας την αξιοπιστία των αποτελεσμάτων σε μελλοντικές έρευνες.

Από αυτή την αρχική προσέγγιση για βελτιστοποίηση του σχεδιασμού λιμένα σκαφών αναψυχής έγινε αντιληπτό πως για τον Βόρειο άνεμο παρατηρείται εντονότερη προσάμμωση εντός λιμενολεκάνης και στην είσοδο του λιμένα για όλες τις εναλλακτικές διατάξεις που εξετάστηκαν με εξαίρεση την εσωτερική. Για το λόγο αυτό η προσομοίωση ενός έντονου ανεμολογικού γεγονότος με επικρατέστερο τον Βόρειο άνεμο κρίνεται απαραίτητη.

Εξωτερικά των λιμένων αναψυχής στο Βόρειο τμήμα επικρατεί η τάση για διάβρωση και συνεπώς κρίνεται απαραίτητη η περαιτέρω έρευνα του βαθμού διάβρωσης καθώς επίσης και οι πιθανές επιπτώσεις στην ευστάθεια της κατασκευής.

Για την οριστική επιλογή της τελικής διάταξης του λιμένα αναψυχής (εσωτερική, παράκτια, υπεράκτια) κρίνεται αναγκαία η εκπόνηση περιβαλλοντικών, κοινωνικών και οικονομικών μελετών όπως επίσης και μελέτες για την καλύτερη πρόσβαση στους λιμένες ως προς την ναυσιπλοΐα.

Η προσομοίωση και η σύγκριση διαφορετικών υπολογιστικών μοντέλων ή ακόμη και φυσικών μοντέλων στο εργαστήριο θα δώσει μια ολοκληρωμένη πρόταση για την λήψη της τελικής απόφασης.

Introduction

This study is an initial investigation of designing a harbour for pleasure boats on the area of Prerow which is of urgent need due to the lack of an emergency stop for the trip from Rostock to Hiddensee. During the last years many accidents occur when kids or elderly people are on board especially under bad weather.

Main goal of the study is to understand in an initial level how three different kind of harbours design (inshore, onshore and offshore) correspond under extreme events and to propose the best performance of harbour variant.

Nowadays, the modern offshore design of harbours for pleasure boats (known as island harbours) shows many hydrodynamic and geomorphological advantages in comparison with the conservative onshore constructions on sandy coasts. Problems such as dredging on shallow water areas with intense sediment transport can be avoided with the offshore design option. Moreover, harbour islands encourage the touristic development as they can provide sea sport activities or host different kind of shops.

As a background of the study, three different tasks have been carried out. Starting with the comparison of some of the simulation tools in the market nowadays in order to choose the most appropriate for this study. The goal of the second task was to point out the importance of metadata and to identify the European and German organizations referring to seadata and find out where the information for this case study are kept. The third task with the use of Shev statistical programme has been needed in order to identify the changes on the coastline of Darsser-Ort during the last decades. rom a global scale with the systems' changes and behaviour during the last decades and going on with the change of Darsser-ort coastline during the last decades.

Hereby, it's important to mention that this case is a simple pre-study. Starting with the data provided which do not let to have a complete picture and it is not possible to know whether the events simulated are typical or not. Timeseries over 10 years should have been analyzed in order to identify the most critical situations. Hence a more detailed study with larger time periods is of high need. A study of this kind could define which storm events are important and which are not. Moreover, measuring stations at Prerow are necessary in order to use simulating programmes able to be calibrated.

Further studies should be executed on the environmental, economical and social domains. Moreover, a full sediment transport study should be applied for Prerow.

Despite the difficulties and the problems on the gap of data, the basic steps were implemented and the procedure was completely followed.

Finally, the proposals given and the conclusions have been made with the assumption that the events simulated are the typical for the year 1997.

Chapter 1: Background

For the need of this thesis some general taskes had to be carried out before starting the simulation process.

The first task has to do with the available simulation tools on the market and to define the most appropriate one for this specific case study. As a result a comparison between some tools on the market was done in order to get an initial feeling of the abilities of each of them.

Another task carried out was to introduce the metadata and the importance of keeping the information alive during time. The European Infrastracture for spartial information (INSPIRE) and the Seadatanet are mentioned. The goal was to identify the German organizations for sea metadata and thus the data for Prerow (study area).

The third task refers to the prediction of Darsser-Ort on 2050 with the use of the Shev statistical programme. Understanding the change of Darsser-Ort during the last decades gives a general overview of the whole system in a long term process and a general feeling about the future form of the coastline.

Task 1: Available simulation tools for coastal areas

Simulation tools are used for the approximation of the reality. The model's purpose is not to make the user understand the physical phenomena but the consequences of events and human activities, as the model is just a correlation between inputs and outputs.

In this task, some of the most popular and practical simulation tools are mentioned. This was done in order to get a feeling about the simulation tools in the market. For this reason a chart was created showing part of the availabilities of each coastal simulation tool, the developed sub programmes, the programmes under development and the costs or free versions of the software packages.

Each simulation programme has different cost, access, efficiency, field of simulation capability, way of installation and many other parameters and thus "the best" simulating programme cannot be proposed.

1.1. Introducing companies under investigation

HALCROW (U.K)

Halcrow has developed ISIS. ISIS is a software package which is used for river modeling. ISIS 2D was released in 2009 and is a fully hydrodynamic computational tool which is designed to work either standalone or within the ISIS suite. It has been developed to the new 2D modeling software called TU FLOW (Halcrow, 2012).

<u>Software packages</u>

The new licensing structure includes its open source. It has the same functionality as ISIS Professional, but is limited to 200 nodes and 10mb of ISIS Mapper input files. It can be used for smaller modeling projects.

DELTARES (NETHERLANDS)

Deltares system is mainly known for its experimental facilities and its software services including coastal waters and estuaries (Delft3D), rivers and urban water management (SOBEK), the design of diaphragm wall structures (D-Sheet Piling) and the stability of flood defences (D-Geo Stability) (Deltares, 2012).

Software Packages

Deltares offers high quality services to consultancy firms, governmental organizations, universities and research institutes worldwide. Several Delft3D service packages, including fully validated high quality Delft3D distributions, are available to cover specific needs.

For consultancy firms, governmental organizations and research institutes worldwide Basic Service Packages, Advance Service Packages, Professional Service Package, Premium Service Package and Enterprise Service Package have been designed. For universities and schools, Education Service Package is offered. Code developers are supported with Developer Service Package.

EDF (FRANCE)

EDF is a nuclear energy company, with solid positions in major European countries. The company has many fields of activities, some of which are scientific computing, hydraulics and ecology. EDF consists of a research and scientific community, which develops new simulating tools, such as TELEMAC (EDF, 2012).

Software Packages

TELEMAC is used mainly for dimensioning and impact studies. TELEMAC for the whole community of consultants and researchers, has made the choice of freeware and open source. Everyone can thus take advantage of TELEMAC and assess its performances by finding necessary resources on the website. However the quality of assistance, maintenance and hotline support are also very important to professional users, and a special effort has been made to offer alternatively a broad range of fee-paying services.

MarCon Computations International Ltd (IRLAND)

MarCon Computations International Ltd. is an Irish company, based in Galway, providing advanced modeling capabilities in the marine and fresh water environment.

The company specializes in the development and application of hydroinformatics software tools, primarily aimed at design appraisal studies of coastal, estuarine and river projects and hydro-environmental impact assessment studies for coastal and inland water bodies. The models are able to investigate processes like water circulation, sediment transport, water quality, eutrophication, force calculations, biological processes, wave climate analysis, particle tracking and heavy metal transport.

Marcon Services can provide a lot of hydraulic simulating tools which have to do with coastal processes modeling, river hydraulic and environmental modeling, coastal hydraulic and environmental modeling, coastal diffuser design and dredge spoil analysis and numerical models. For coastal modeling and estuarine DIVAST model has been developed (MarCon, 2012).

MIKE by DHI (DENMARK)

MIKE by DHI is consisted of a variety of model able to simulate many fields of water.

The coastal software packages are typically used to simulate flow phenomena and related processes in coastal areas and seas. The two main products are MIKE 21 and MIKE 3 for two- and three-dimensional water modeling. Moreover, LIPTRACK by DHI is a specific tool for physical processes controlling the transport and sedimentation of beach materials. Last but not least, MIKE FLOOD is a tool available for flood modeling (DHI, 2012). The basic characteristics and application areas of each model will be analyzed in the following pages.

<u>Software Packages</u>

MIKE by DHI has web based demonstrations but one can also download demo versions. Moreover, student licenses can be provided.

1.2 Comparison

After having analyzed the simulating tools from 5 different companies, a comparison was done showed on Tables 1.1, 1.2 and 1.3. Through this comparison, it is able to find out which programme is the most appropriate or has more sub-programmes for a specific simulation. More extensive characteristics for the simulation tools can be found at the manuals or websites of each company.

The tables 1.1, 1.2 and 1.3 show the application areas of each simulating programme. Some programmes use subprogrammes for specific implementations. Therefore, specific signals are used at the chart (ex. Delft 3D has the sub-programmes Delft 3D - flow to simulate waves, currents, air pressure, turbulence and floods and it is showed with the signal ⅩⅩ). Moreover with the green colour it is showed that some simulating tools are still under development (such as the ISIS water quality processes) Finally, with dark blue are showed the areas that some simulating tools can be used for (such as TELEMAC with the COWADIS which is able to simulate sediment transport) but not detailed information had been found.

Table 1.1 Comparison of dimensions, hydrodynamics and sediment transport applications

		ISIS		DELTARES		TELEMAC				DIVAST	DHI			
		TUFLOW	TUFLOW FV	DELFT3D	BREAKWAT	2D	3D	ARTEMIS	COWADIS		MIKE21	MIKE3	FLOOD	LIPTRACK
DIMENSIONS	1D	•											•	
	2D	•	•	•		•				•	ɪ		•	
	3D		•	•			•					•		
HYDRORYNAMICS	WINDS	•	•	Њ						•	ɪ т Ǝ ♦	•		ʅʈ
	WAVES	•	•	Ӿ Њ	•			•	•	•	ɪ т Ǝ ▲ ♦	•		ʅʈƹ
	CURRENTS		•	Ӿ	•			•	•	•	т			ʅƹ
	AIR PRESSURE			Ӿ					•					
	TURBULENCE			Ӿ		•				•				
	TIDES		•											ʈ
	SHOALING			Њ							█╫			ʈƨ
	WAVE BREAKING			Њ							▲█			
	REFRACTION			Њ							Ǝ ▲ ♦╫			ʈƨ
	DIRECTIONAL SPREADING			Њ										
SEDIMENT TRANSPORTATI	SUSPENDED LOAD			þ										
	BED TOTAL LOAD			þ						•				ƹ
	SAND(ST)	•	•			•		•			▦ т	•		
	MUND (MT)		•								▦ т	•		
	PARTICLE (PT)						•				т	•		

Ӿ	DELFT3D D-FLOW
þ	DELFT3D D-MORPHOLOGY
Њ	DELFT3D -WAVES
Џ	DELFT3D- D-WATER QUALITY
Ж	DELFT3D- ECOLOGY
(light green)	UNDER CONSTRUCTION
(dark teal)	AVAILABLE TO SIMULATE

ʈ	LITDRIFT
ʅ	LITSTP
γ	LITLINE
ƨ	LITPROF
ƹ	LITTREN

ɪ	FLOW MODEL
т	FLOW MODEL FM
Ǝ	SPECTRAL WAVES FM
▲	BOUSSINESQUE
♦	NEAR SHORE SPECTRAL WAVES
█	ELLIPTIC MID SLOPE WAVE MODEl
╫	PARABOLIC MILD SLOPE EQUATIO
▦	SEDIMENT TRANSPORT

One example can be given for the use of these charts. Supposing that a wave module for a specific simulation is needed, then it can be observed from the chart above that there are many options between the companies.

However, Delft-3D has specific tools for waves and those are Delft-3D flow and Delft-3D waves. The same option is given from MIKE21 with the Flow model, Flow model FM, spectral waves FM, nearshore–spectral waves and Boussinessque.

Hence, one can see the options that are provided and by studying the manuals of each sub–programme, the most appropriate tool for the simulation can be chosen.

Table 1.2: Comparison of water quality process, ecology and equations

		ISIS		DELTARES		TELEMAC				DIVAST	DHI			
		TUFLOW	TUFLOW FV	DELFT3D	BREAKWAT	2D	3D	ARTEMIS	COWADIS		MIKE21	MIKE3	FLOOD	LIPTRACK
WATER QUALITY PROCESS	TRANSPORT			ɥ										
	EROSION			ɥ										
	ORGANIC/ INORGANIC			ɥ										
	SUSPENDED OR BED SEDIMENTS			ɥ										
	SETTLING OF COHENSIVE/NON-COHENSIVE			ɥ										
	EUTROFICATION			Ж						•				
ECOLOGY	BIOTIC/ABIOTIC ECOSYSTEMS			Ж										
	ENVIRONMENTAL IMPACT										•	•		
EQUATIONS	NLSW		•								•			
	2D FREE SURFACE	•								•				
	BERKHOFF'S EQUATION							•						
	MID SLOPE EQUATION							•						
	ST.VENANT(SWE)						•							
	1D ST. VENANT					•								
	DIFUSSION EQUATION									•				ʅɛ
	SIGMA APPROACH							•						

ɀ	DELFT3D D-FLOW
ƅ	DELFT3D D-MORPHOLOGY
Ҍ	DELFT3D -WAVES
ɥ	DELFT3D- D-WATER QUALITY
Ж	DELFT3D- ECOLOGY
ʈ	LITDRIFT
ʅ	LITSTP
ɣ	LITLINE
ƨ	LITPROF
ɛ	LITTREN
ɪ	FLOW MODEL
ᴛ	FLOW MODEL FM
ɜ	SPECTRAL WAVES FM
▲	BOUSSINESQUE
♦	NEAR SHORE SPECTRAL WAVES
▌	ELLIPTIC MID SLOPE WAVE MODEL
╫	PARABOLIC MILD SLOPE EQUATIO
▓	SEDIMENT TRANSPORT
(light green)	UNDER CONSTRUCTION
(dark teal)	AVAILABLE TO SIMULATE

Table 1.3: Comparison of computational methods, software packages, availability of advection/dispersion, structures, storm events and floods

		ISIS		DELTARES		TELEMAC				DIVAST	DHI			
		TUFLOW	TUFLOW FV	DELFT3D	BREAKWAT	2D	3D	ARTEMIS	COWADIS		MIKE21	MIKE3	FLOOD	LIPTRACK
METHODS	FINITE VOLUME	•	•			•	•				ɜᴛ			
	FINITE ELEMENT					•								
	FINITE DIFFERENCE									•	ɪ♦╫			
ADVECTION/ DISPERSION	PLUMES POLLUTANTS	•	•								ɪ			
	DECAY COEFFICIENT	•	•								ɪ			
OTHERS	STRUCTURES	•	•	•	•	•		•			ɜ▲▌	•		ɣ
	STORM EVENTS		•								•	•		ƨ
	FLOODS	•		ɀ						•	•	•	•	
SERVICES	SERVICE PACKAGES	•		•		•				•	•			
	EDUCATIONAL /FREE PACKAGES	•		•		•				•	•			

ɀ	DELFT3D D-FLOW
ƅ	DELFT3D D-MORPHOLOGY
Ҍ	DELFT3D -WAVES
ɥ	DELFT3D- D-WATER QUALITY
Ж	DELFT3D- ECOLOGY
ʈ	LITDRIFT
ʅ	LITSTP
ɣ	LITLINE
ƨ	LITPROF
ɛ	LITTREN
ɪ	FLOW MODEL
ᴛ	FLOW MODEL FM
ɜ	SPECTRAL WAVES FM
▲	BOUSSINESQUE
♦	NEAR SHORE SPECTRAL WAVES
▌	ELLIPTIC MID SLOPE WAVE MODEL
╫	PARABOLIC MILD SLOPE EQUATIO
▓	SEDIMENT TRANSPORT
(light green)	UNDER CONSTRUCTION
(dark teal)	AVAILABLE TO SIMULATE

In this case study a wave model, a flow model (hydrodynamic model) and a sand transport model were needed. These implementations could be fully covered from Mike21 of DHI software packages. Moreover, student license DHI has been provided to the university and later on a dongle key from DHI.

Task 2. Metadata, the European framework and the German organizations for seadata

In this task, the definition and the importance of Metadata is analyzed while at the second part the European framework for Sea Metadata is explained. At the end, the German organizations are mentioned. For this thesis part of the data have been found from the Morwin project (http://morwin.hosted-by-kfki.baw.de/) which has been completed. The data from the Morwin project are maintained within the framework of another German coastal engineering research council project called Nokis.

2.1 Definition of Metadata

Metadata is structured data that explains, describes, locates, or in other words makes it easier to use, or manage an information resource. A Metadata record is a file of information, which most of the times is presented as an XML document, and includes the basic characteristics of data and information resource and represents the who, what, when, where, why and how of the resource. Metadata is data providing information about one or more aspects of the data. In other words, Metadata ensures that resources will survive and continue to be accessible. Metadata is usually called data about data or information about information.

Metadata give information about the means of creation of the data, purpose of the data, time and date of creation, creator or author of data, placement on a computer network where the data was created, standards used and many other information. In other words, metadata is also data.

2.2 INSPIRE Directive – Infrastructure for Spartial Information in Europe

The INSPIRE Directive established an infrastructure for spatial information in Europe to support Community environmental policies but also policies or activities which may have an impact on the environment (http://inspire.jrc.ec.europa.eu/).

INSPIRE is based on the infrastructures for spatial information and is organized and regulated by the European Union. The Directive directs 34 spatial data themes needed for environmental applications, with key components specified through technical implementing rules.

The INSPIRE directive has a goal; to create a European Union (EU) spatial data infrastructure. As a result, sharing of spatial information among public sector organizations will be enabled and public access to spatial information across Europe will be easier.

A European Spatial Data Infrastructure will support in policy-making across boundaries. As a result, the spatial information considered under the directive is wide and includes a great variety of topical and technical themes. This is the reason why INSPIRE is depending on common principles:

- Data should be collected only once and kept where it can be maintained most effectively.

- It should be possible to combine seamless spatial information from different sources across Europe and share it with many users and applications.

- It should be possible for information collected at one level/scale to be shared with all levels/scales; detailed for thorough investigations, general for strategic purposes.

- Geographic information needed for good governance at all levels should be readily and transparently available.

- Easy to find what geographic information is available, how it can be used to meet a particular need, and under which conditions it can be acquired and used.

2.2.1. Sea DataNet: a representative example of INSPIRE

SeaDatanet works under the framework of INSPIRE and is specialized on collecting and providing data for the European Seas.

As it is widely analyzed at the original site (http://www.seadatanet.org/) SeaDataNet is a standardized system for managing the large and diverse data sets collected by the oceanographic fleets and the automatic observation systems. The SeaDataNet infrastructure network develops the currently existing infrastructures, which are the national oceanographic data centres of 35 countries, active in data collection. The networking of these professional data centres, work and provide integrated data sets of standardized quality on-line.

2.3 Organizations for seadata in Germany

In Germany, under the framework of SeaDataNet, the national databases for SeaData are operated by the organizations called NOKIS, MUDAB, CONTIS, MYRSYS and CoastDat. The role of these organizations the obligations and the way they function is widely analyzed at the original site (http://www.seadatanet.org/). A short description for the those organisations is following.

- NOKIS-Information Infrastructure for the North and Baltic Sea is an information system with the aim of shared internet-based use of existing geodata, hosted by the German Coastal Engineering Research Council KFKI. NOKIS++ is a project which mainly deals with the research on the implementation of information infrastructures as part of Integrated Coastal Zone Management. In this case study, parts of the data were provided from the Morwin (http://morwin.hosted-by-kfki.baw.de/) research project which was completed on 2000 and is now maintained within the framework of Nokis[1].

[1] Since the project was completed long time ago, there are many folders of the research procedure that have been removed from Morwin website.

- MUDAB-Marine Environmental Data Base. Germany is the primary database for marine environmental monitoring data collected by German federal states and state agencies, operated by the German Oceanographic Data Centre (NODC).
- CONTIS-Continental Shelf Research Information System Germany is an ocean data base developed by the Federal Maritime and Hydrographic Agency (BSH) in order to visualise geodata of present and future uses of the marine environment.
- MURSYS (Meeresumwelt-Reportsystem - Marine Environment Reporting System) is a regularly published report providing information on physical and chemical parameters (sea surface temperatures, water levels, current conditions) in the area of Baltic Sea
- The coastDat database is operated by the Institute for Coastal Research at GKSS providing atmospheric, oceanic, sea state and other parameters for the North Sea and NE Atlantic as results from either reconstructions or future projections based on numerical models driven by observed data or climate change scenarios.

Task 3: Prediction of Darsser–Ort shoreline using the statistical coastline analysis programme Shev

In this part, the area under investigation is Darsser Ort (Figure 1.2), which length is approximately 4.6km. The goal is to make an estimate on possible location of the shoreline of 2050, under statistical analysis, using existing data.

This region was chosen in order to get familiar with the sediment transport changes on a global scale and learn in a long term process the general behavior of the area. Moreover, understanding the historical development of the coastline and its progression the last decades will help to estimate the future location of the shoreline.

This specific area was chosen due to the fact that it is not exposed to yearly dredging activities or human structures as it is a protected area. Hence, the results wouldn't be affected and would be representative.

Figure 1.1 Map of Darsser-Ort

Figure 1.2 Darsser-Ort shoreline

The figures 1.1 and 1.2 show the shoreline at Darsser–Ort today. On figure 1.2 can be observed the "like tree rings" the progression of the coastline.

The shoreline data used as database have to do with the years 1950, 1972, 1998 and 2030. The data were found after research of the Halle university (http://mars.geographie.uni-halle.de/geovlexcms/golm/geomorph/darssgenese/animation)

Specifically, the maps which were used are the following:

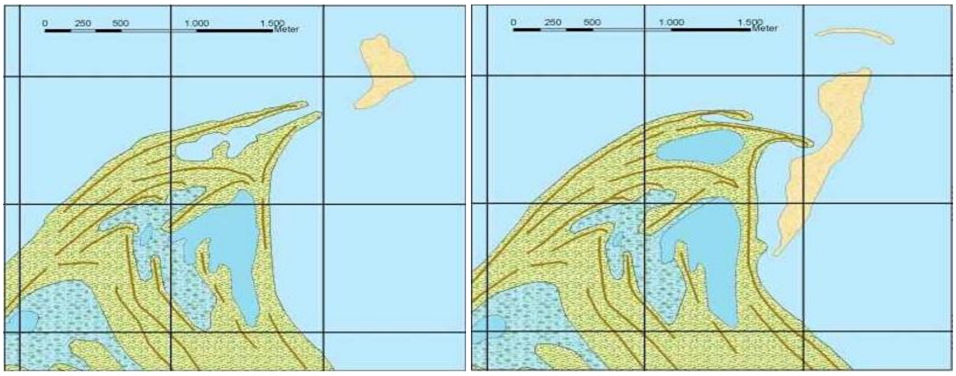


Figure 1.3: Maps 1950 and 1972

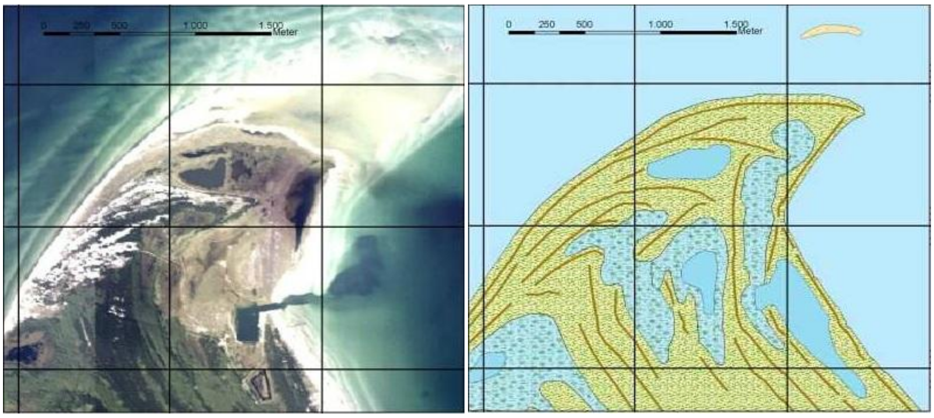


Figure 1.4: Maps 1998 and 2030

The maps on figures 1.3 and 1.4 were transferred to Autocad2005 environment and the shorelines were distracted. The goal was the distances between the different year coastlines to be defined. Those distances were introduced into the statistical analysis programme used; Shev and the annual rate of change of the coastline was predicted.

3.1 Rate of coastline change

The rate of the coastlines is one of the most important parameters used to determine the dynamic of the coastal zone. The rate of the coastlines most of the times shows a cumulative impact of all the events that have happened to the coast in the past and have affected it. The accuracy that the rate of the coastline expresses this impact depends on:

- The accuracy of representation of the coastline
- The amount of the changes of the coastline through the years
- The number of data points (counted coastline positions that have been used)
- The temporal closeness of each observation at the time of a real change
- The time period between measurements at the coastline
- The total amount of data for the coastline through the years
- The method that is used for the rate to be calculated

The forces that affect the change of the coastline include natural causes (tides, change of average water sea level, feed of sediment, geological issues, climate change) as well as human causes (constructions at the coastal zone) (Doukakis, 2012).

3.1.1 Errors at the whole procedure

There are many ways, that errors at the procedure of the rate calculation can take place. Those errors affect the total result and it is good to be avoided or minimized. Those errors can appear at the part of receiving the information, posting the information, the means that are used for posting the information or changes of average sea water level between some time periods. Below three kind of errors are introduced and have to do with the part of receiving the information, posting the information and the mathematical calculations.

3.1.1.1 Receiving the information

Recording the right date and time of the information is a very important issue cause it is easier the average sea surface elevation to be counted closer to reality. The factors that affect the surface elevation of the sea are usually periodical, such as tides, but unfortunately their period or range is unknown. Moreover, storm events, currents, winds and waves can also affect the sea water level usually during the winter.

The best period to survey a coastline is summer season and especially the last months after the procedure of sand replacement has been completed due to the changes on summer and winter beach profile as showed on figure:1.5.

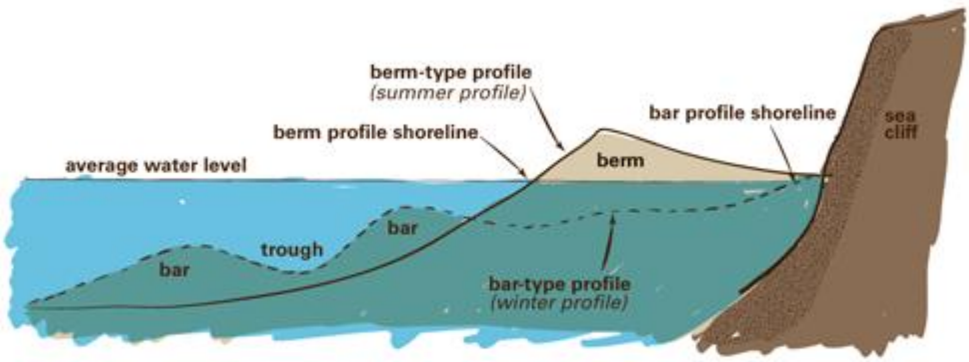


Figure 1.5: Winter and summer profile of the beach (source: http://fcit.usf.edu/florida/teacher/science/mod2/images/Fig_06_summwintprof.png)

3.1.1.2 Posting of the coastline

At the posting procedure, the errors that are introduced come from primary data (topographic maps, aerial photos etc). Their affect can be calculated though. The errors come from the method that the posting is done. Nowadays, posting is done with digital methods mainly.

3.1.1.3 Mathematical calculations

Each method used to calculate a coastline, is based on a mathematical model that analyzes the data and calculate the rate of the coastline. The simple methods that are usually used to determine the coastline give bigger errors than the most complicated modern ones. Moreover, the methods which suppose the same linear interpolation at the whole length of the coastline have bigger errors than those which do not use a linear interpolation model or divide the coastline into smaller parts with different rates.

The Shev programme which was used in order to predict the coastline of 2050 uses 10 mathematical methods. Three of the most appropriate for this exercise methods have been used at this task. The rest methods need a lot of information in order the calculations to be done (more than 3 coastlines), this is why they are not used for this case study.

The mathematical equations that these 3 methods are using are analyzed extensively at the annex C.

3.2 Implementation of Shev programme at Darsser ort predicting the shoreline for 2050

Two scenarios were used in order the shoreline of 2050 to be predicted.

At the first scenario, the already predicted from the university of Halle shoreline of 2030 was not used as data base. This was done in order to predict the 2030 shoreline with the Shev programme and to compare it with the already predicted one from Halle university.

At the second scenario, the already predicted from the university of Halle shoreline of 2030 was used as a real coastline. This was done in order to compare it with the 2050 shoreline which was predicted from the scenario A.

<u>Scenario A</u>:

The cross sections were divided every 50m vertical to the shoreline of 1998 because this is the year with the latest shoreline data. The cross–sections which did not cross all the shorelines (1950 and 1972) were erased. On figures 1.6 the shorelines of 1950, 1972 and 1998 are showed as well as the cross-sections vertical to 1998 shoreline.

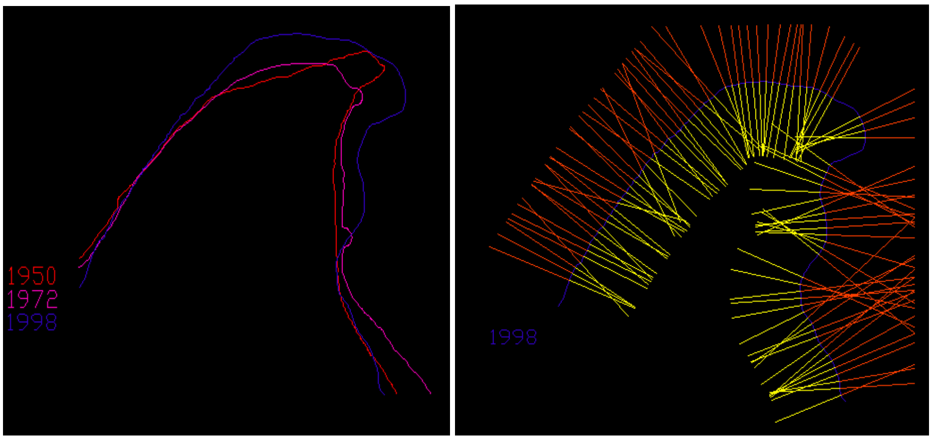


Figure 1.6 : Shorelines 1950, 1972 and 1930 and cross sections vertical to 1998

Using the Shev Programme, the average rate of the coastline predicted with EPR, AOR and AER Methods which is showed on table 1.4.

Table 1.4 : Average rate taking into account 1950 and 1972 coastlines

Method EPR	2.12 +/- 4.1667e-005 m/yr
Method AOR	2.088 +/- 0.0001129 m/yr
Method AER	2.072 m/yr

Using the individual rate of each cross section, the programme is able to provide the prediction of the coastline at 2030. The shoreline for 2030 was predicted with AOR method as it is the most representative due to the Tmin criterion (explained at annex C).

Figure 1.7 Predicted 2030 with Shev (brown) and comparison with the Hall's university (green)

As it is can be easily seen, the predicted coastline is not close to the already predicted from the Halle university. This is mainly because the Shev programme is just a statistical programme and it doesn't take into account the dynamics of the area. Moreover, the period between the maps is almost 20years as there are no information in between. Questions are also created about the accuracy of the oldest 1950 shoreline. Last but not least, due to lack of information the way that the 2030 was predicted from Halle university is not known.

Despite that, taking a closer look to figure 1.8, it is seen that at one specific area the coastline instead of increasing (as it was expected from the shape of the coastline the last decades), is by far decreasing. This is due to the fact that the 1950 shoreline affects the mathematical calculations.

Figure 1.8: Shev's programme 2030 prediction in comparison with Hall's university prediction

For this reason, one more calculation is done without using the 1950 shoreline. Thinking further the information of 1950 are possible not to be accurate or close to reality due to the lack of good measurement tools of the past.

Following the same procedure the new increased rate of the coastline without taking into account the 1950 information, is shown at the table 1.5:

Table 1.5 New rate of the coastline

Method EPR	2.7813 +/- 7.6923e-005
Method AOR	2.7813 +/- 0.00051887 m/yr
Method AER	2.7813 m/yr

From table 1.5 is observed that all the methods give the same result. This was expected due to the fact that the data are reduced and only the shorelines of 1972 and 1998 are used. The shoreline was once more drawn using the analytical for each cross section prediction of AOR method showed on figures 1.9.

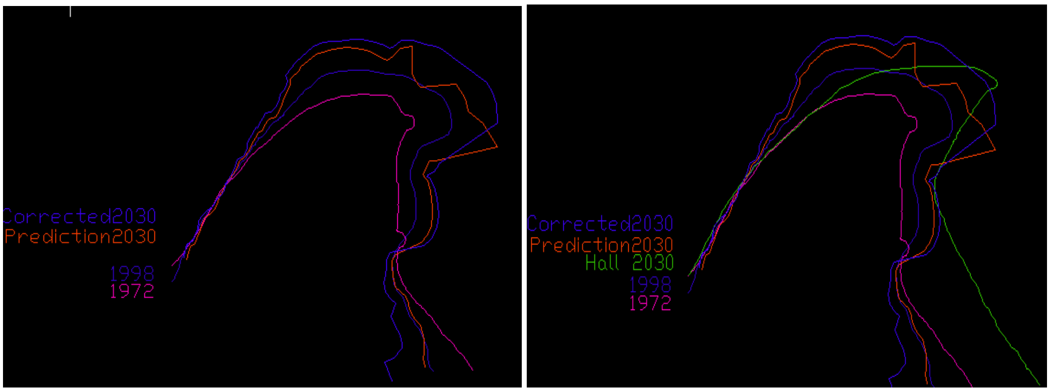


Figure 1.9: New prediction of 2030 without using the information of 1950–comparison with Hall's university prediction (green)

As is was expected, the rate increased and the shoreline is increasing at the whole north part. Again, it is not following the coastline predicted from the Hall university.

Finally the 2050 shoreline was predicted (without the use of the 1950 shoreline) and is shown on table 1.6 and figure 1.10:

Table 1.6: Average coastline evolution rate

Method EPR	2.7813 +/- 7.6923e-005
Method AOR	2.7813 +/- 0.00051887 m/yr
Method AER	2.7813 m/yr

The average rate as it was expected remained the same with the 2030 prediction because at each occasions the same coastlines are providing data (1972 and 1998).

On figure 1.10 the predicted shoreline of 2050 is showed:

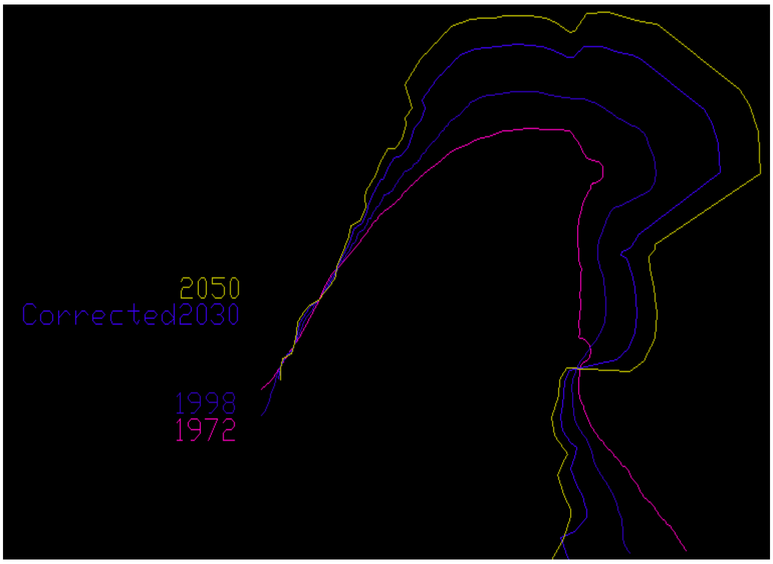


Figure 1.10: Prediction of 2050 shoreline

As it can be observed , the shoreline will keep depositing sediment at north part, and with bigger rate at the north east. At the south east part it is observed loss of sediment during the next years.

Scenario B:

On figure 1.11 the coastlines used at the programme Shev are shown and also the cross sections vertical every 50m to the 2030 shoreline.

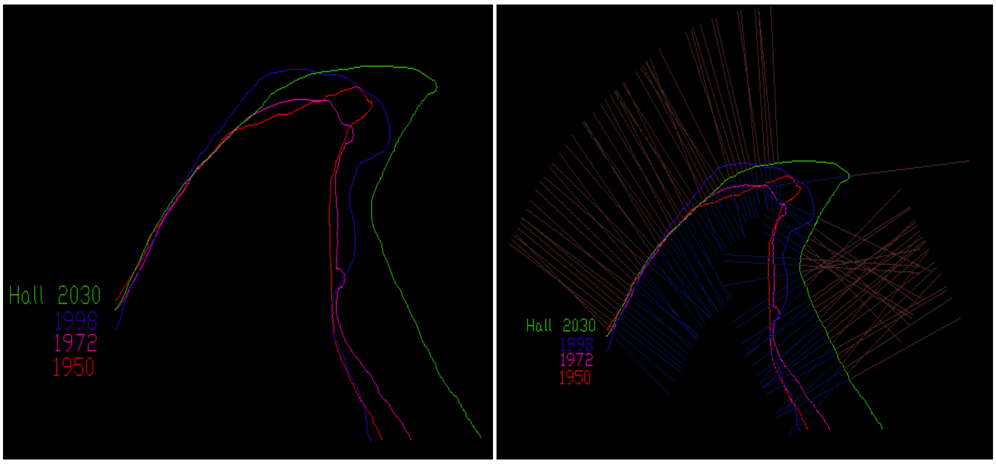


Figure 1.11: Coastlines used and crossections for scenario B

Once more, it must be reminded that the cross sections which did not cross all the coastlines have been erased.

The rates that were calculated from the Shev programme are showed at the table 1.7. The predicted shoreline of 2050 with the AOR method is showed on figure 1.12.

Table 1. 7 Rates of coastline

Method EPR	2.8341 +/- 2.5e-005 m/yr
Method AOR	2.6469 +/- 3.537e-005 m/yr
Method AER	2.6157 m/yr

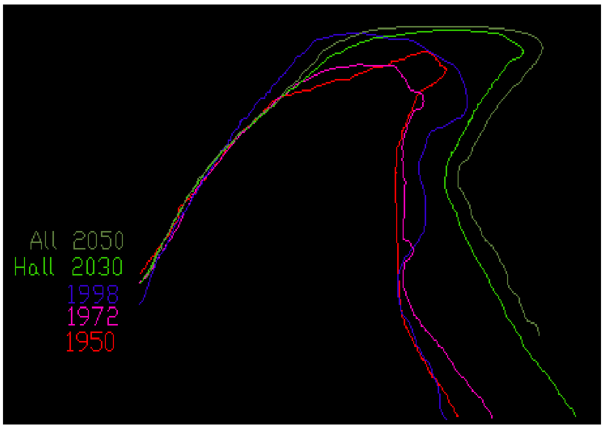


Figure 1.12: Predicted 2050 shoreline

The shoreline looks like the 2030 shoreline by far. Sedimentation is observed at the north east part where the biggest length that the shoreline moved is 133m and the rate of the cross section is the biggest (6.6 m/yr).

Finally, the 1950 was not included and the procedure was once more done. This was done due to the inaccuracy of the 1950 shoreline. The rate, as it was expected, appeared to be bigger as it is showed on table 1.8 and figure 1.13.

Table 1.8: New rate of coastlines

Method EPR	3.4903 +/- 3.4483e-005 m/yr
Method AOR	3.4111 +/- 8.8165e-005 m/yr
Method AER	3.3715 m/yr

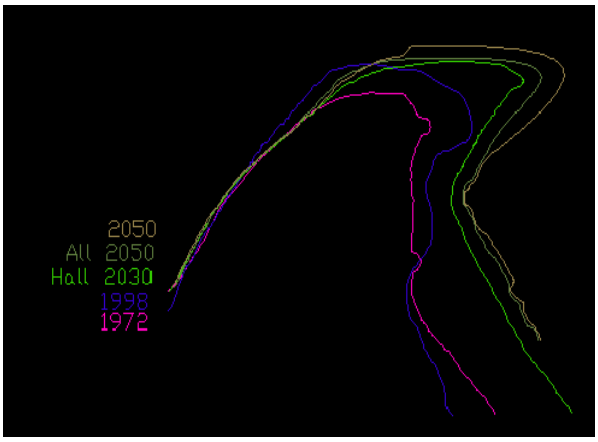


Figure 1.13: New predicted 2050 shoreline without using data of 1950

On figure 1.13, the shorelines of 2050 using all the shorelines (showed with green all 2050) and not using the 1950 (showed with brown 2050). The biggest rate of the cross section is again appeared at the north east part and is moving 9m/yr (total length after 20years is 180m).

Comparison of scenarios A and B:

Finally, a comparison of the 2050 predicted with both scenarios coastlines without the use of 1950 shoreline is showed on figure 1.14:

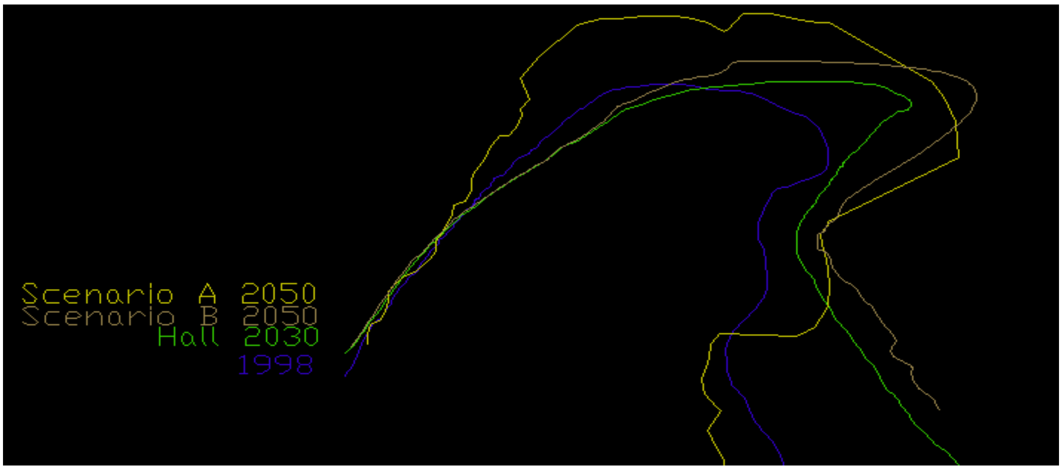


Figure 1.14: Comparison of the two scenarios for the 2050 predicted shoreline

From figure 1.14 the scenario B seems to be more representative. Observing the shape of the coastline today then the shape of scenario A on 2050 is not possible to be acquired. Assuming that the predicted from the Hall university shoreline is correct, then scenario B follows that rate and is more representative.

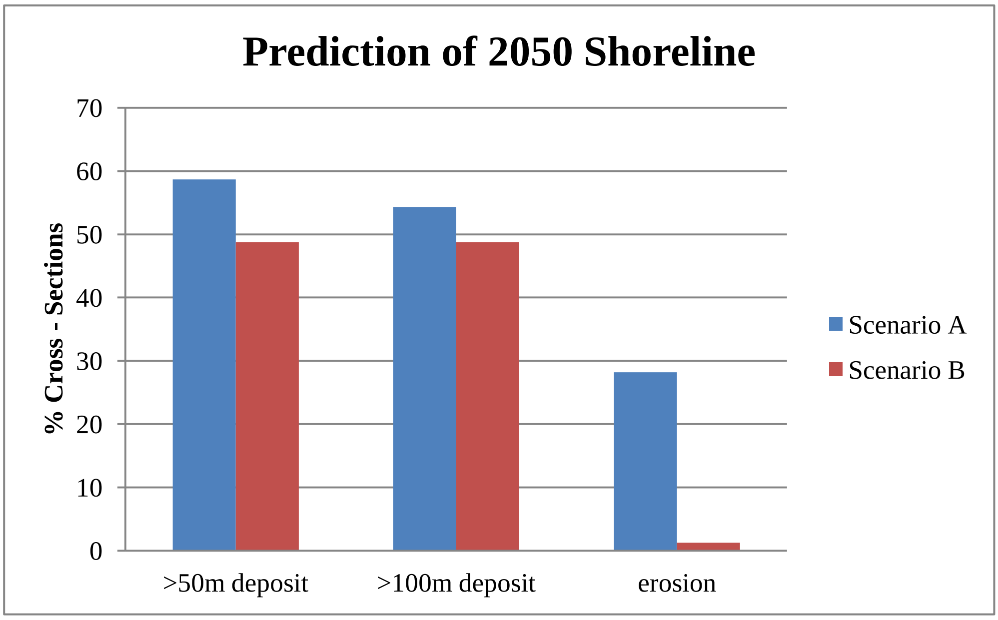


Figure 1.15: Percentages based on cross-sections for deposit and erosion for the two different scenarios for 2050 prediction

At both shorelines the 1950 was not included. The difference is that the one uses the 1998 as a base (scenario A) and the other one uses the 2030 (scenario B). The average rate at the first scenario A is 2.7 m/yr and at the scenario B is 3.4 m/yr. This increase is mainly because the scenario B is based on the already predicted by the Hall university shoreline, which rate is bigger.

Beside the fact that the rate is different, both shorelines have a trend of sedimentation to the north east and this gives the first feeling of the wind conditions of the area (dominant the west).

The coastline predicted with the scenario A is increasing not only at north east but also at the whole north area. This is because this scenario is based only to two shorelines (1972 and 1998) and follows the trend of those two coastlines.

Moreover, from the graphs on figure 1.15, which is based on the cross-sections of the two different scenarios, observations for deposit and erosion can be concluded. For the scenario A , the 58.7% of the cross- sections show deposit more than 50m while for scenario B the is 48.7%. The percentages which have deposit over 100m are 54 and 48.75 for scenarios A and B respectively. The difference is not that big between the two scenarios. In both occasion the deposit is bigger in the first scenario. This is mainly at scenario A the deposit is done in more places than the scenario B. At scenario A the deposit is North but also NorthEast and NorthWest while at scenario B is only NorthWest. Finally, erosion is observed at a percentage of 28.2% for scenario A and 1.25% for scenario B. As it observed from the Figures of Autocad, at scenario A erosion is at SouthWest and a lot at SouthEast while at scenario B is only at SouthWest.

3.3 Conclusion

This method did not help a lot the specific example. This is due to many reasons. First of all, there is lack of information between the years and the total amount of information is not enough. The information that were found are old and have more than 20 years difference between the maps (ex. 1950-1972 or 1972-1998). As a result, except for the fact that the data are inadequate, one could say that they are also inaccurate.

Furthermore, the Shev programme is a statistical programme. The more information it is provided the more accurate results the programme will return. The Shev programme is better used for straight and not curved coastlines. At straight coastlines, the areas of accumulation and erosion can be defined in a better way.

Chapter 2: Baltic sea hydrodynamics, basic marinas construction criteria and the idea for a marina at Prerow

This chapter specializes in the basic characteristics of marinas (shallow draft projects). At the beginning the kinds of harbours are distinguished. Thereafter, the design conditions for small-craft projects are mentioned. Moreover, the reasons why the location of a marina in Prerow is explained. The three kind of harbours which are analyzed in this case study are introduced. Finally, the basic construction criteria used for the harbours are mentioned.

2.1 Baltic sea

The area under investigation is a sandy coast in the Baltic Sea, at the northern–east part of Germany and specifically, Prerow. In this chapter it is analyzed the location of the case study and the area where the four cases of harbours will be implemented (Prerow). Furthermore, the basic hydrodynamic characteristics of the Baltic Sea are mentioned.

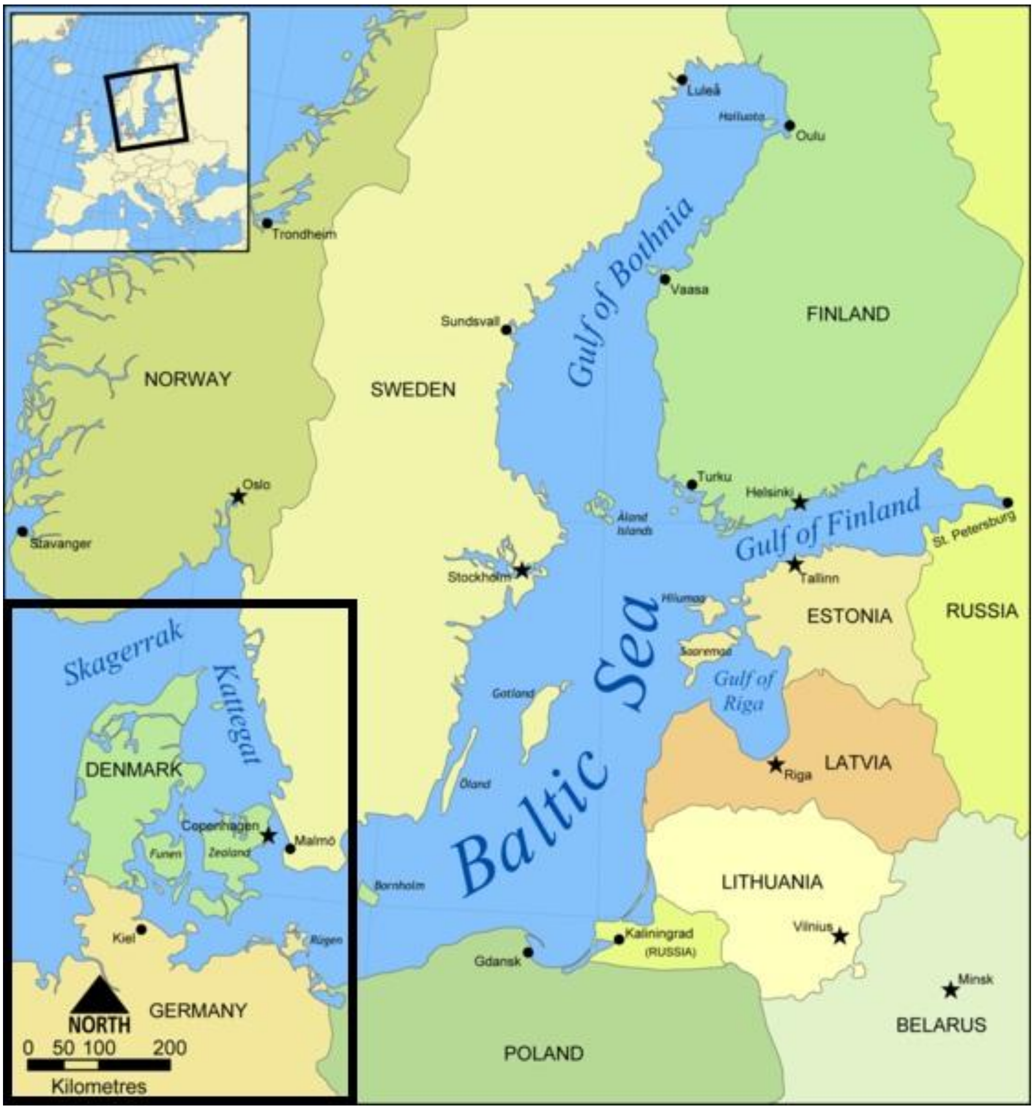


Figure 2.1: The Baltic Sea (source: en.wikipedia.org)

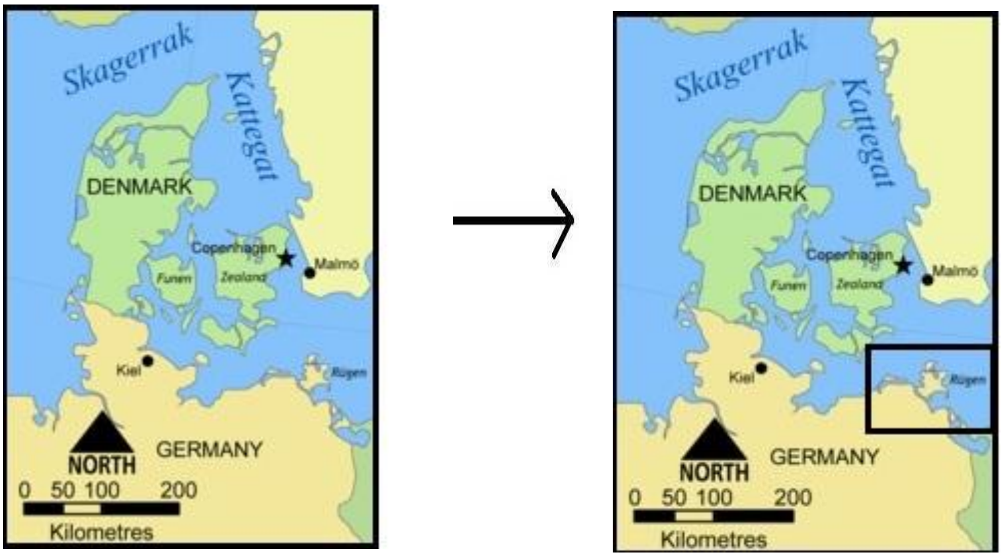


Figure 2.2: Defining the study area

The coastline of Germany is divided into two parts. The west coastline is exposed at the North Sea and the East (where Prerow belongs) is at the Baltic Sea. As it can be seen at the pictures 2.1 and 2.2 Denmark is in between those two parts.

Figure 2.3: Prerow and Rügen Island (source: Google earth)

Figure 2.4: Darss-Zingst Peninsula (source: Google earth)

The Darss–Zingst peninsula is composed of two main parts. At the exterior part, there is the south-westward barrier at Fischland-Darss and at eastwards is the Darss-Zingst. The formation of the Fischland-Darss is a result of a combination between hydrodynamics and sediment transport. The interior part consists of a lot of lagoons as showed on figures 2.3 and 2.4.

Hydrodynamics of Baltic Sea

The change of the coastline at the southern Baltic Sea is affected by processes such as hydrodynamics and sediment transport. Above those processes is the climate change. The Baltic Sea has a big variety of coastal types. Generally, till material predominates along the southern and south-eastern coasts while hard-bottom and rocky shores are typical on northern coasts.

The Baltic Sea can be described as a non tide dominated area. The hydrodynamics of the Baltic Sea is characterized mainly by meso to large scale wind-driven currents and local-scale wind-induced waves. Tides coming from the North Sea attenuate quickly after entering the Baltic Sea through many narrow channels. The tidal range in the southern Baltic area is normally between 5 and 10 cm while by combining other forces they can rise up to 20 or 40 cm. Lastly, by large-scale meteorological situations the water level changes are of the order of 1.5m within one day.

The inverse Barometer Effect

One large scale metereological situation that affects the water level change is the inverse barometer effect. Sea level varies from day to day and week to week, depending on the weather conditions. Air pressure has a direct influence on the sea level.

High air pressure exerts a force and results in water movement. Hence, high air pressure results to low sea level while a low air pressure will allow the sea level to rise.

The air pressure within a year varies between 950 and 1050 hPa so the variation in sea level due to air pressure is between +63 and -37cm (average sea level during a year is 0cm) (source: http://www.balticseanow.info/).

The big changes of water level at Baltic Sea

Strong winds can cause a set up in the Baltic Sea level, which is able to push the water to the coast so that a gentle slope from one side of the sea to the other takes place. As the wind changes, this sea level slope cannot anymore longer maintain and the water starts an oscillation like the water in a bathtub.

Those oscillations continue back and forth for many times and are dissipated by friction. A standing wave is the result effect. Those oscillations in the Baltic Sea from north to south have a period of 4days and may continue for some weeks. The amplitude close to Sweden can reach up to 0.5m. (source:http://www.balticseanow.info/)

2.2Basic construction criteria for marinas

2.2.1 Categories of harbours

All cities on water, inland or on the coasts have harbours. Ports and harbours nowadays, offer many facilities than just mooring (ex. Drinking water, electric energy, waste disposal).

The existing harbours have different kinds of design which is mainly based on the history that has affected them. Some of the main kinds of existing harbours are:

- The marinas
- The fishing ports
- The commercial ships
- The military harbours or harbour belonging to the navy.

As it is mentioned at the CEM, there are **two categories of harbours** :

- the deep – draft projects (channel depth greater than 4.6m)
- the shallow – draft projects (channel depth less than 4.6m)

In this case study, the three kind of marinas (offshore, onshore and inshore) which will be investigated belong to the second category due to the draft of the pleasure boats. General **guidelines for minimum depth clearance requirements in channels influenced by waves** are given by PIANC (1997):

<u>Water depth</u>

$$\frac{water\ depth}{ship\ draft} > 1.3\ when\ H \leq 1m\ (3.3ft)$$

$$\frac{water\ depth}{ship\ draft} > 1.5\ when\ H > 1m\ (3.3ft) and\ wave\ periods\ and\ directions$$

$are\ unfavorable$

Where H = wave height

Shallow–draft vessels are either recreational or small fishing vessels. The length ranges from 3.6m to 60m with beams of 4.6m or less. They are usually driven by engine power or sail. The sailboats have narrow beam and require large maneuvering space in contrast with the powerboats. However, the maneuverable width is not as critical as it is for deep – draft ships.

2.2.2 Design conditions for small–craft projects

Design transit conditions for small- craft projects include wind, wave, water level, currents and also vessel maneuverability especially when parts of the project accommodate sailing vessels. The typical criteria according to CEM are:

Mooring areas: Significant wave height will not exceed 0.3m more than 10% of the time.

Access channels: Significant wave height will not exceed 0.6m more than 10% of the time.

2.2.3 Navigation system

Ports and harbours operations are a system with three main components :

- Waterway engineering: navigation channels, dredging, mapping services
- Marine traffic: operational rules, pilot service, communication and vessel traffic services
- Vessel hydrodynamics: vessel design, maneuverability and controllability, human factors

For small craft, operational concerns vary significantly depending on the type of harbour. Power boats are driven by engines while sailboats usually travel under wind power following a zig-zag course.

2.3 The idea for a Marina at Prerow

Sandy coasts are subject to intensive sediment transport. Building pleasure boat harbours along such coastlines is a challenge and some options for design are to be investigated.

Background for these investigations is the discussion about touristic development of the German Baltic Sea and especially of urgent interest is a new harbour place at the coast of Zingst-Darss.

At the present, there is one marina at Warnmunde Rostock and the next one is at Hiddensee as showed on figure 2.5.

In between there is the Darsser –Ort emergency harbour which is a small harbour and used mainly for rescue services and emergency cases. For the public, the harbour maybe only accessed from 16:00- to 9:00 overnight. Furthermore, the harbour is located into a biosphere reservation and is subject to heavy sedimentation and regular costly dredging. Even with dredging, there are problems because Darsser-Ort is a natural area under protection.

Figure 2.5: Available marinas (source: http://www.portbooker.com/de/liegeplatz/deutschland)

The distance between Rostock and harbours on Hiddensee/Rügen is more than 95km (60 nautic miles). This distance is very big as it is showed on figure 2.6. This distance is difficult to be done at once, especially for small pleasure boats with kids or old people on board. Every year, five to six deaths occur due to the big distance and the case of bad weather during the trip.

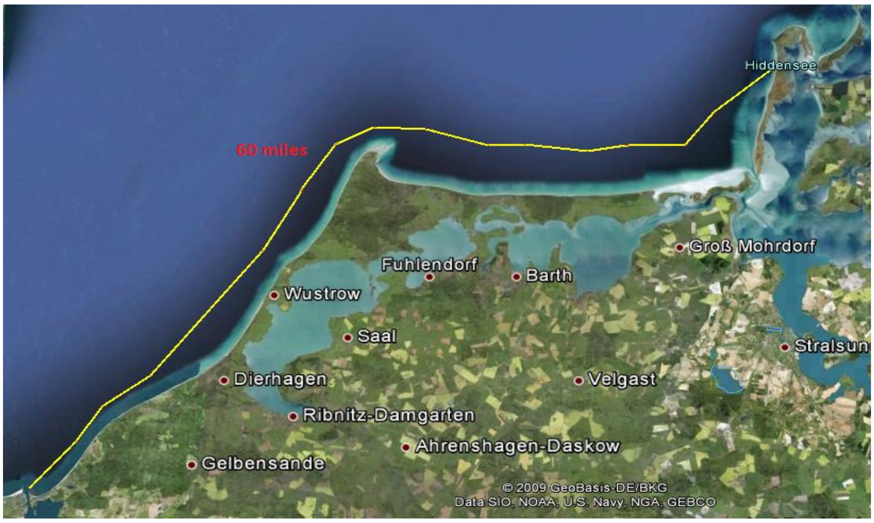


Figure 2.6: Distance between the 2 available marinas (source: Google Earth)

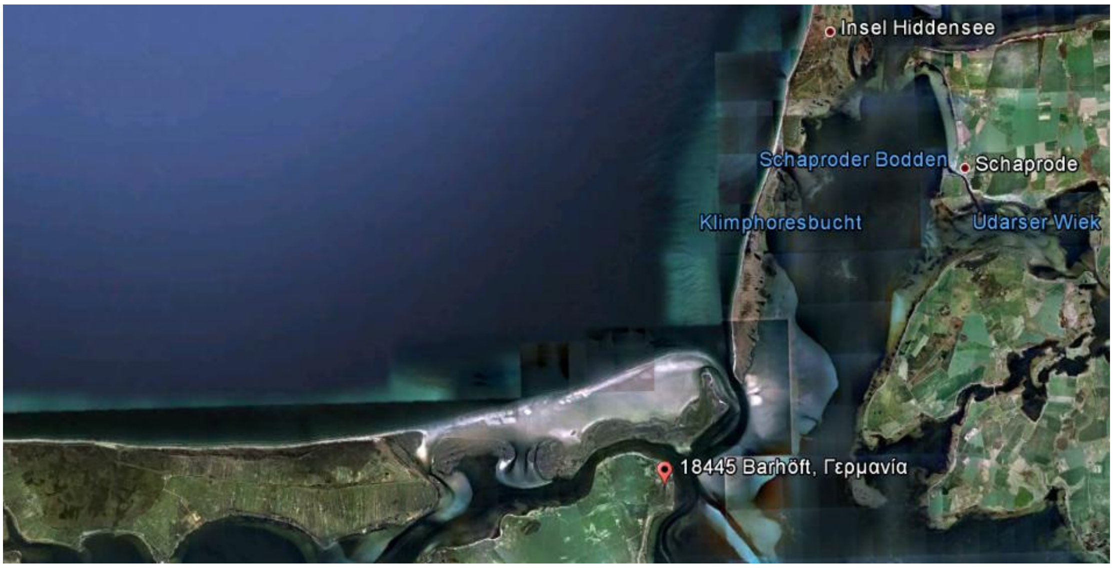


Figure 2.7: Alternative solution mooring at Barhöft (source: Google Earth)

The nearest Yacht service harbour on the way from Rostock to Rügen /Hiddensee is at Barhöft right inside the laggon which opens to the Baltic Sea between the east tip of the Darss-Zingst peninsula and the south tip of Hiddensee. This trip is long at bad weather and demands much attention when entering the shallows in front of Hiddensee island.

Hence, it is needed to divide the distance by creating one marina at Prerow, between Rostock and Hiddensee. Thus, the emergency small harbour at Darsser–Ort should be replaced by a new one.

Figure 2.8: Final location of the harbour positions under investigation

As it it easily seen from figure:2.8 Prerow has a navigation distance around 32.8 miles from Rostock and 21.5 from Hiddensee.

2.3.1 Hydrodynamics of the proposed location

The proposed location at Prerow is between two important phenomena.

- The eroding beach on the right
- The eddy due to Darsser–Ort
- The "Prerow Bank" deposits

On the right side of the proposed location as it is showed on figure 2.9 there is a system of groins because the beach is eroding.

Figure 2.9: Left part of the groyne system (source: Google Earth)

On the left side of the proposed location as it is showed on figure 2.10 eddies are created due to the existence of Darsser-Ort. Darsser-Ort functions as physical barrier protecting the proposed location of the prevalent West winds.

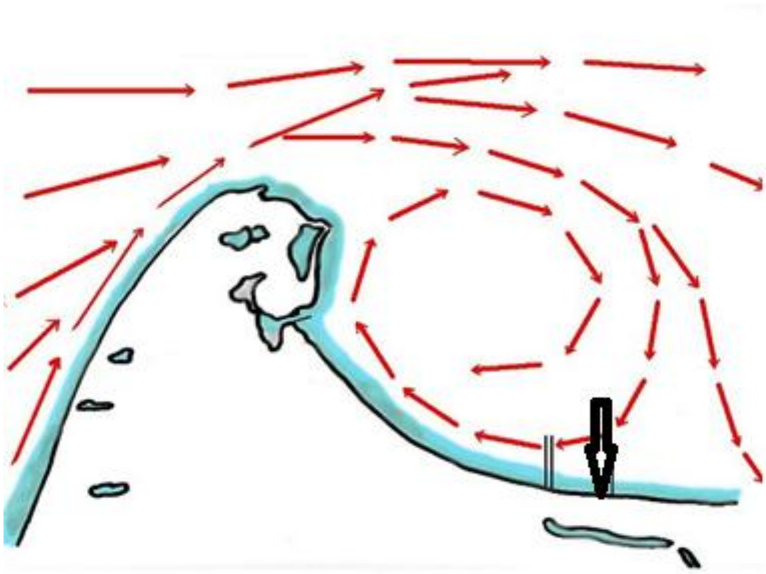


Figure 2.10: Direction of flow and sediment transport from West to East at high west wind conditions (source: http://www.darsserort.de/strandidyll-prerow/nothafen.htm)

Figure 2.11: Sedimentation at Darseer–Ort (source: http://www.darsserort.de/strandidyll-prerow/nothafen.htm)

The proposed location is close to the end of the provoked by the west wind eddy and before the eroding part begins. Hence, it is an optimal location because both phenomena affect the least the suggested marinas. Moreover, the proposed location is behind the Prerow Bank (see figure 2.12) which functions as a submerged breakwater or physical barrier against the South winds.

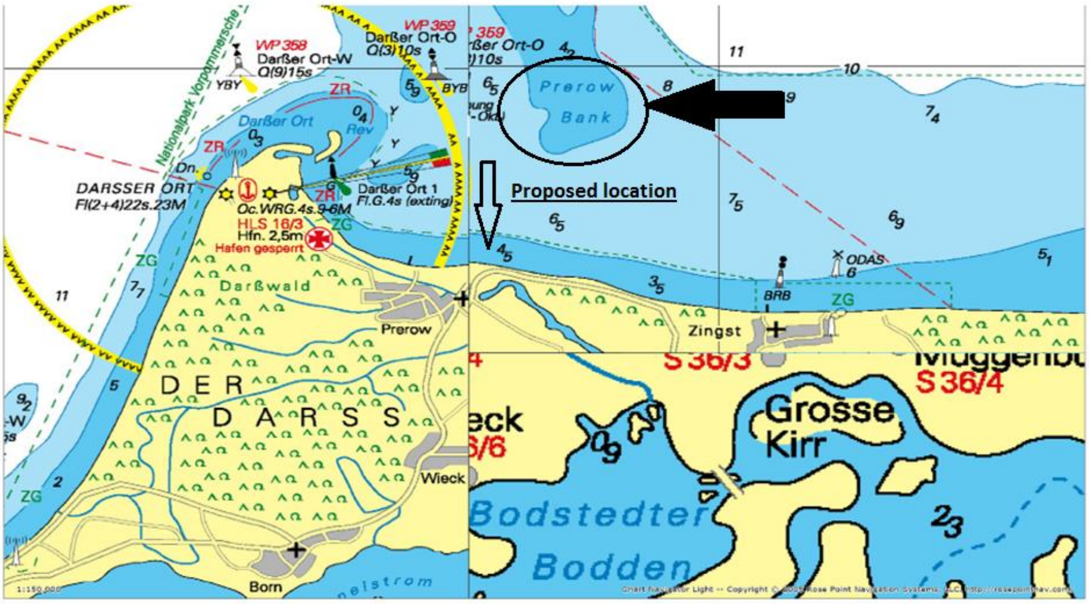


Figure 2.12: Map of Prerow (source: Sportboothafen Prerow , 2009)

Last but not least, the proposed location is close to roads so it is easily accessible from the coast. It has high availability to water, electricity and all basic services needed.

2.3.2 The kind of marinas under investigation

Basically three kind of harbour design can be thought of : Inshore, Onshore and Offshore.

The Inshore harbour is located in the city and access from the sea to the harbour is given by navigation channel protected by two breakwaters 500m length. Accessibility is given directly from the city.

The Onshore harbour is attached to the shoreline. Accessibility is given directly from the land.

The Offshore harbours examined in this case study are two. The first is located 0.5km offshore in the deep water and the second is located 1km offshore. They are artificial and protected to all sides. Access is given by a bridge in open construction to let sediment pass between the harbour and beach. For this case study, it is assumed that the contruction of the bridge do not affect the sediment and it will not be investigated.

Intention of this study is to investigate and compare the three options for harbour design and draw conclusions with respect to best performance of the three variants with respect to accessibility of the harbours at extreme condition in terms of bathymetry (navigation) and in terms of safety during extreme events (mooring).

2.3.3 Shallow–draft channel design guidance according to CEM

The marinas are designed for 300 vessels with 3m width and 10m length. For those dimensions of boats the mean draft is 2.1 m. The area of the port is approximately $15400m^2$ (dimensions around 120m*130m) while the width of the breakwaters around is 30m.

Entrance channels are wider than the interior channels mainly because of waves and currents which make the navigation difficult at entrances and also result in sediment movement and dynamic shoaling patterns.

For small – craft harbours the entrance channel width should be a minimum of 23m (ASCE 1994).

The small – craft *channel* design guidance for an expected volume of two –way traffic takes into account the next approach (ASCE 1994, Dunham and Finn 1974):

$W = W_{min} + 0.03\ N_B$ in meters

Where

W = design small craft channel width

W_{min} = minimum width = 5B or 15m

where B = average beam

N_B = number of boats using the project

Thus, in this case where the project is for 300 small boats of 3m beam , the minimum width of the channel entrance for the inshore harbour should be :

W = 5*3 + 0.03*300 = 24m > 23m

The entrance of the channel of the inshore harbour for safety reasons is assumed to be one meter longer; 25m. The entrance of the onshore and offshore harbour is chosen to be 25m the same as the channel entrance of the inshore harbour.

Chapter 3: Governing equations

3.1 Introduction

The basic equations of Mike21 simulating tools that were used in the simulation procedure of Prerow will be analyzed in this chapter. A short introduction in numerical approximation methods for space and time is mentioned. The basic characteristic of explicit and implicit schemes are also briefly analyzed. The basic equations of the Spectral Wave model are presented while the equations for the hydrodynamic and sand transport module follow.

3.2 Numerical approximation methods

Numerical approximation models for water related physical processes describe physical behaviour using appropriate approximation methods. The natural physical state variables depend on space and time coordinates in the model domain.

3.2.1 Space approximation

Mainly, there are three basic types of numerical approximation methods that the modern simulating tools use; the Finite Difference Method (FDM), the Finite Element Method (FEM) and the Finite Volume Method (FVM).

After dividing the domain in small finite approximation objects (sections, cells or elements) for the three methods, the nodes are introduced. By introducing the nodes, the geometry of the model domain is specified as well as the topology of the approximation objects.

The **Finite Difference Method** (FDM) is based on setting up equations *at the nodes* within the model domain. At each node, the differential equation is solved exactly by related numerical difference quotients. In other words, the FDM uses finite difference equations to approximate derivates. The FDM requires structured grids and as a result it cannot calculate every single domain.

The **Finite Element Method** (FEM) is based on setting up equations within *small finite elements*. For each element, a related integral equation is set up and combined to the equations for the whole system. This set of integral equations is minimized towards the approximation error in the whole model domain. Thus, the FEM assures a global conservation of the related equations. The FEM is used for unstructured meshes, such as different kind of triangles.

The **Finite Volume Method** (FVM) is based on setting up equations on control volumes for *each node or cell* within the model domain. The balance equation of all control volumes is set up and combined towards a system of equations for the whole model domain to be solved. Thus, the FVM assures a local conservation of the related equations. The FVM is used for unstructured meshes like FEM does (F. Molkenthin, Numerical Approximation and Shape Function notes, 2011).

Mike21 has two basic hydrodynamic programmes; the Flow Model (FDM) and the Flow Model Flexible Mesh (FVM). In this chapter, the basic characteristics of the MIKE21 models which were used in this case study, will be analyzed. Specifically, the wave model Spectral Wave FM and the Flow Model FM, both using unstructured meshes and Finite Volume Method. The discretisation in solution domain is performed using a cell centred finite volume method.

The spatial domain is discredited by subdivision of the continuum into non – overlapping elements (cells). The elements are usually triangles (can be also quadrilateral).

3.2.2 Time approximation

The models of Mike21 FM are using an internal timestep as showed on figure 3.1:

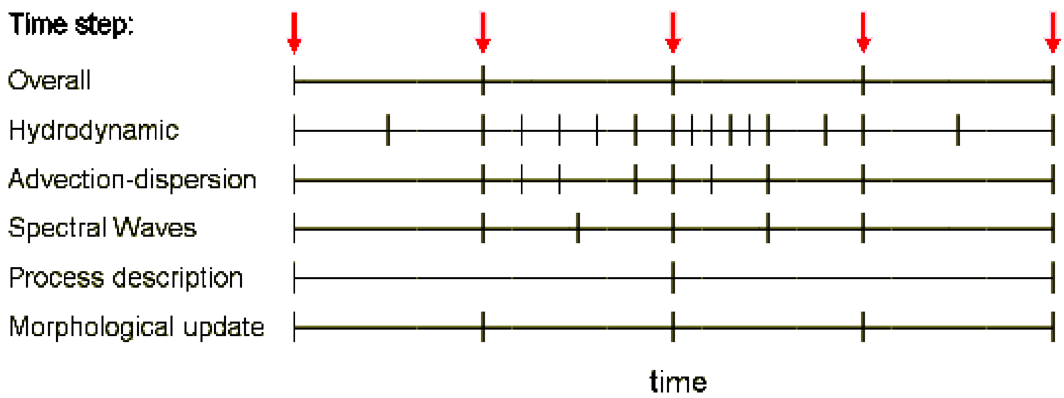


Figure 3.1: Overall timestep realted to internal timestep (source: Mike21 Scientific Doc)

For the hydrodynamic and spectral waves calculations that this thesis focus on, the timesteps are determined to satisfy stability criteria. All the timesteps within the simulation are synchronized at the overall discrete timestep.

For the Sand transport module the timestep can be multipla of the overall timestep so as to update the process description.

3.3 Explicit and Implicit schemes

The explicit and implicit methods are used in computer simulations of physical approaches. They are approaches required in numerical analysis for getting numerical solutions of time-dependent ordinary and partial differential equations.

Explicit schemes are using a time and space approximation. This leads to equations in which only one unknown state variable appears and the unknown values can be calculated without solving an equations system. In simple words, explicit methods calculate the state of the system on the next timestep using the current timestep's values.

Implicit schemes are using time and space approximation which lead to several unknown state variables in an equation which has to be solved. In other words, implicit methods calculate the state of the system at the next timestep by solving an equation system which involves both the current system and the later one.

3.4 Spectral Wave

Mike21 SW is a wind – wave model which uses unstructured meshes. It simulates wind and generated waves in offshore and coastal areas.

Two different formulations are used:

- The directional decoupled parametric formulation (based on a parameterization of the wave action conservation equation) which was used in this case study

- The fully spectral formulation (based on the wave action conservation equation)

3.4.1 Main features of the model

The Mike21 SW includes many physical phenomena such as wave growth by action of wind, non–linear wave–wave interaction, dissipation due to white–capping, bottom friction and depth-induced wave breaking. Moreover, refraction and shoaling due to depth variations, wave–current interaction and effect of time–varying water depth can be analyzed.

The main application areas are the design of offshore, coastal and port structures where accurate calculation of wave loads is very important. It is applicable for estimating the waves climates in offshore and coastal areas, on a regional or on a local scale.

Mike21 SW is used to calculate the wave conditions and associated radiation stresses.

3.4.2 Basic equations of Spectral Wave

The basic equations of the Spectral Wave model, as they are analyzed at the Mike by DHI scientific document, will be showed in this paragraph.

The transport equation for wave action density describes the dynamics of the gravity waves. For small scale applications the basic transport is formulated in Cartesian co –ordinates while the spherical polar co–ordinates are used for large–scale applications. The wave actions density spectrum varies in time and space and is a function of two wave phase parameters.

The wave phase parameters are the wave direction θ and either the relative angular frequency $\sigma = 2\pi f$ or the the absolute angular frequency $\omega = 2\pi f_a$. Here, the wave direction θ and the relative angular frequency will be anazysed.

The action density N(σ,θ) is related to the energy density E (σ, θ) by N=E/σ

For wave propagation over slowly varying depths and currents, the relationship between the relative angular frequency and the absolute angular frequency is given by the next linear dispersion relation:

$$\sigma = \sqrt{gktanh(kd)} = \omega - \vec{k}\,\vec{U} \tag{3.1}$$

Where d is the water depth and U is the current velocity vector. The magnitude of the group velocity c_g of the wave energy relative to the current is given by

$$C_g = \frac{\partial \sigma}{\partial k} = \frac{1}{2}\left(1 + \frac{2kd}{\sinh(2kd)}\right)\frac{\sigma}{k} \tag{3.2}$$

The phase velocity ,c, of the wave relative to the current is given by c = σ/k.

The frequency spectrum fluctuates between a minimum frequency ,σ_{min} and a maximum σ_{max}. The frequency spectrum is split up into a deterministic prognostic part of frequencies lower than a cut –off frequency and an analytical diagnostic part for frequencies higher than the cut-off frequency. A dymanic cut- off frequency depending on the local wind speed and mean frequency is used.

The deterministic part of the spectrum is determined solving the transport equation for wave action density using numerical methods. Above the cut-off frequency limit of the prognostic region, a parametric tail is applied

$$E(\sigma,\theta)=E)(\sigma_{max},\theta)(\frac{\sigma}{\sigma max})^{-m} \quad (3.3)$$

Where *m* is a constant. The maximum prognostic frequency is determined as

$$\Sigma_{cut\text{-}off} = \min\left[\sigma_{max}, \max(2.5\,\bar{\sigma}, 4\sigma_{PM}\right] \quad (3.4)$$

Where σ_{max} is the maximum discrete frequency used in the deterministic wave model, $\bar{\sigma}$ is the mean relative frequency and $\sigma_{PM}= g/(28u_{10})$ is the Pierson – Moskowitz peakl frequency for fully developed waves (U_{10} is the wind speed at 10m above the mean sea level). The diagnostic tail is used for the calculation of the non-linear transfer and for the calculation od the integral parameters used in the source functions. Below the minimum frequency the spectral densities is assumed to be zero.

Wave action conservation equations for Cartesian co–ordinates

The conservation equation for wave action can be written as

$$\frac{\partial N}{\partial t} + \nabla(\vec{v}\,N) = \frac{S}{\sigma} \quad (3.5)$$

Where N(x, σ, θ, t) is the action density, x = (x,y) are the Cartesian co – ordinates, ν = (c_x, c_y, c_σ, c_θ) is the propagation velocity of a wave group in the four-dimensional phase space x, σ and θ and S is the source term for the energy balance equation. ∇ is the four – dimensional differential operator in the x, σ and θ-space. The four characteristic propagation speeds are

$$(c_x, c_y) = \frac{d\vec{x}}{dt} = \overrightarrow{c_g} + \vec{U} \quad (3.6)$$

$$c_\sigma = \frac{d\sigma}{dt} = \frac{\partial\sigma}{\partial d}\left[\frac{\partial d}{\partial t} + \vec{U}\nabla_x d\right] - c_g\vec{k}\frac{\partial\vec{U}}{\partial s} \quad (3.7)$$

$$c_\theta = \frac{d\theta}{dt} = -\frac{1}{k}\left[\frac{\partial\sigma}{\partial d}\frac{\partial d}{\partial m} + \vec{k}\frac{\partial U}{\partial m}\right] \quad (3.8)$$

Where s is the space co-ordinate in the wave direction θ,and m is a coordinate perpendicular to s. $\nabla_{\bar{x}}$ is the two dimensional differential operator in the x-space.

This is a short description for the basic equations used from the model according to the manuals of DHI where more details can be found on the scientific documents.

3.5 Flow Model FM

3.5.1 Main features of the model

The main features that the simulations with MIKE21 Flow Model FM – Hydrodynamic model include, are the flood and drying, momentum dispersion, bottom shear stress, coriolis force, wind shear stress, barometric pressure gradients, ice coverage, tidal potential, precipitation/ evaporation, wave radiation stresses and also sources and sinks.

3.5.2 Solution technique

The order of the numerical schemes used in the numerical calculation is absolutely connected with the simulation time and accuracy. Mike21 HD can specify both time integration and space discretization schemes. A first order scheme (lower order) or a higher order scheme can be selected. The lower order scheme is faster but with lack in accuracy in comparison with the higher order which takes more time. At the simulations of this case study a lower order technique was used.

3.5.3 2D Governing equations in cartesian coordinates-Shallow water equations

The 2D governing equations for Cartesian coordinates that are analyzed at the scientific manual of DHI will be presented below. This is due to the fact that, the case study under investigation is using non UTM coordinates. Thus, the equations for spherical coordinates will not be analyzed in the present case study.

The two – dimensional shallow water equations can be obtained after integrating the three-dimensional incompressible Reynolds averaged Navier-Stokes equations at the horizontal momentum equations and the continuity equation over depth h = η + d as showed below:

Continuity equation

$$\frac{\partial h}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{v}}{\partial y}=hS \qquad (3.9)$$

Momentum Equation for x direction

$$\frac{\partial h\bar{u}}{\partial t}+\frac{\partial h\bar{u}^2}{\partial x}+\frac{\partial h\overline{vu}}{\partial y}=f\bar{v}h-gh\frac{\partial \eta}{\partial x}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial x}-$$

$$\frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial x}+\frac{\tau_{sx}}{\rho_0}-\frac{\tau_{bx}}{\rho_0}-\frac{1}{\rho_0}\left(\frac{\partial s_{xx}}{\partial x}+\frac{\partial s_{xy}}{\partial y}\right)+$$

$$\frac{\partial}{\partial x}(hT_{xx})+\frac{\partial}{\partial y}\left(hT_{xy}\right)+hu_sS \qquad (3.10)$$

Momentum Equation for y direction

$$\frac{\partial h\bar{v}}{\partial t}+\frac{\partial h\overline{uv}}{\partial x}+\frac{\partial h\bar{v}^2}{\partial y}=f\bar{u}h-gh\frac{\partial \eta}{\partial y}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial y}-$$

$$\frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial y}+\frac{\tau_{sy}}{\rho_0}-\frac{\tau_{by}}{\rho_0}-\frac{1}{\rho_0}\left(\frac{\partial s_{yx}}{\partial x}+\frac{\partial s_{yy}}{\partial y}\right)+$$

$$\frac{\partial}{\partial x}\left(hT_{xy}\right)+\frac{\partial}{\partial y}\left(hT_{yy}\right)+hv_sS \qquad (3.11)$$

Where

t the time, *x*,*y* are the Cartesian co-ordinates, *η* is the surface elevation, *d* is the still water depth, *h= η+d* is the total water depth, *u,v* are the velocity components in the x and y direction, *f=2Ωsinφ is the Coriolis parameter* (*Ω* is the angular rate of revolution and *φ* the geographic latitude) g is the gravitational acceleration, *ρ* is the density of water, s_{xx}, s_{xy} ,s_{yx},*and* s_{yy} are components of the radiation stress tensor,

ρ_o is the reference density of water, S is the discharge magnitude due to point sources and u_s,v_s is the velocity by which the water is discharged into the ambient water.
The overbar indicates a depth average value. For example, $\bar{u}$ and $\bar{v}$ are the depth-averaged velocities defined by

$$h\bar{u} = \int_{-d}^{n} udz,\ h\bar{v} = \int_{-d}^{n} vdz \tag{3.12}$$

The lateral stresses T_{ij} include viscous friction, turbulent friction and differential advection. An eddy viscosity formulation is used which is based on the depth average velocity gradients:

$$T_{xx} = 2A\frac{\partial\bar{u}}{\partial x} \tag{3.13}$$

$$T_{xy} = A\left(\frac{\partial\bar{u}}{\partial y} + \frac{\partial\bar{v}}{\partial x}\right) \tag{3.14}$$

$$T_{yy} = 2A\frac{\partial\bar{v}}{\partial y} \tag{3.15}$$

3.6 Sand Transport module

3.6.1 Main features of the model

Sediment transport is described by the bed load (rolling and sliding material along the bed), suspended load (suspended material in the flow for some time) and wash load (transport of material finer than bed material with no relation to the transport capacity of the stream).

Sediment is being transported under action of current, waves or both current and waves. MIKE21 Sand transport module considers the bed material load using pure current or combined current and waves.

In this case study, the combined current and wave module was used. Thus, the basic equations according to the scientific document of DHI, are described below.

3.6.2 Basic equations

The sediment transport is calculated adding the bed load transport and the sediment transport in suspension ($q_t = q_b + q_s$).

The STPQ3D model is used to calculate the bed and suspended load separately and give the total result. At this model the bed load transport model of Engelund and Fredsoe(1976) is used where the bed load transport is calculated from the instantaneous Shields parameter. The suspended sediment transport is calculated as the product of instantaneous flow velocities and the instantaneous sediment concentration:

$$q_s = \frac{1}{T}\int_0^T \int_{2d}^{D}(uc)dzdt \tag{3.16}$$

Chapter 4: Setting up the model

4.1 Introduction

At the beginning of this chapter the wind and waves data are introduced. Both are measured data in the closest stations available. Analyzing the wind data and the water level data gave the three events which were simulated.

The methodology followed to set up the Flow model is extensively analyzed. The initial water level boundaries given, refer to Rügen overall model. However, the area where the 4 different marinas were created is Prerow. As a result, a step by step procedure was followed in order to bring the water level boundaries from Ruegen overall model close to Prerow region model. The way the model was downscaled until the Prerow model approach is shown on figures 4.1 and 4.2.

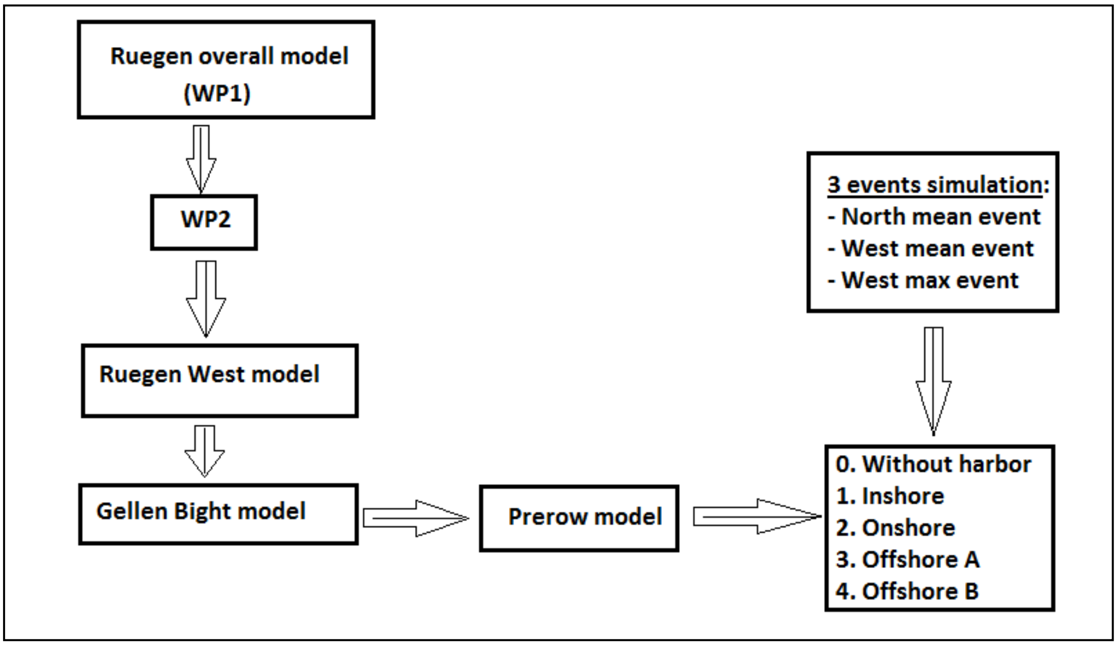


Figure 4.1: Downscaling the Ruegen overall model

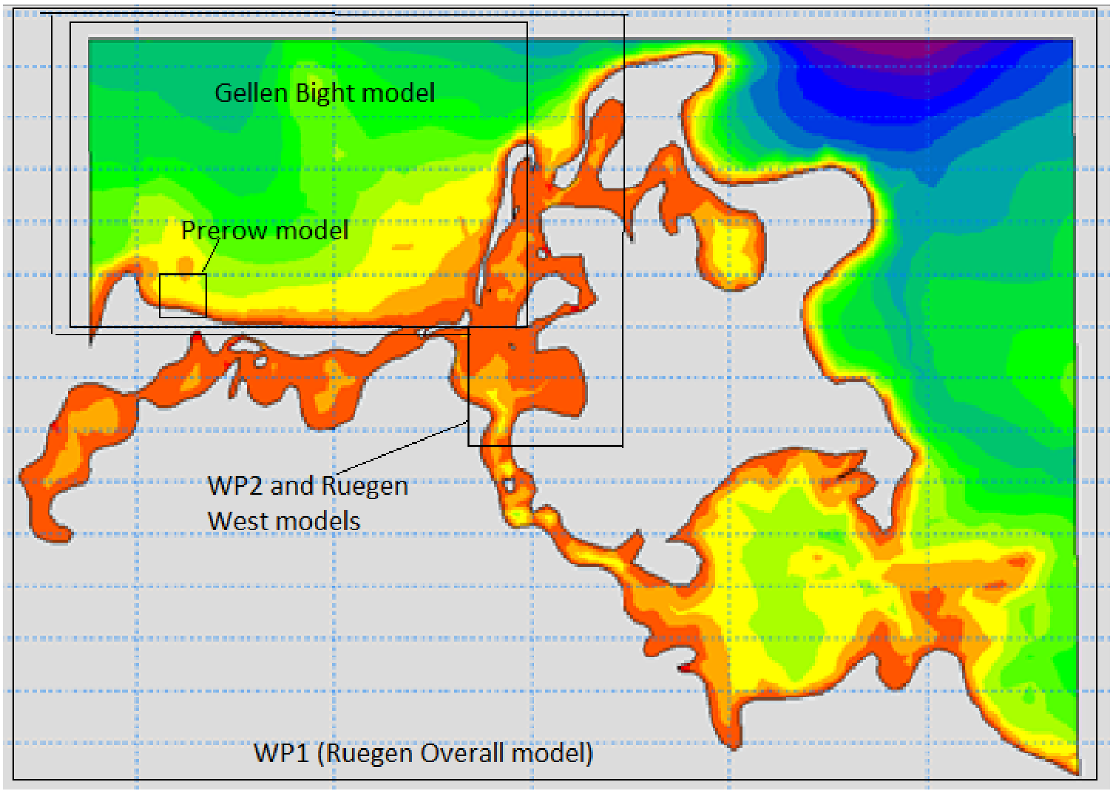


Figure 4.2: Overview of the models used during downscaling

The same procedure was followed in order to bring the wave boundaries for the Spectral Wave model from the station that is provided from GKSS (Figure 7.2) to Prerow model. The measured wave data were used as boundaries to the SW model to the mesh of Gellen Bight model and new wave boundaries were exported at the Prerow model. An overview of the sequence of the use of tools is shown on figure 4.3:

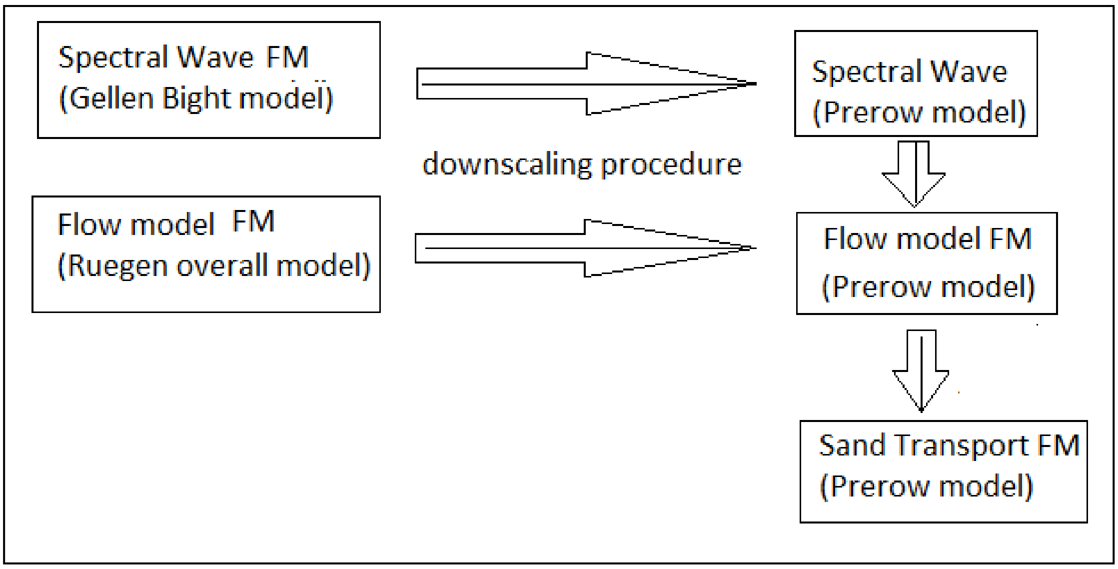


Figure 4.3: Overview of the sequence of the simulating tools used

Moreover, the measured water level data at the closer gauging stations are included and compared with the results of the downscaling models. At the final Prerow model, the construction of 4 different harbours follows. At this model, the simulating procedure which was followed for each programme (Spectral Wave, Flow Model and Sand Transport) is presented.

4.2 Introducing wind and waves measured data

4.2.1 Wind

Hourly boundary conditions of water level for three months (1.10.1997 – 31.12.1997) were provided for the east, north and west boundaries from the operational (numerical) Baltic Sea model. For the same period, wind measurements nearby Zingst (node 1662) were provided as shown on figure 4.4.

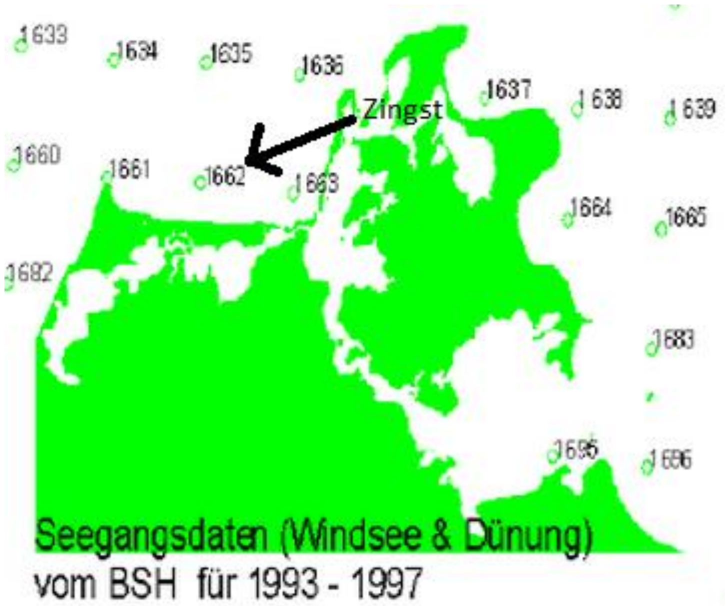


Figure 4.4: Wind data provided from BSH (http://morwin.hosted-by-kfki.baw.de/)

The wind rose of Zingst (node 1662) was created for the three months mentioned, and is presented on figure 4.5:

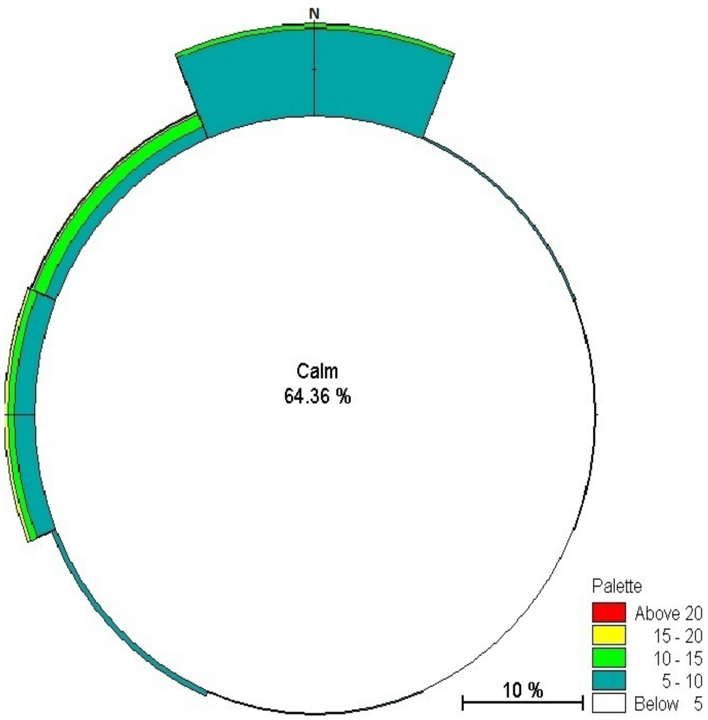


Figure 4.5: Wind Rose nearby Zingst

From the wind rose it is observed that 64% of the time there is no wind. Moreover, the prevalent winds are the West and North. The frequency of North wind is higher than the West.

Due to the freezing of the Northern Baltic (Finland, Russia etc), it can be easily seen on figure 4.6 (point timeseries of East BC) that the water level timeseries is decreasing approximately 20cm every month as the winter comes (decrease of volume of liquid). On October (first 743 timestep) the water level has the highest values in comparison with the rest two months (timestep 744-2207).

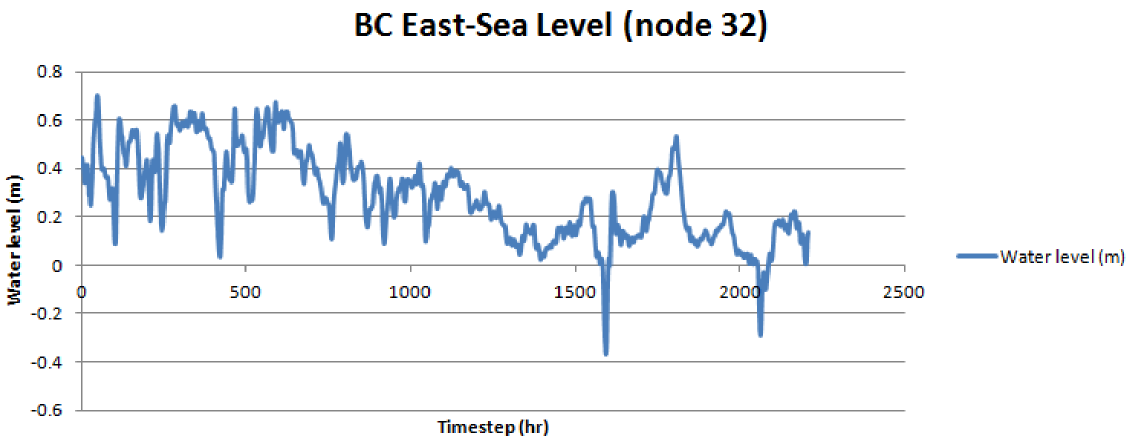


Figure 4.6: Water level hourly timeseries

Analyzing the flow boundary conditions (water level) and the velocity of the wind at Zingst (area where the harbours will be designed) during those three months, October was the month with the highest values of both parameters. Moreover, a good data base for wave measurements was also given for October 1997.

The prevalent winds as it is showed at the wind rose are the West and North. This is the reason why at the final Prerow model the events simulated (turning on wind and wave) are one mean event for the North wind and one mean event for the West wind. Moreover, during October 1997 two West extreme events occurred. One of them was also simulated in order to analyze how much the harbours have been affected. Table 4.1 presents the events simulated.

Table 4.1 Simulated events

	Simulation Period	Hourly Timesteps	Velocity (m/s)	Beaufort
North Mean	24-28 October	108	8 to 13	4 to 6
West Mean	23 October	24	8 to 13	4 to 6
West Max	2 October	24	13 to 20	7 to 9

4.2.2 Waves

Moreover, a good data base for the wave timeseries is given for October 1997, from a station provided by GKSS (28km north of Staun) as it is shon on figure 4.7.

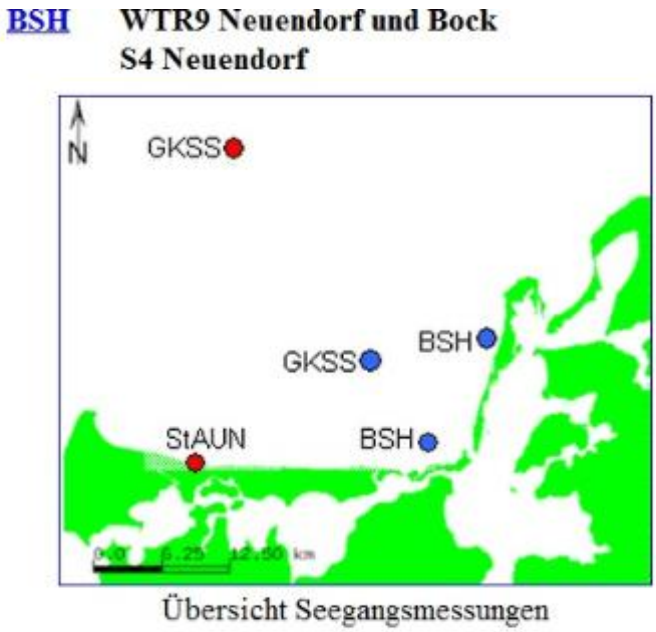


Figure 4.7: Measured wave data (source: http://morwin.hosted-by-kfki.baw.de/)

The wave data were provided from GKSS 28km North from Staun. As a result, the Gellen Bight model was used in order to bring the wave boundaries close to Prerow. The simulation of the wave model was done without turning on wind. The wind was turned on only at the final Prerow model

4.3 The Ruegen Overall Module and the step by step procedure of downscaling

4.3.1 Methodology followed to create the bathymetry at Ruegen overall model

The shoreline data of Ruegen were inserted into the MikeZero mesh generator tools in order to create the bathymetry. Due to license restriction at the number of nodes, redistribution of the vertices was done in order to be able to have a representative model of the area. The changes at the shoreline data are showed on figures 4.8 and 4.9.

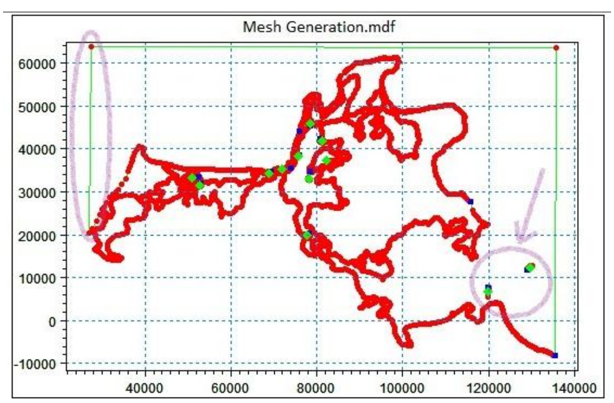


Figure 4.8: Shoreline data given

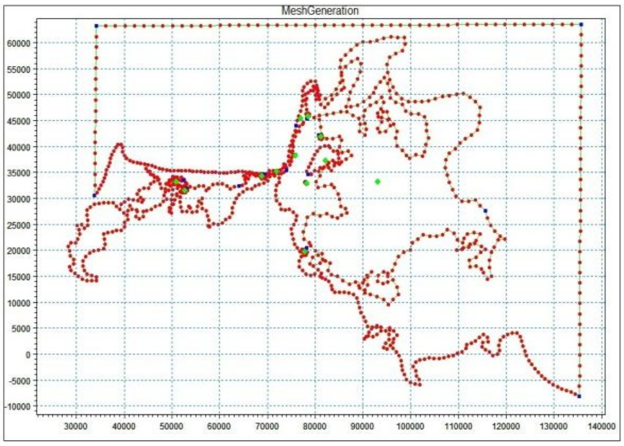


Figure 4.9: Changes on the shoreline given data

- The small two islands on the right were erased
- The boundary on the left was moved to the right in order to be in accordance with the scatter data
- The redistribution of the vertices due to license permission was done as shown on table 4.2

Table 4.2 Redistribution of the land vertices

boundaries	every 2000m
main land	every 800m
big islands	every 1000 or 1500m
small islands	8-25 nodes each

A grid has been generated following the allowed number of nodes from the student license. The optimal grid has been determined by the parameters shown on table 4.3:

Table 4.3: Definition of the grid parameters

max. element area	2.500.000m^2
smallest allowable angle	26^o
max. number of nodes	2500

Hence, the generated mesh consisted of 3867 elements and 2415 nodes as showed on figure 4.10:

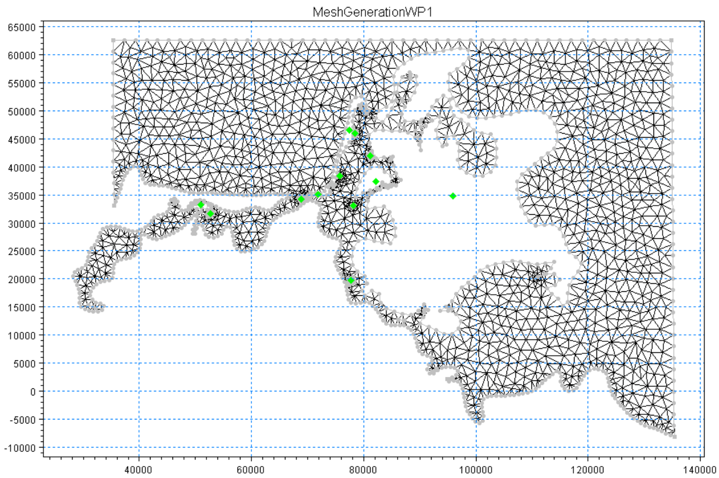


Figure 4.10: Generated Mesh

The next step was to give the elevation value to the elements of the mesh. After inserting the scatter data given, linear interpolation was implemented (see figure 4.11).

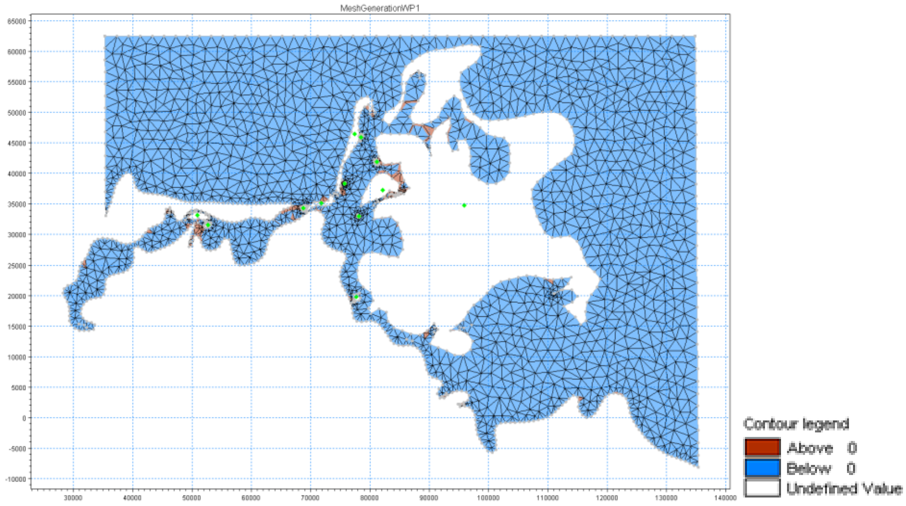


Figure 4.11: Interpolated Mesh

Before exporting the mesh, some corrections at the narrow channels were done. As showed on figure 4.12, the triangles in the narrow channels are covering all its width and as a consequence during the interpolation process the elevation assigned for these elements is the land level. To avoid this situation, arcs were created to trace the path of the flow.

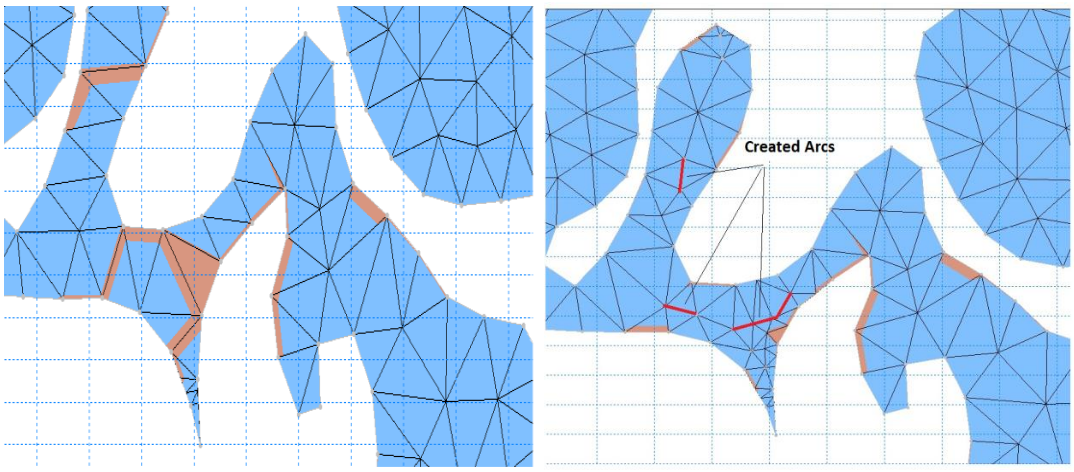


Figure 4.12: Correcting the flow in narrow channels

After correcting the narrow channels, the mesh was exported as showed on figure 4.13:

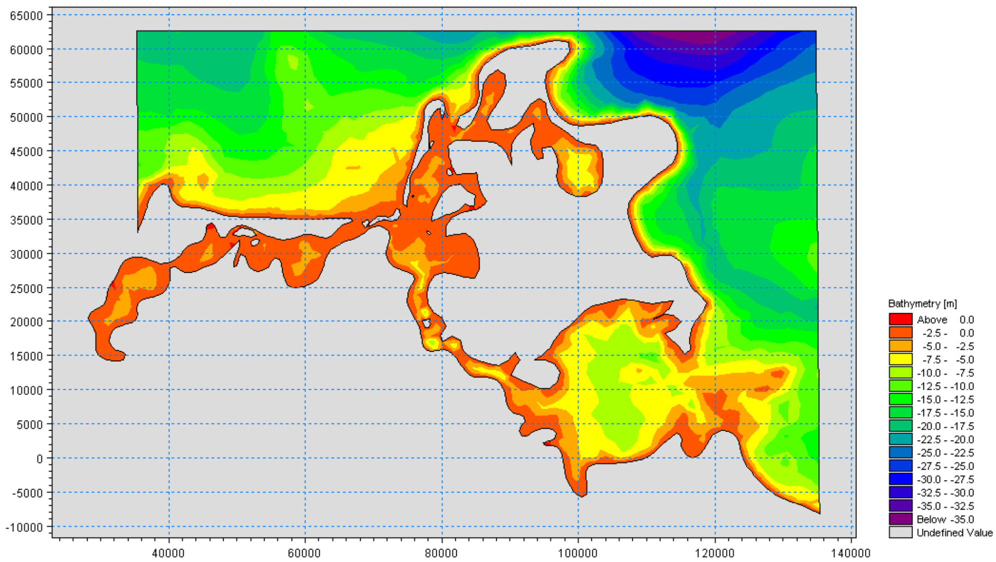


Figure 4.13: Bathymetry of the whole domain

The same procedure was followed for all the bathymetries created at the following models.

4.3.2 Setting up the Flow Model FM and the methodology for the Prerow model approach

The Rügen overall model was downscaled towards local models. Boundary conditions were calculated using nesting models during downscaling process. The goal was to create the water level boundaries for the Prerow model.

The first simulation at the Flow Model FM was done (from now on referred as WP1) in order to create BC for a reduced, smaller area (referred as WP2). The simulation is determined by the following factors:

- Simulation period: 1.10.1997 – 31.10.1997
- Timestep: 1hour (743timesteps)
- Coriolis force neglected (small area)
- Wind Forcing[2]: No wind
- Initial Conditions : Zero as constant value of water elevation
- 3 Boundary conditions (hindcasted by operational (numerical) Baltic Sea model)
- Outputs: 6 new line series water level BC for the new reduced model

[2] The simulations of the downscaling procedure were done only with flow (wind and waves were neglected). The boundary condition hindcasted by the operational Baltic Sea model include all meteorological effects (wind, air pressure). The 3 gauging stations used for defining the boundary conditions correspond to node values from the operational Baltic Sea model.

The boundaries used were the water level boundaries for west, east and north which were created by interpolation of the 4 given water level data on East-Land, East – See, West – Land and West –See (see figure 4.14). The type was specified level and the format was varying in time and along boundary.

This procedure was followed mainly for two reasons:
1. The harbours have been designed close to Prerow and the domain has to be reduced due to the detail of harbours definition.
2. The 3 gauging stations with measured water level data (Wittow, Neuendorf Hafen and Stralsund) have been used for comparison with the results of the model that are inside the reduced domain for calibration.

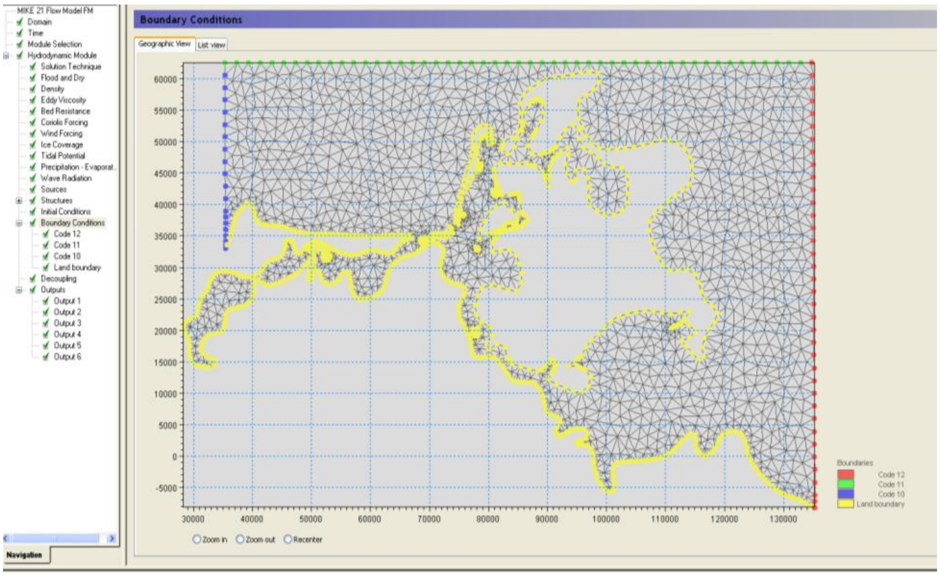


Figure 4.14: Boundary Condition for WP1

The outputs are the 5 red lines marked on figure 4.15:

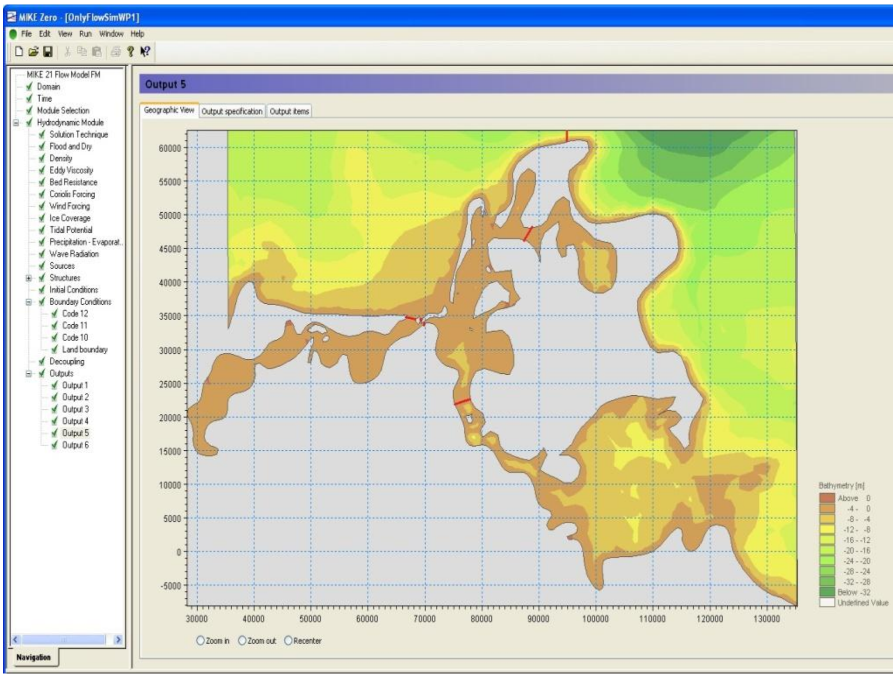


Figure 4.15: Water level output for WP2

A new mesh was generated (from now on refered as Mesh WP2) with the methodology mentioned before (3556 elements 2070 nodes).
The grid parameters is showed on table 4.4 and while the bathymetry and boundaries of the new domain on figures 4.16 and 4.17.

Table 4.4: Definition of grid parameters for WP2

max. element area	800.000m^2
smallest allowable angle	26^o
max. number of nodes2500	2500

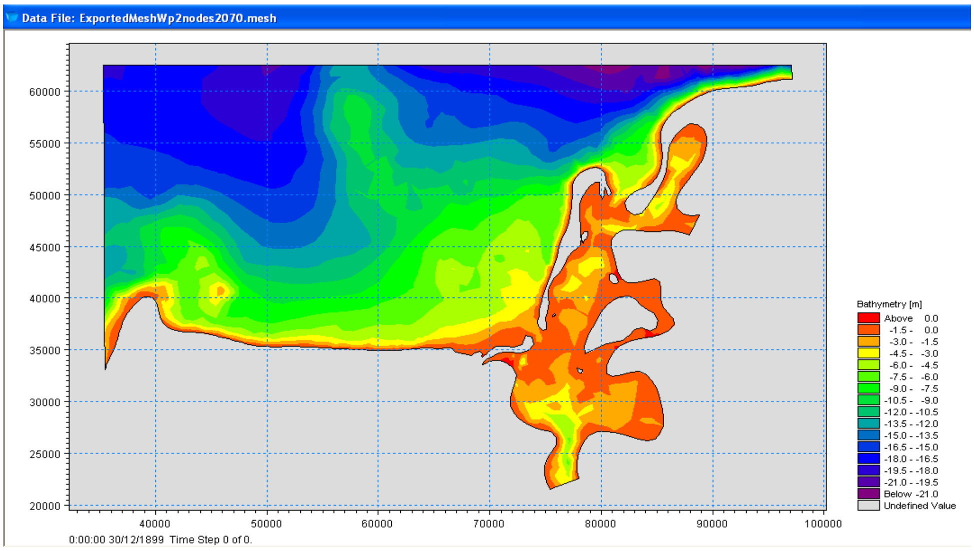


Figure 4.16: Bathymetry of WP2

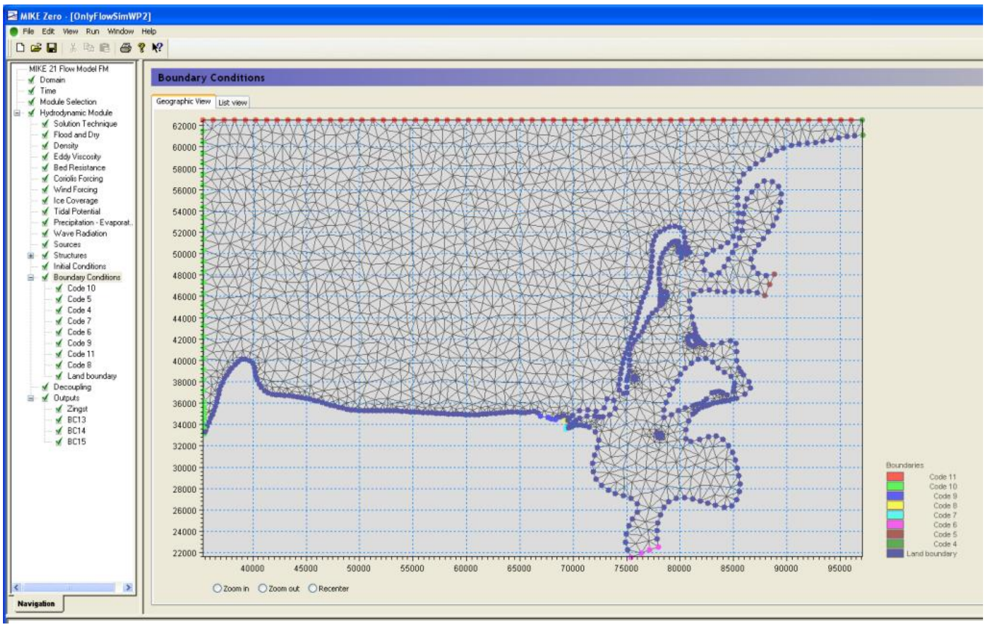


Figure 4.17: Boundary Conditions of WP2

4.3.3 Downscaling procedure and model calibration

A step by step procedure was followed to downscale the Ruegen area and to compare the results with the 3 measured water level results of the 3 gauging stations (see figure 4.18) mentioned before. By downscaling also the number of gauging stations is reduced.

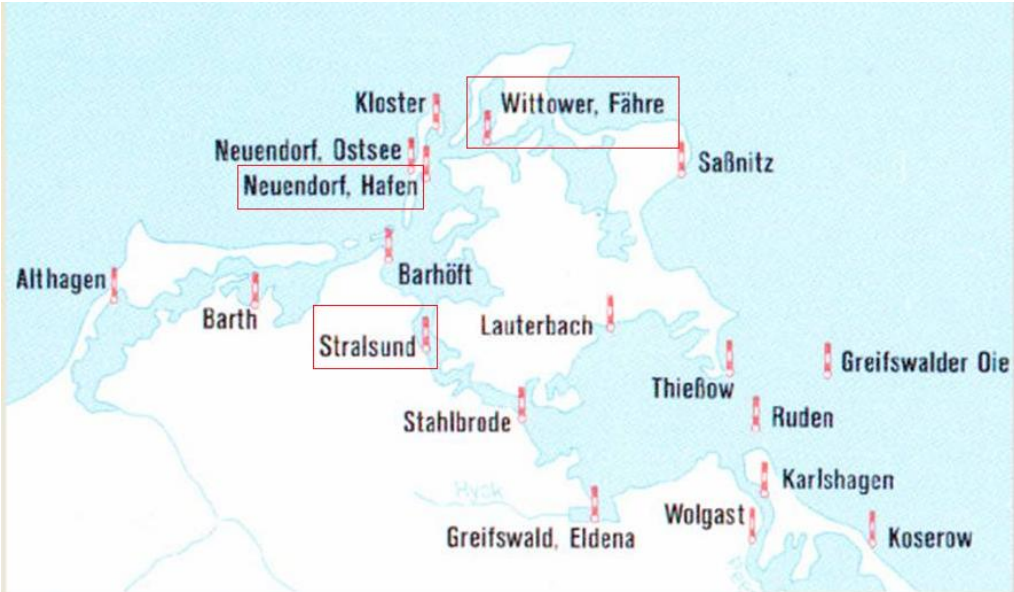


Figure 4.18: Map of the Gauging Stations

Step1: After running the WP2 model the results at the three gauging stations (Wittow, Stralsund and Neuendorf Hafen) were compared with the measured data. The simulations run for the whole October 1997 (hourly 743 timesteps) as October is the month with the highest water in comparison with the rest 2months.

Step 2: At the same reduced WP2 model the Wittow measured data were introduced as boundary condition and calculation for October 1997 was done. Results at the rest two (Stralsund and Neuendorf Hafen) Gauging stations were compared with the measured data.

Step 3: Both, Stralsund and Wittow measured water levels were used as boundaries and comparison was done with the rest 1 Gauging station (Neuendorf Hafen).

Step 4: The bathymetry at Bock area was modified prohibiting overflow of the Bock. New shoreline was generated and comparison of the shoreline modification and step 3 at Neuendorf gauging station was done. This model is called Ruegen West Model.

Step 5: The Ruegen West model was validated and reduced to Gellen Bight Model by shifting the eastern boundary towards to the top of Hiddensee and by creating another boundary between Bock-Hiddensee.

Step 6: As final step, the Gellen Bight model run and gave the boundary conditions for the Prerow model were the harbours were created.

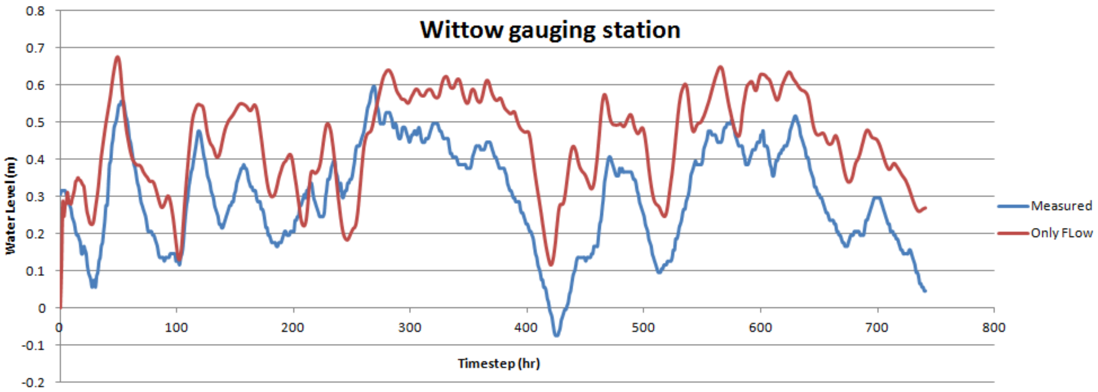


Figure 4.19: Comparison Measured with results from WP2 water level data at Wittow Gauging station

From the graph on figure 4.19 can be observed that a mean value difference between the measured and the models results is about 10 cm, that is a big difference when taking into account that the Wittow Gauging station is in between 0–4m depth. In genral, the results of the model for the one month of simulation (743 timesteps hourly measurements) follow the measured curve.

Comparison at Stralsund Gauging Station

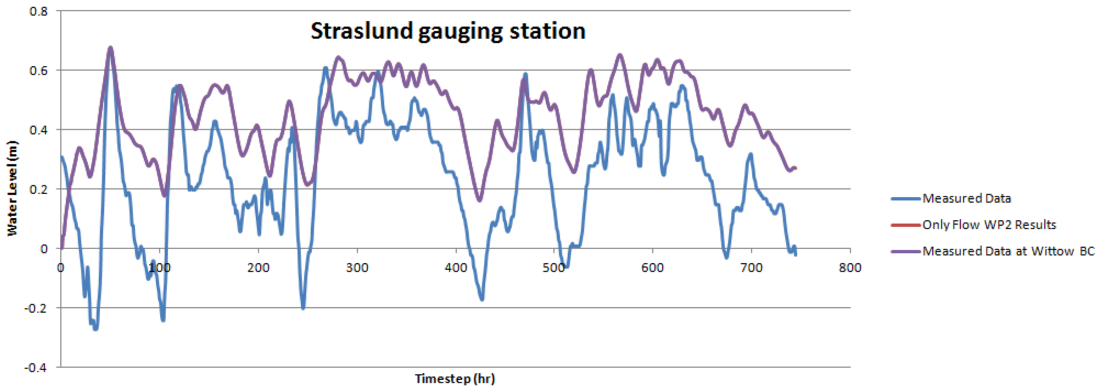


Figure 4.20: Comparison of measured data, WP2 results and measured data used as boundary at Wittow

From the graph on figure 4.20, can be observed that using the Wittow measured water level data as boundary conditions at one boundary, does not have any effect at the results. Moreover, the mean difference with the measured data is also around 10 cm (Stralsund Gauging Station depth 2.5–5m).

As a next step, the bathymetry at Bock area was modified by generating new shoreline (following picture) and a new mesh was generated with 7432 elements and 4272 nodes.

Table 4. 5: Definition of grid parameters for Ruegen West model

max. element area	400.000m^2
smallest allowable angle	26^o
max. number of nodes	3500

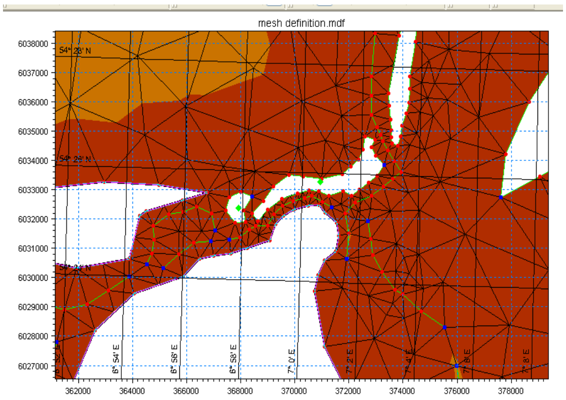


Figure 4.21: Bock channel before

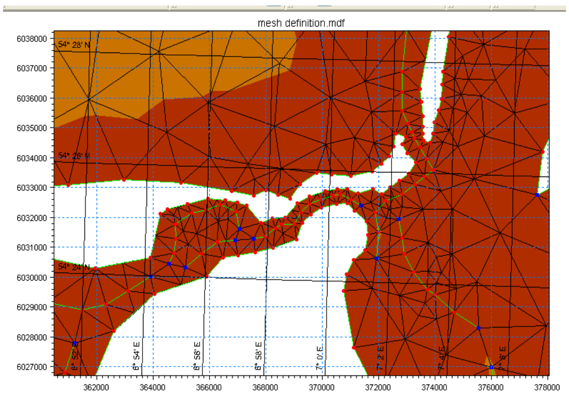


Figure 4.22: Modification of Bock channel before and after

This modification at Bock channels (see figures 4.21 and 4.22) will occur one day due to nature processes. The reason is the water is very shallow at this region and a lot of sedimentation occurs. Closing Bock channels do not affect the results as it will be presented at the graph on figure 4.25. The domain is reduced by two boundaries though.

The figures 4.23 and 4.24 show the boundaries and the bathymetry of the domain, respectively.

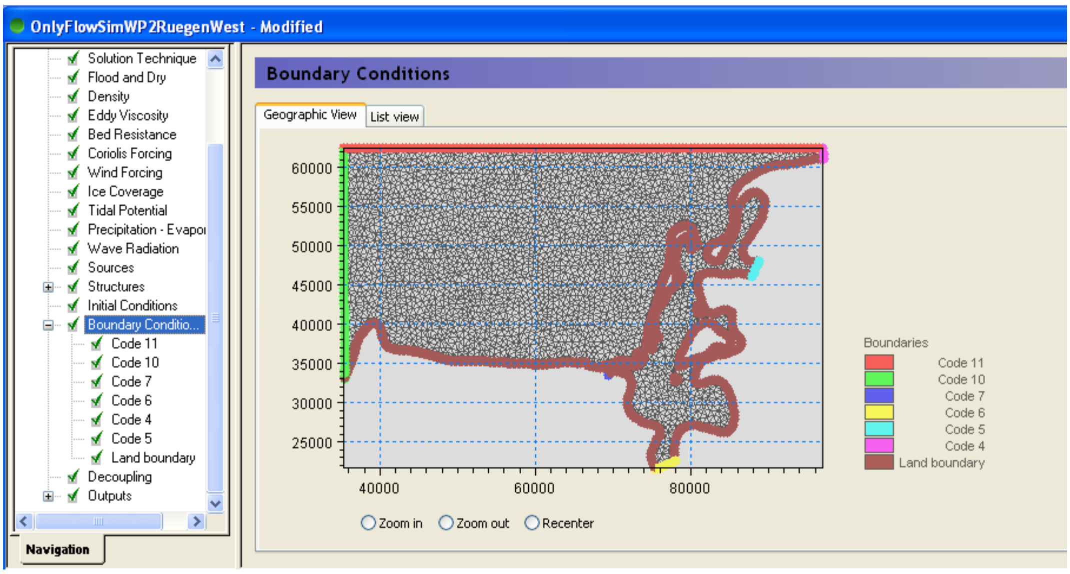


Figure 4.23: Boundary conditions of Ruegen West model

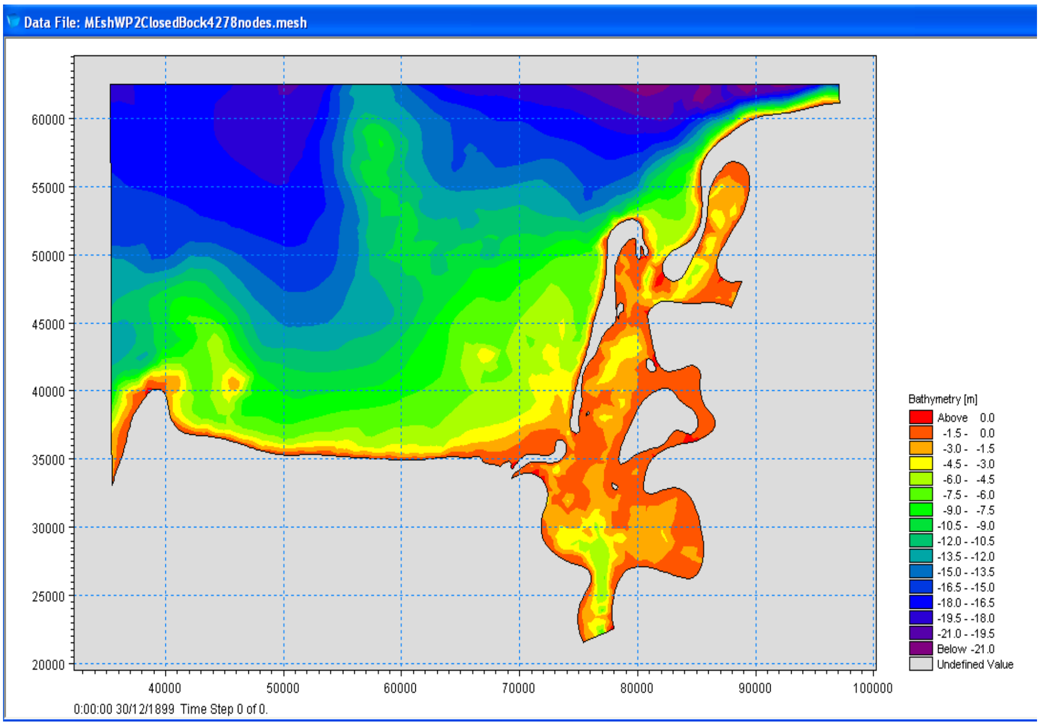


Figure 4.24: Bathymetry of Ruegen West model

The Rügen West model run with the measured water level data at Wittow and Stralsund and results for the boundaries of the next model (Gellen Bight Model) were exported.

Comparison at Neuendorf Hafen Gauging Station

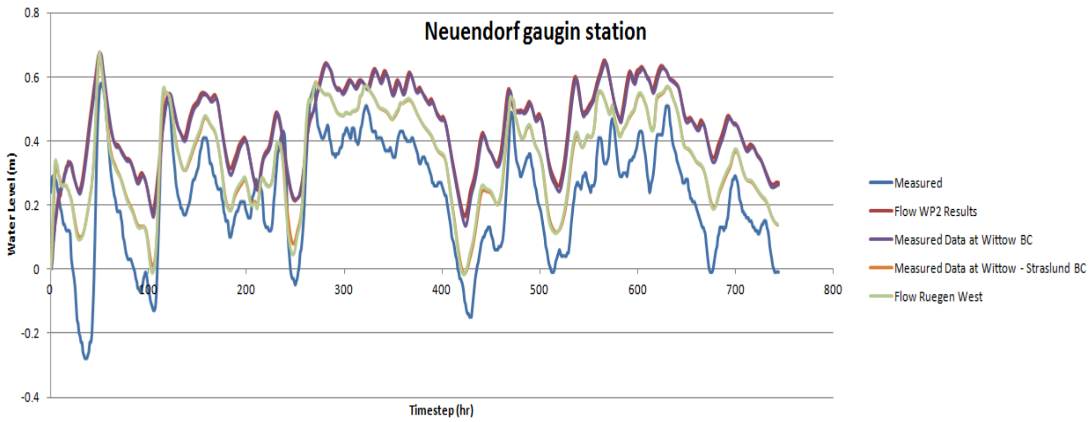


Figure 4.25: Comparison at Neuendorf Hafen Station

From the graph on figure 4.25 many things are observed. First of all, using the Wittow measured data as boundary conditions instead of the closest boundary from WP1, do not have any effect in the results. The water level difference with the measured data is reduced to 5cm when both the Wittow and the Stralsund measured data from the Gauging stations are used as boundaries instead of those exported from WP1. Closing the channels at Bock doesn't have any more effect and the difference is also at 5 cm. The depth at Neuendorf Hafen GS is approximately 1.5–3m.

4.4 Validation of the model

At this stage and due to data restriction, the model is validated as only 5cm difference with the measured data is observed. However, those changes at the domain and the calibration at the Ruegen West model are not enough to provide with safety correct calibrated results at the Gellen Bight model.

The Gaugin stations with the measured data are far away from Prerow. Even in the case of any difference between measured and simulated data, this would not give the assurance of correct results at Prerow which is on the other side of the domain. This is the best approach which could be implemented with the data provided though.
Furthermore, calibration was implemented changing the hydrodynamic parameters (friction coefficient) with different ways and the goal was those 5cm to be reduced. However, the 5cm difference was not affected[3].

4.5 Gellen Bight Model

4.5.1 Creating Water Level Boundary Conditions for Prerow HD model

At step 5 the Gellen Bight model was created by shifting the eastern boundary towards to the top of Hiddensee and by creating another boundary between Bock–Hiddensee(see figure 4.26). The Gellen Bight model was created with 5122 elements and 2802 nodes.

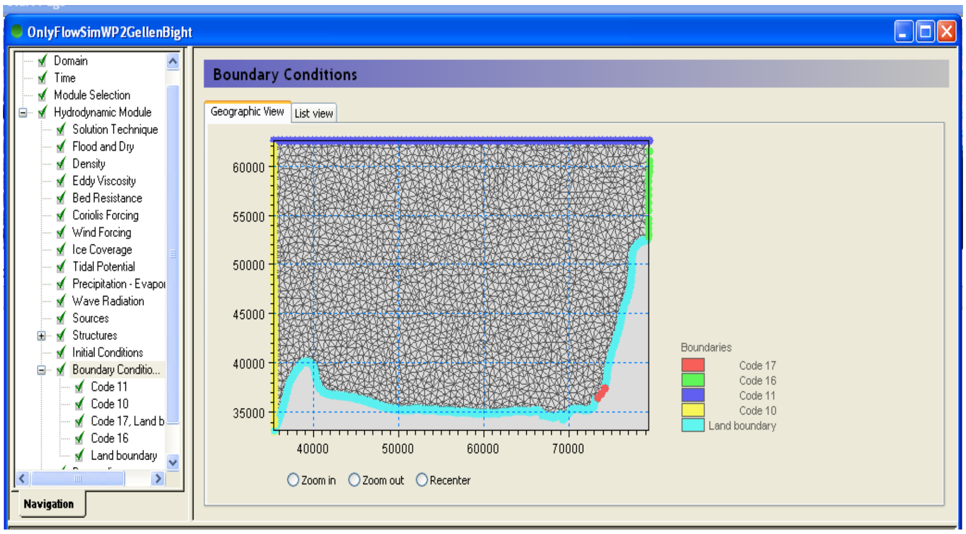


Figure 4.26: Gellen Bight Model Boundary conditions

[3] The source of the 10cm initial difference was finally discovered. All boundary conditions and water–level specification from BSH model should be lowered 10cm because of difference in reference level between BSH-model and bathymetry reference level used in Morwin model. This was noticed after the simulations of the harbour models were implemented with the 5cm calibrated difference.

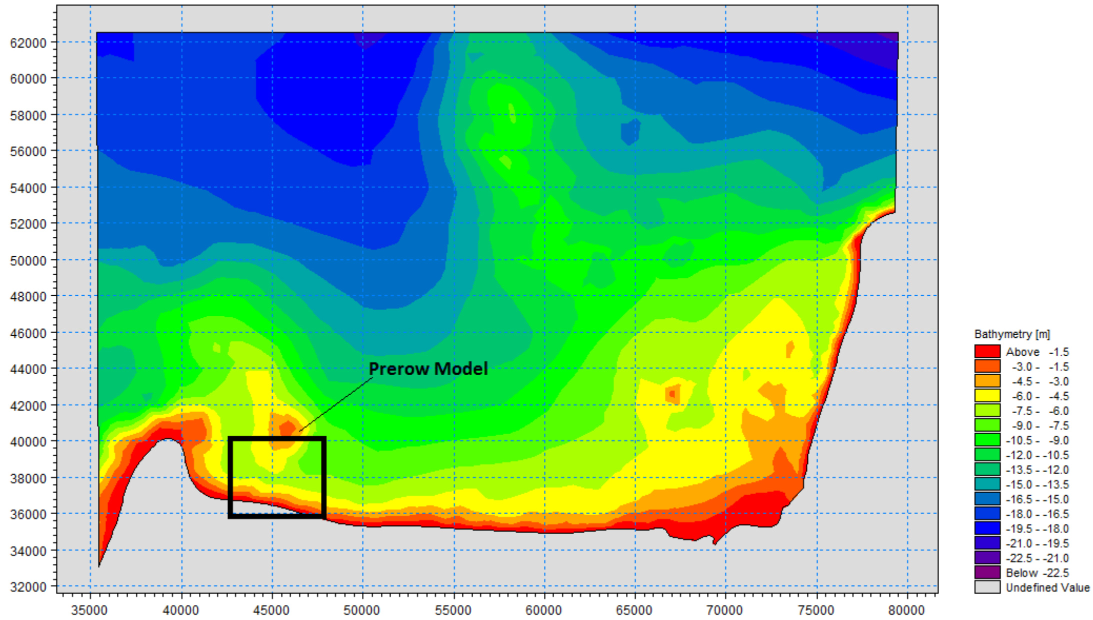


Figure 4.27: Bathymetry of Gellen Bight model

The Gellen Bight model was the model which run only with flow and gave the water level BC for Prerow final Flow model on which the harbours were created and implemented.
As it can be seen on figure 4.27, above the Prerow model there is a shallow area called "Prerow Bank" and this is why in the bathymetries following one can observe suddenly the bathymetry to become again a bit shallow in the deep water away from the coast.

4.5.2 Creating Wave Boundary conditions for the Prerow Wave Model

The Gellen Bight model was also used for another reason. The wave measured data of October 1997 were 28km North of Prerow (GKSS). As a result, the Spectral Wave FM model was set up importing the Gellen Bight bathymetry with wave boundary conditions using the measured data from GKSS. As output the wave data for the Prerow boundaries were exported. The model run two times. The difference was at the boundary conditions and at the spectral discretization.

The simulation is determined by the following factors:

- Simulation period: 1.10.1997-31.10.1997 (743 hourly timesteps)
- Wind : No wind
- Water level: varying in time and domain (output of Gellen Bight previous model)
- Initial Conditions: Zero spectra
- Spectral Discretization: Directional sector – 4 number of directions
  - ✓ 1.North Wind simulation: minimum direction 315 and maximum 45 for the North wind
  - ✓ 2.West Wind simulation: minimum direction 180 maximum 315
- Boundary Conditions: Waves (Hs,Tp,MWD,DSD) varying in time constant along line –calculated from the Gellen Bight Wave model

- ✓ 1. Used at the North boundary (see next picture: Code11) rest boundaries lateral for the North Wind simulation
- ✓ 2. Used at the West boundary (Code 10) rest boundaries lateral for the West Wind simulation[4]

- Outputs : Line series (Hmo, Tp,MWD,DSD)
  - ✓ The North wind simulation gave the Code 22 North boundary of the Prerow model (Figure 8.1)
  - ✓ The West wind simulation gave the Code 21 West boundary of the Prerow model (Figure 8.1)

4.6 Harbours design

4.6.1 Approximation to the optimal number of nodes with ArcGIS

The new Prerow model was the one where the harbours have been designed. An approximation to the optimal number of nodes was done in accordance with the volume of the basin[5]. Different meshes (ranging from 2000-7000 nodes) were generated. For each mesh a txt file was created with the information of nodes (x,y,z). Those files were imported to ArcGIS, interpolated by Kringing interpolation and the volume was calculated.

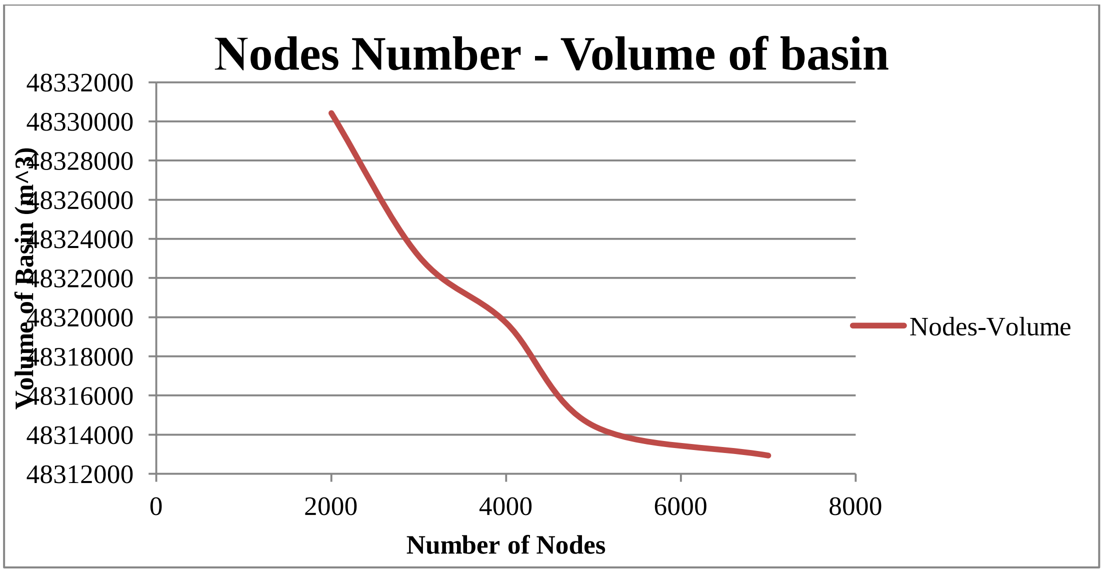


Figure 4.28: Optimal approximation of node numbers

The graph on figure 4.28 shows a decrease of the basin volume for an increase of the number of mesh nodes. Consequently, a coarser mesh implies an overestimation of the water volume. The values tend to converge close to 48312000m^3 with an important change of slope at 5000 nodes. This is the reason why this inflection point is considered as the optimal number of nodes regarding volume as geometry criteria for mesh refinement. All the following bathymetries use 5000 as maximum number of nodes.

---

[4] The West boundary is defined as varying in time and constant along line. As bed level of the West boundary is decreasing towards the coastline, defining it as constant along line is just and assumption. The reason is the lack of data.

[5] From now on the DHI software with unlimited number of nodes was provided so the student license is no more used for the rest following simulations.

4.6.2 Meshes for the 4 harbours

Four kind of harbours were assessed: one onshore, one inshore and two offshore (0.5km and 1km).

At a radius of 100m at the offshore harbours a refinement of the nodes was used to achieve better accuracy on the bathymetry. The local maximum area of the triangles inside the refinement was 300m^2 while at the rest of the domain the maximum element area was 4000m^2. Details are showed on table 4.6.

Table 4.6: Definition of the grid parameters for the Harbour models

	Local maximum element area (m^2)	Maximum Element area (m^2)	Smallest Allowable angle	Max number of nodes	Number of elements	Number of nodes
Without	-	4000	26	5000	6420	3436
Inshore	-	4000	26	5000	6500	3512
Onshore	-	4000	26	5000	8801	4708
Offshore A	300	4000	26	5000	7490	4011
Offshore B	300	4000	26	5000	7746	4138

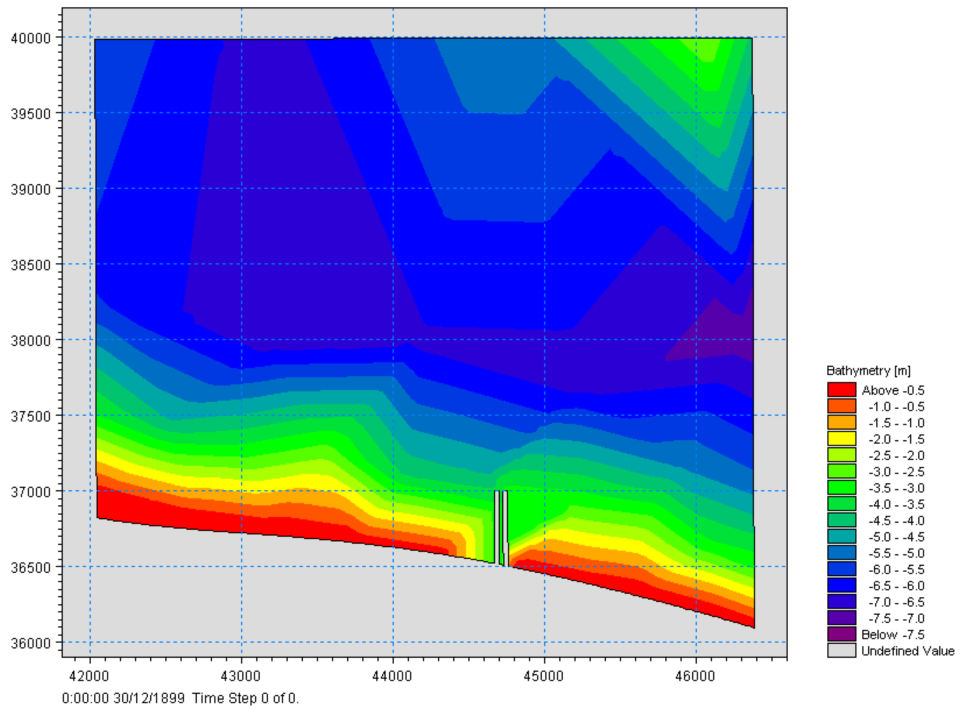


Figure 4.29: Exported Mesh Inshore Harbour

Figure 4.29 shows the bathymetry of the inshore harbour. The entrance is a channel 25m width consisted of 2 breakwaters 30m width each and 500m length.The mooring areas are assumed to be inside the city. This does not affect the model thus avoided to be assessed.

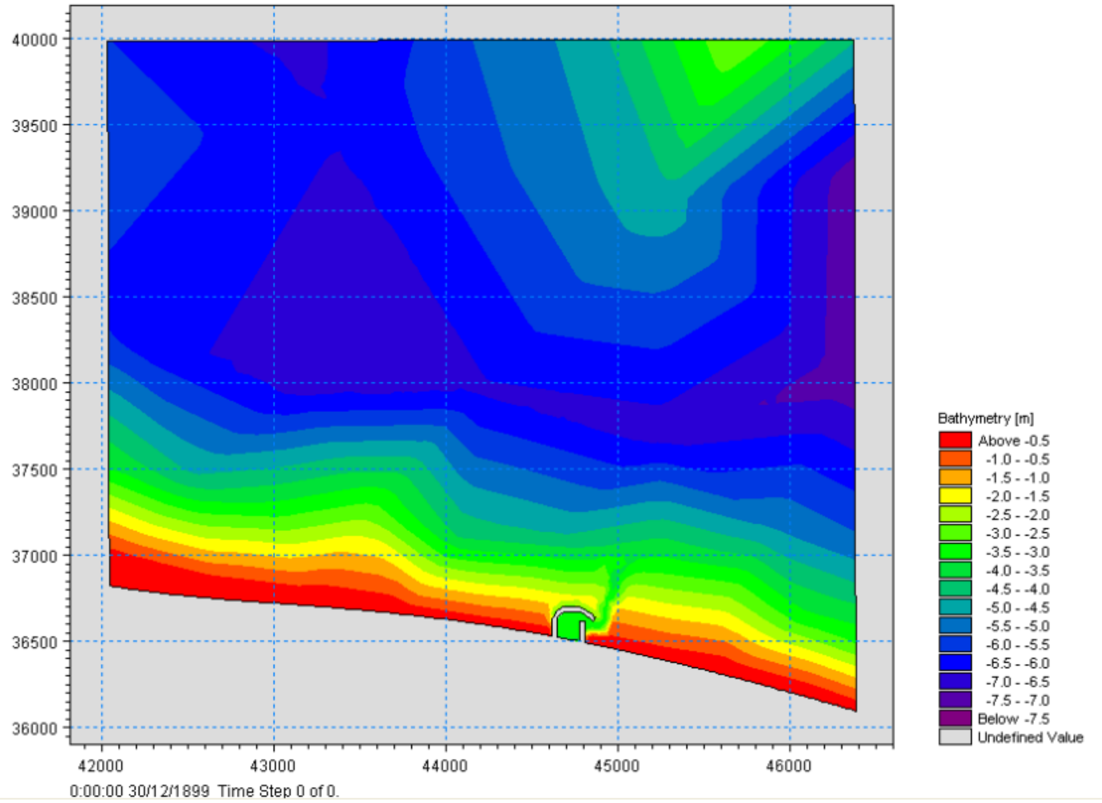


Figure 4.30: Onshore Harbour

On figure 4.30 is showed the onshore harbour. It is not consisted of navigation channel but dredging until the depth of 3.2m w implemented.

General **guidelines for minimum depth clearance requirements in channels influenced by waves** are given by PIANC (1997):

<u>Water depth</u>

$$\frac{water\ depth}{ship\ draft} > 1.3\ when\ H \leq 1m\ (3.3ft)$$

$$\frac{water\ depth}{ship\ draft} > 1.5\ when\ H > 1m\ (3.3ft) and\ wave\ periods\ and\ directions$$

$$are\ unfavorable$$

Here, the draft of the boats is 2.1 m so the minimum water depth has to be 3.2 m. As a result, the minimum water depth of 3.2 m was assumed at all kind of harbours.

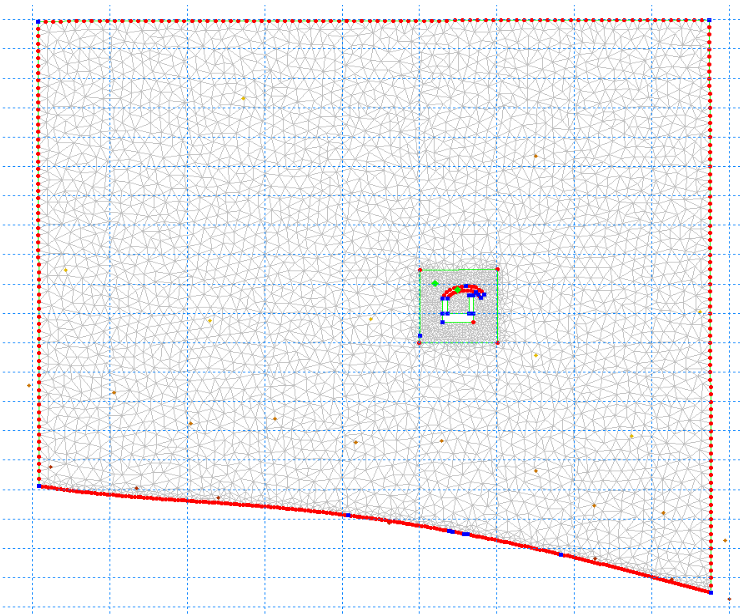


Figure 4.31: Generating mesh of offshore harbour with refinement

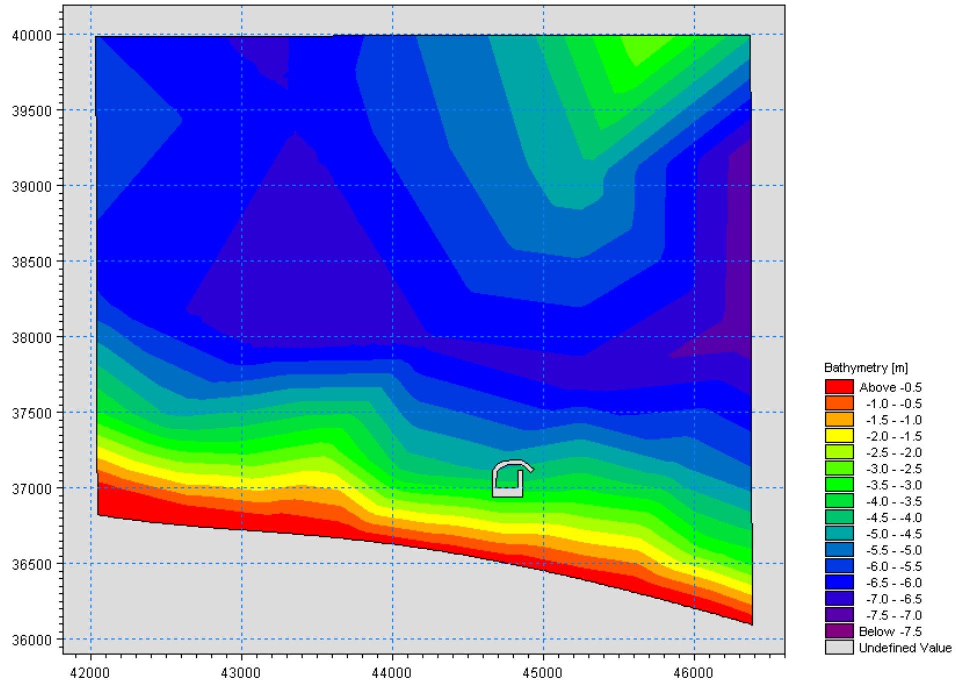


Figure 4.32: Offshore Harbour 0.5km from coast (Offshore A)

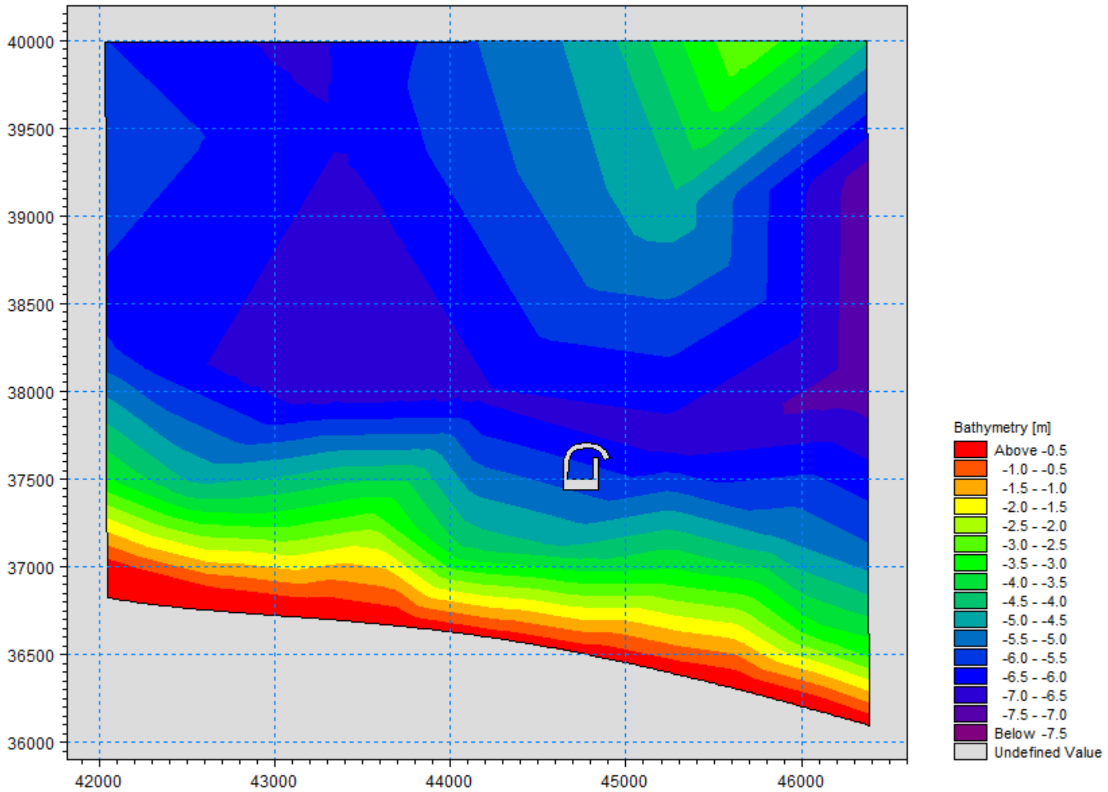


Figure 4.33: Offshore Harbour 1km from coast (Offshore B)

On figures 4.31the mesh of the offshore B harbour is showed while on 4.32 and 4.33 the bathymetries of the offshore cases are presented. The offshore harbours are assumed to be connected with the coast with a bridge for cars of 2 directions. This is the reason why parking place is provided.

4.7 Simulation procedure

4.7.1 Simulation for the Spectral Wave model

The Spectral Wave FM is used for 3 specific reasons:

- Two typical criteria for the harbours design are to be checked:
  Mooring areas: Significant wave height should not exceed 0.3m more than 10% of the time
  Access channels: Significant wave height should not exceed 0.6m more than 10% of the time
- The radiation stresses will be created and will be used as an input at the Flow Model FM
- The waves forces (H_{mo}, Tp, Mean Wave Direction(MWD)) will be used as an input at the Sand transport model

4.7.1.1 Simulation for North event:

The simulation is determined by the following factors

- Simulation period: 24.10.1997-28.10.1997 (108 hourly timesteps)
- Wind (speed and direction): provided nearby Zingst
- Water level: varying in time and domain (output of Gellen Bight previous model)
- Initial Conditions: actual simulation began at 23.10.1997
- Boundary Conditions: waves (Hs,Tp,MWD,DSD) varying in time and along line –calculated from the Gellen Bight Wave model used at the north boundary (see figure 4.34: Code22)
- Boundary Conditions : lateral used at the East and West boundary (see figure 4.34: Codes 21 and 23)
- Outputs : 2 kind of outputs for each harbour simulation
    - ✓ Significant wave height for entrance and mooring areas
    - ✓ Radiation Stresses Whole Domain (used as input at the Flow model FM follows)
    - ✓ Wave forces (H_{mo}, Tp, Mean Wave Direction(MWD)) used as input at the Sand transport model

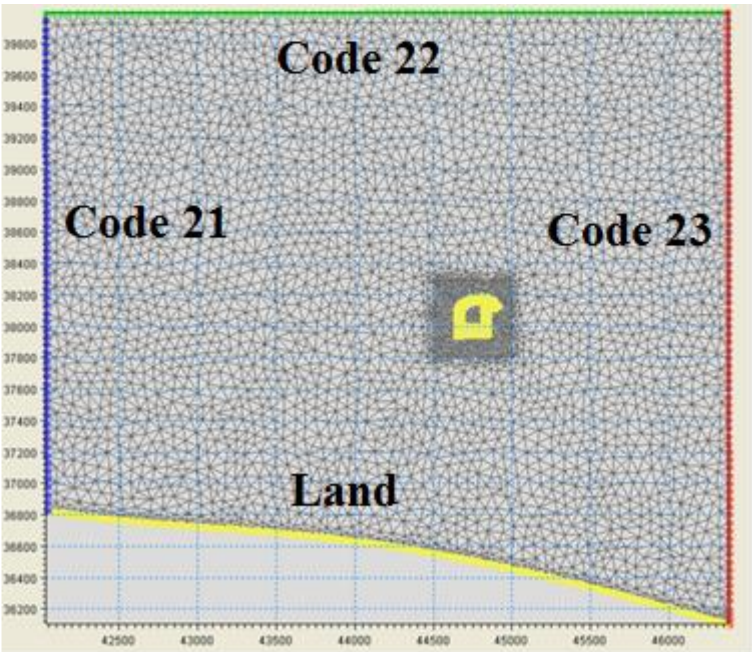


Figure 4.34: Boundary Conditions for SW model (same for all kind of harbours)

4.7.1.2 Simulation for the West events:

The simulation procedure was the same as the North event. The difference is at the simulation time and at the boundaries. At the West events the boundaries were as follows:

- Simulation period: 2.10.1997 (mean event) and 23.10.1997 (max event) (24 hourly timesteps)
- Initial Conditions: actual simulation began one day before
- Boundary Conditions: waves (Hs,Tp,MWD,DSD) varying in time and along line –calculated from the Gellen Bight wave model used at the west boundary (see previous picture: Code21)
- Boundary Conditions : lateral used at the East and North boundary (Codes 22 and 23)

4.7.2 Simulation for the Flow model and Sand Transport FM models

4.7.2.1 North event

The simulation for the Flow model is determined by the following factors:

- Simulation period: 24.10.1997-28.10.1997 (108 hourly timesteps)
- Wind (speed and direction): provided nearby Zingst
- Wave radiation : specified wave radiation – varying in time and domain (calculated from Spectral Wave model – North event)
- Initial Conditions: Actual simulation began at 23.10.1997
- Boundary Conditions: Specified level - varying in time and along boundary (output of Gellen Bight previous model)
- Output : whole area
    - ✓ Total water depth
    - ✓ Current speed

The simulation for the Sand Transport model is determined by the following factors:

- Model type : wave and current (described by sediment transport table)
- Grain diameter : 0.2mm
- Forcings: waves–varying in time constant in domain (calculated from Spectral Wave model – North event)[6]
- Boundary Conditions: zero sediment flux gradient for outflow, zero bed change for inflow

4.4.2.2 West event

The same as the North event but with different simulation time. For the mean event it was 23 of October and for the max it was 2 of October.

[6] Output from the Spectral Wave model was a NON-UTM dfsu file (varying in time and domain). This file could not be read from the programme. The reason could be problem in the data, in the handling of the tools by misunderstanding the software documents or a bug and this needs further investigations. Thus, a pointserie (dfs0) file was extracted from the same NON-UTM dfsu file and used as an input only varying in time and assumed constant in domain.

Chapter 5: Presentation and comments on the results

5.1 Introduction

In this chapter, the Spectral Wave module, the Hydrodynamic and Sand Transport module FM were set up with conditions mentioned at the end of chapter 7. The models run 5 times. One without any harbour and four times with the created harbours at the Prerow Module. The goal was to understand the impact of the harbours on the area. This is why it is compared before and after the creation. This will be more easy understood by figure 5.1:

North mean event:	West mean event:	West max event:
0. Without	0. Without	0. Without
1. Inshore	1. Inshore	1. Inshore
2. Onshore	2. Onshore	2. Onshore
3. Offshore A	3. Offshore A	3. Offshore A
4. Offshore B	4. Offshore B	4. Offshore B

-Comparison at the same event before and after the construction of the harbour (without any harbour)
-Coarse comparison between the events at the entrance of the harbours and at mooring areas

Figure 5.1: Comparison between the harbour cases and the events

At Spectral Wave FM the results of the significant wave height were used in order to check the design criteria at the entrance of the harbours and at mooring areas during the whole simulating procedure according to CEM. Comparison before and after the creation of each harbour was done.

Moreover, comments on the maximum values observed during the simulating procedure of each event of each kind of harbour are presented at the end of the paragraph 5.2.3

From the hydrodynamic model the currents and the total water depth are presented and analyzed. The total water depth should be more than 3.2m at harbour entrances and mooring places after the event in order not the boats to face problems during access or exit.

From the Sand Transport model, the bed level before and after the simulation is presented. This is done mainly to identify the tendency of erosion or accumulation areas nearby or at the harbours.

The goal is to propose the best performance with respect to:

a. Accessibility of the harbours at extreme conditions in terms of bathymetry (navigation)
b. Safety in the harbour during extreme events (mooring)

5.2 Spectral Wave model - Results and comments

5.2.1 Results for the North-mean event

The following graphs show the significant wave height at points chosen at the entrance of each harbour during the North event. The modules run 5 times in total for each event. The first runnings were at the Prerow area without any harbour. The next runnings at the 4 harbours (inshore, onshore, offshore A (0.5km), offshore B (1km)) gave outputs time series at points in the entrance of each harbour. Comparison at the signigicant wave height at that points before and after the construction of each harbour is showed at the graphs on figure 5.2.

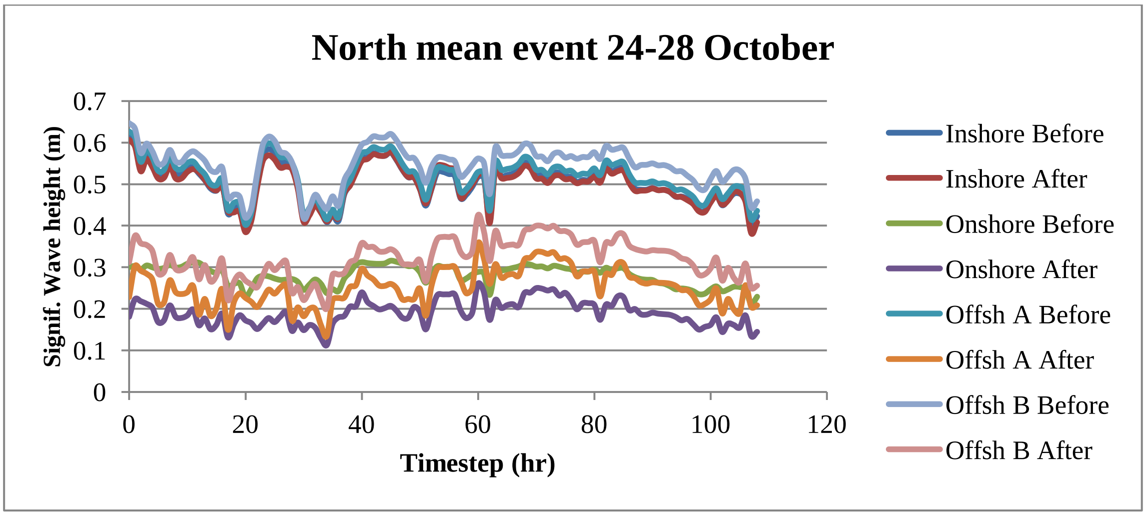


Figure 5.2: Hmo for point series – North mean event

The typical criteria according to CEM are:
<u>Mooring areas</u>: Significant wave height will not exceed 0.3m more than 10% of the time.
<u>Access channels:</u> Significant wave height will not exceed 0.6m more than 10% of the time.

As it is seen from the graph above the significant wave height is smaller than 0.6m at the 90% of the time (as the criteria demands) even before the construction of the harbours. After the construction of the harbours the significant wave height is not more than 0.3m at all cases (again smaller than 0.6m at 90% of the time).

Important is to observe that Inshore harbour is the only one which significant wave height is affected only 10cm after the construction. This is mainly because the chosen point was outside of the harbour channel (see figure 5.3). The rest of the harbour constructions affect the significant wave height at that area as it is reduced almost at half of its initial value.

The Onshore harbour has lower values than the rest. At the most of the simulating time its around 0.30 to 0.40m while after the construction it is around 0.2m.

The two Offshore harbours have values fluctuating at 0.5m before the construction while after the Offshore A (0.5km from coast) has less than 0.3m and the Offshore B has less than 0.4m (1km from coast)

In general the values before the construction are not so high. One reason could be the Prerow Bank that exists close to the North boundary. The Prerow Bank functions as a submerged breakwater where the waves lose big part of their energy.

At mooring areas (inside the harbour basin) the significant wave height was also checked and it was smaller than 0.3m at the 90% of the simulation.

Hence the boats design criteria for the harbours at access and mooring areas are covered under North mean conditions.

The following figures show the maximum significant wave height for the whole domain that is observed during the simulating period of the North event for the four different cases. A comparison between the values of all the events is showed at the end of the 5.2.3 paragraph. The points that created the time series for the previous graph on figure 5.2 are also shown on figures 5.3, 5.4, 5.5 and 5.6.

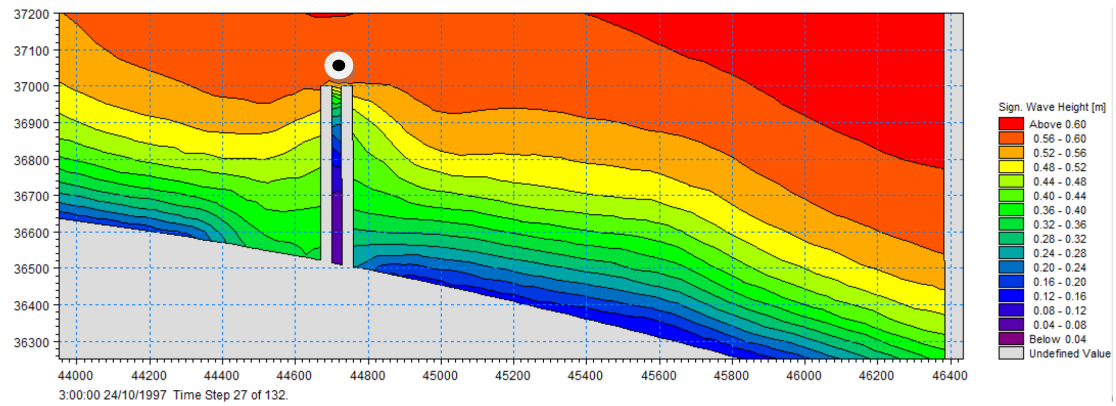


Figure 5.3: Maximum H_{mo} for Inshore – North mean event

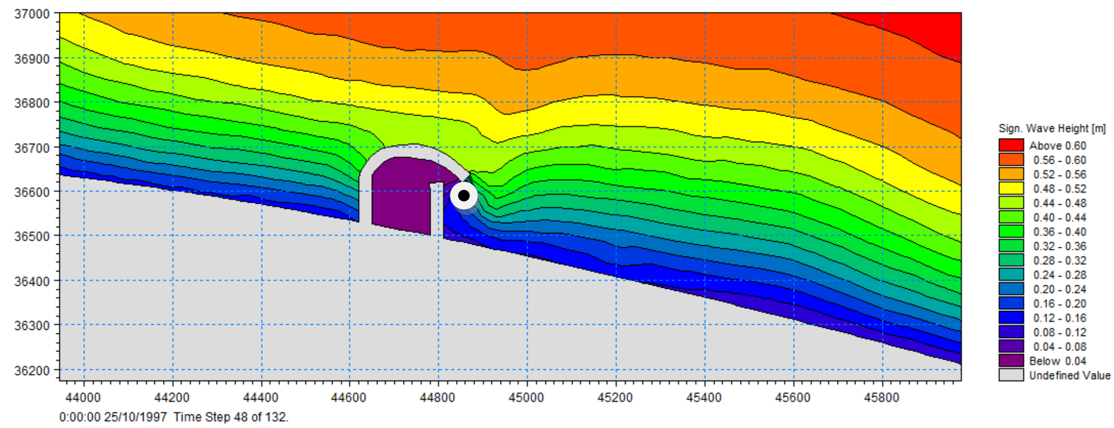


Figure 5.4: Maximum H_{mo} for Onshore–North mean event

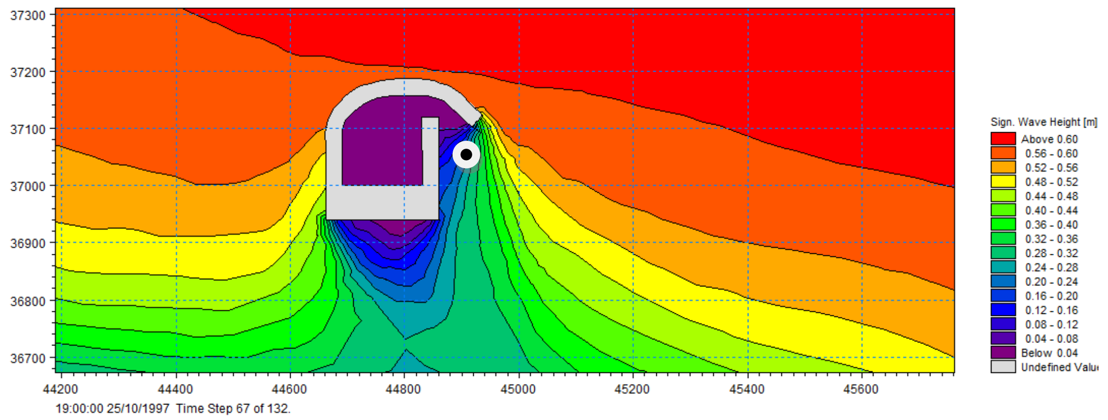


Figure 5.5: Maximum H_{mo} for Offshore A – North mean event

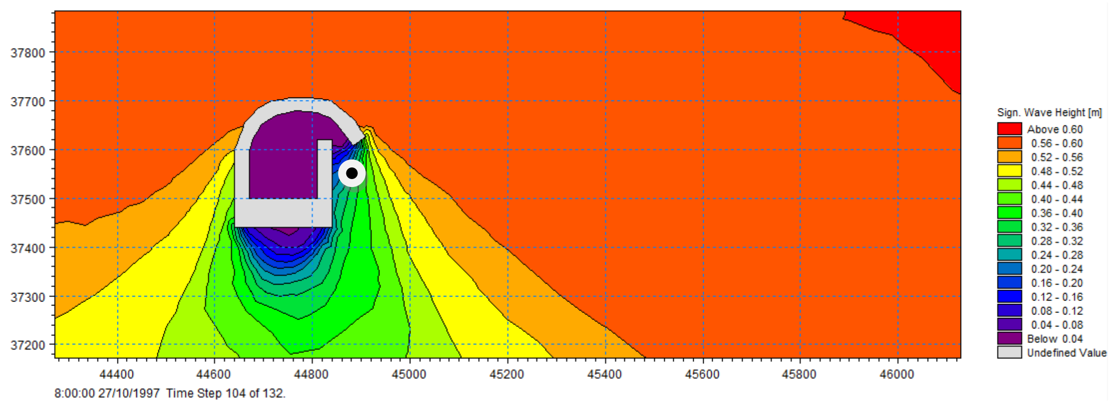


Figure 5.6: Maximum H_{mo} for Offshore B – North mean event

The figures 5.3, 5.4, 5.5 and 5.6 prove that the design criteria for the harbours are covered as the significant wave height is less than 0.6m even at the maximum value of the simulating procedure. This was already proved with the point series graph analyzed on figure 5.2. At mooring areas the Hmo is less than 0.3m, so the harbours provide safe mooring during North mean weather conditions. More comments follow at the end of 5.2.3 paragraph.

5.2.2 Results for the West-mean event

The figure 5.7 shows the H_{mo} after the West mean event nearby the harbours entrance.

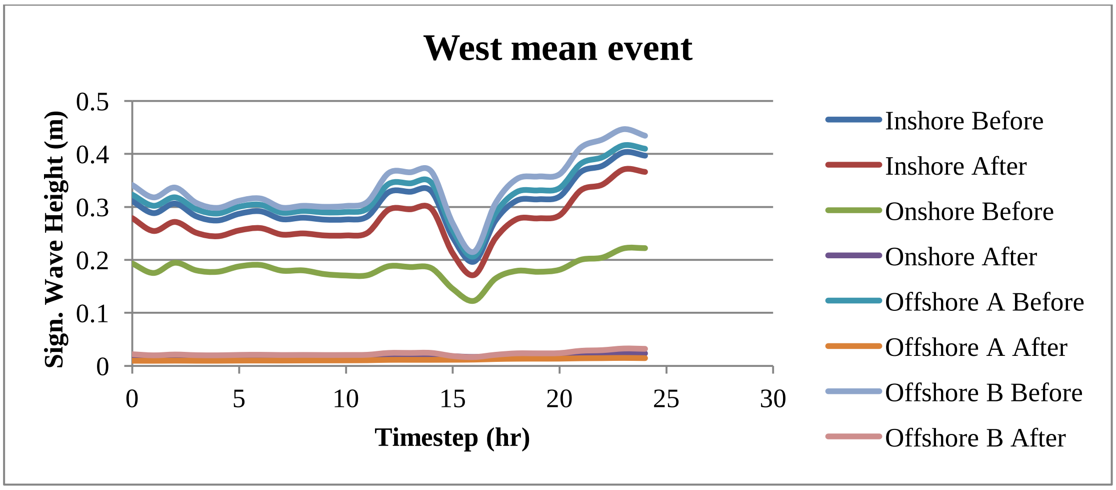


Figure 5.7: Hmo for point series–West mean event

From the graph on figure 5.7 it is concluded that the design criteria for the harbours are covered when the wind blows from the West. The values of the significant wave heights at the entrance of the harbours are less than 0.05m. A comparison can be made at the values before the construction which are between 0.3 and 0.35 (Onshore between 0.15m and 0.2m) while for the North event mentioned before the values were close to 0.50m (Onshore around 0.30m). From this it is realized that the North events affect more the harbours than the West.

Figures 5.8, 5.9, 5.10 and 5.11 show the maximum significant wave height nearby the harbours.

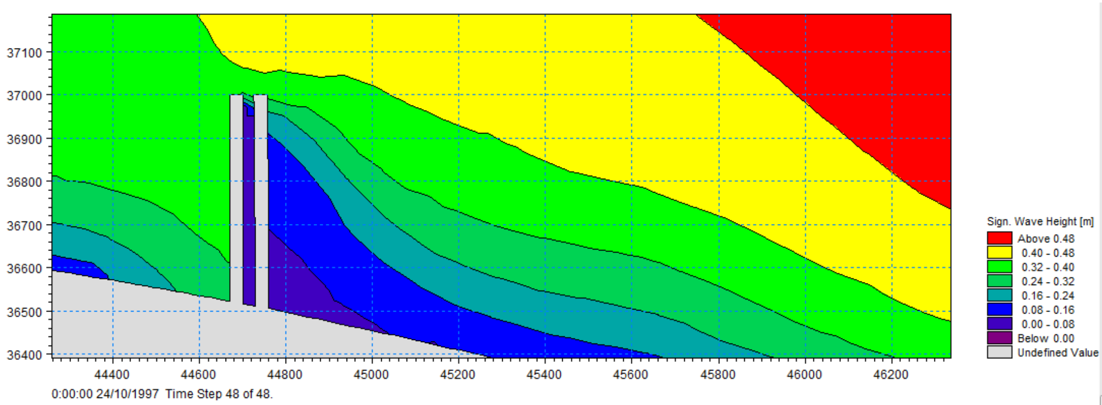


Figure 5.8: Maximum H_{mo} for Inshore–West mean event

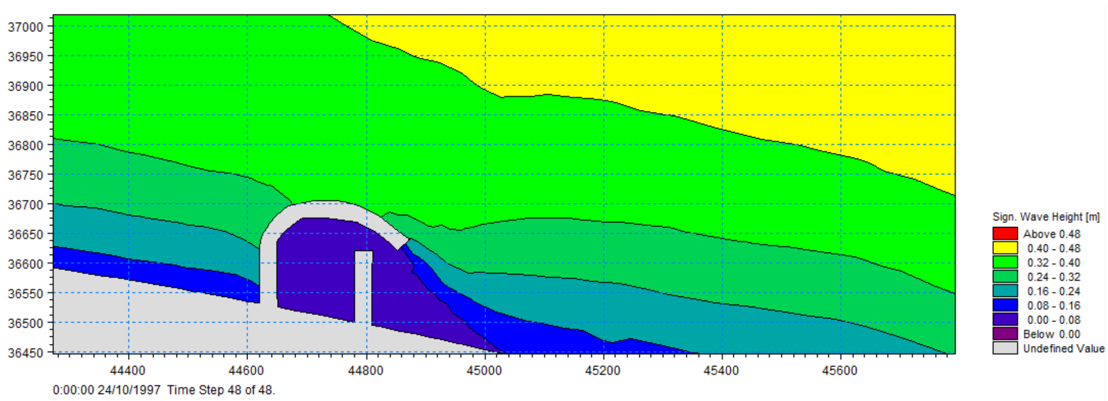


Figure 5.9: Maximum H_{mo} for Onshore–West mean event

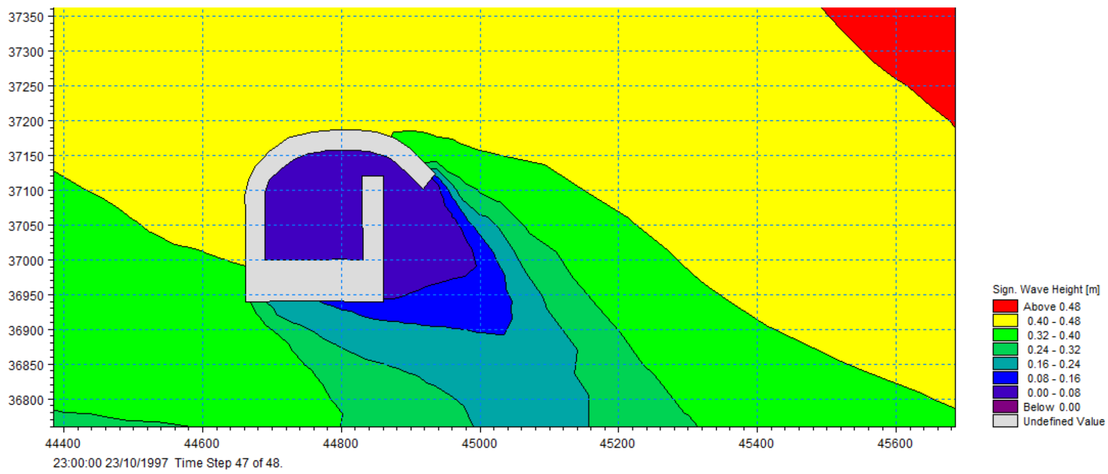


Figure 5.10: Maximum H_{mo} for Offhore A–West mean event

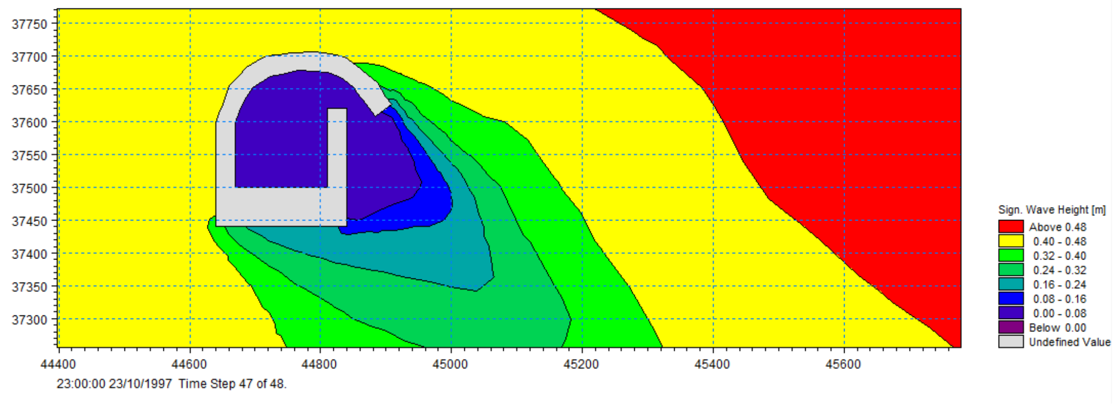


Figure 5.11: Maximum H_{mo} for Offhore B–West mean event

The maximum significant height observed close to the entrance of the harbours is lower than the mean North event. Comments for the maximum values observed during the simulating procedure of the West mean event follow at the end of the paragraph 5.2.3

5.2.3 Results for the West-max event

On figure 5.12 pointseries of the significant wave height during the West max event are presented before and after the design of harbours.

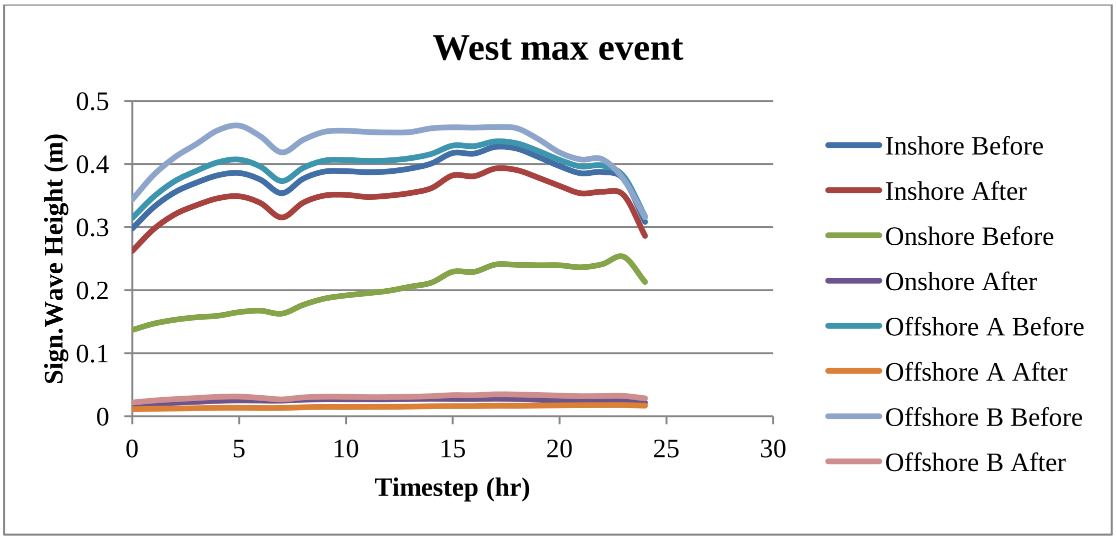


Figure 5.12: Hmo for point series – West max event

The values shown during the max event (7-9 Beaufort) are again lower than the mean North event. In comparison with the mean West event the values are approximately 0.15m higher. The boats can safely moor at the harbours under extreme West conditions. On figures 5.13, 5.14, 5.15 and 5.16 is showed the maximum significant wave height observed during the West max event nearby the harbours.

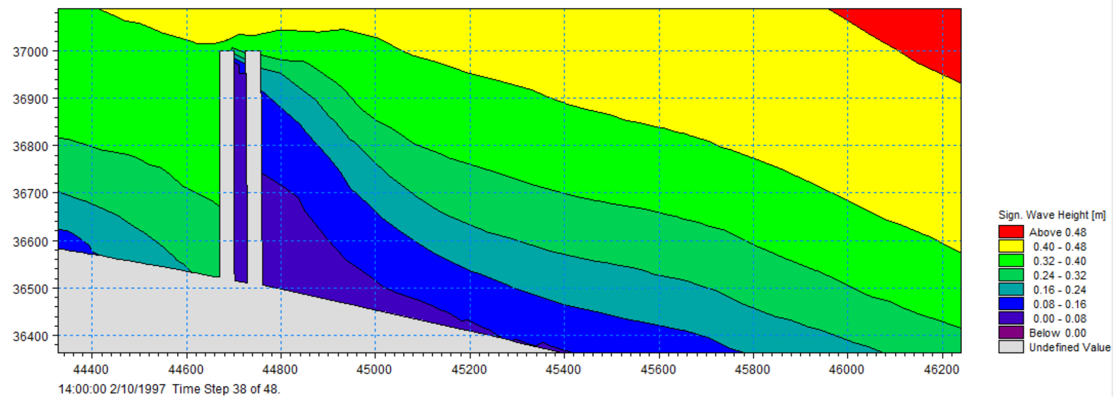


Figure 5.13: Maximum H_{mo} for Inshore–West max event

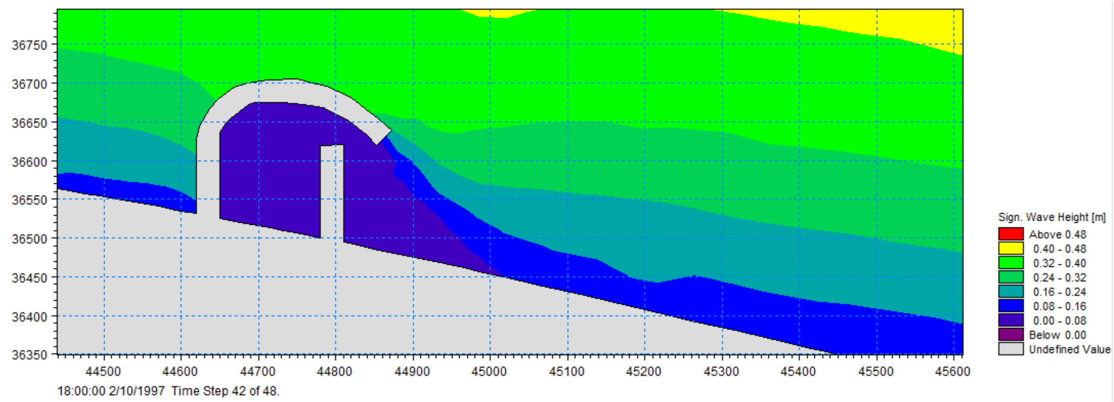


Figure 5.14: Maximum H_{mo} for Onshore–West max event

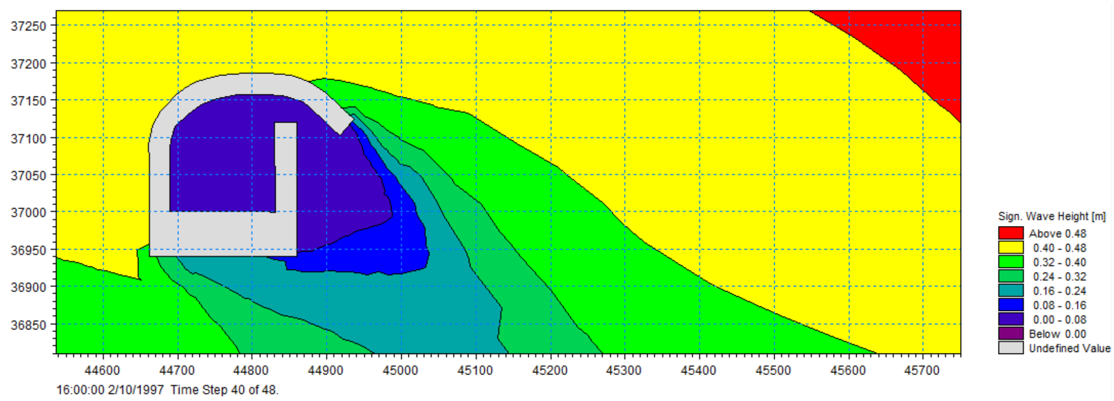


Figure 5.15: Maximum H_{mo} for Offshore A–West max event

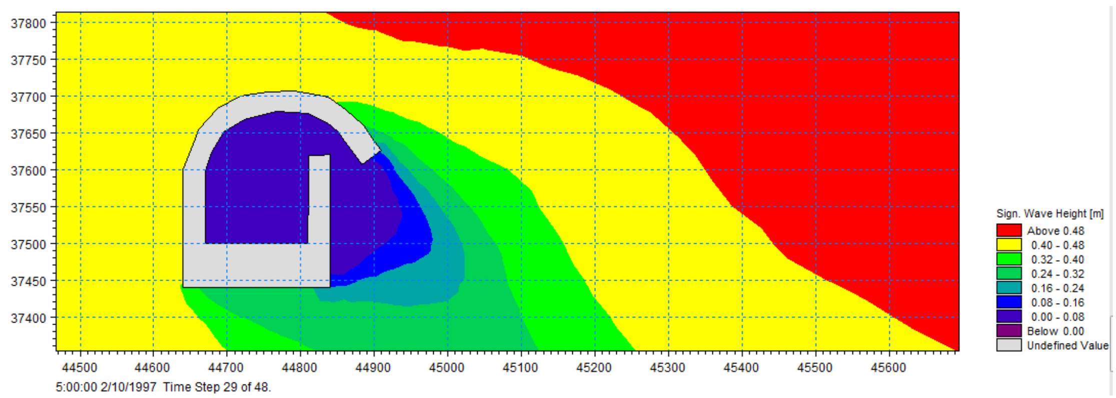


Figure 5.16: Maximum H_{mo} for Offshore B–West max event

The table 5.1 shows the values observed nearby the entrance of the harbours for each of the occasions presented before. This is done in order to compare the effects that each of the events has on the different kind of harbours and to have an overview of which could be the most significant.

Table 5. 1 Maximum values observed nearby the harbour entrances

H_{mo} (m)			
	North event	**West mean**	**West max**
Inshore	0.48-0.56(m)	0.32-0.4(m)	0.32-0.4(m)
Onshore	0.12-0.36(m)	0-0.24(m)	0-0.24(m)
Offshore A	0.04-0.52(m)	0-0.32(m)	0-0.32(m)
Offshore B	0.04-0.52(m)	0-0.32(m)	0-0.32(m)

From the table 5.1 can be seen that the maximum values of the mean North event are much higher than those of the two West events. Moreover the values of the West events are the same whether the West event is mean or an extreme event. This shows that the harbours are not that sensitive against the West wind as they are against the North.

The low values of the West events especially at the Onshore and Offshore cases probably have to do with the shape of the construction which protects the entrance.

The prevalent winds are the West and the North and those constructions protect the entrance from both winds. On the other hand, the entrance of the Inshore channel is the one which is totally exposed to all kind of winds mainly due to its shape. This is the reason why the values at the Inshore are in general higher than the remaining kind of harbours. However, the criteria are also covered.

The West wind as a result is not so significant as the North. One basic reason is the existence of Darsser-Ort which protects the harbours of the West winds.

5.3 Flow Model FM – Results and comments

At the beginning of each event graphs have been created at points in the entrance of each harbour in order to showing the currents' values before and after the design of the harbours. This is done in order to understand the affect of the constructions to the area.

At the second part of the current comments, the maximum current velocities observed during the simulating time are presented.

Moreover, the results for the total water depth *at the end* of the simulating time are analyzed. This is done in order to check if the harbours are still accessible after the events (water depth>3.2m) with the assumption that the events are the critical of the year 1997.

5.3.1 Results for the North-mean event

5.3.1.1 Currents

The next figure shows the values of the currents at points in the entrance of the harbours before and after each construction. This is done in order to see the effect of the constructions to the area.

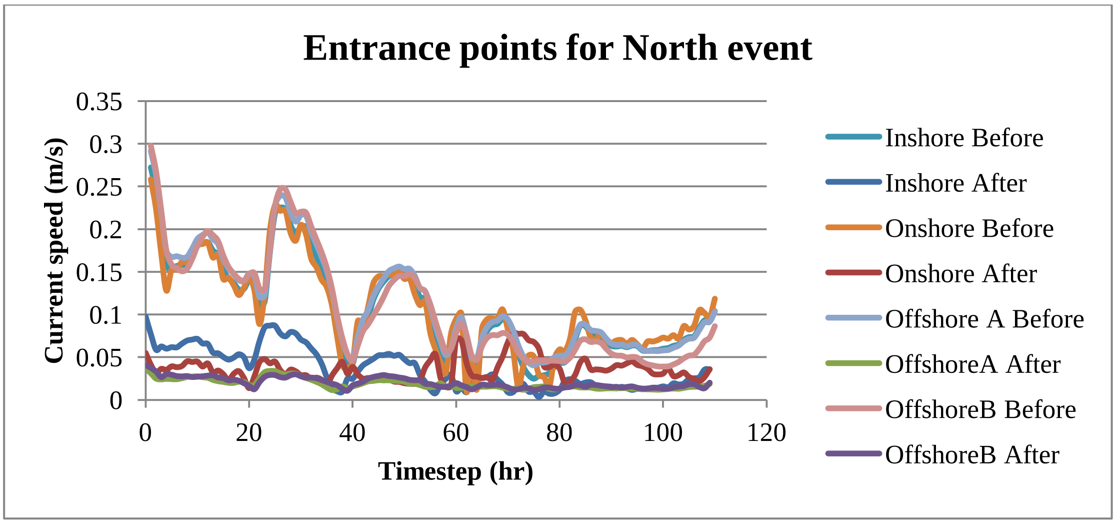


Figure 5.17: Currents pointseries nearby the harbours entrance for the North event

At the graph on figure 5.17 the current speed values at points in the entrance of the harbours are presented.

The mean value (average) of the current speed during the simulation procedure at the entrance of the Inshore harbour before and after the constuction is 0.10 and 0.046 m/s. That means that the currents nearby the entrance of the Inshore harbour are reduced at half of theis initial values.

For the Onshore harbour the currents reduced from 0.1m/s to 0.04 m/s. For both Offshore harbours, the current values were reduced from 0.10m/s to 0.02m/s.

On figures 5.18, 5.19, 5.20 and 5.21 the maximum values observed during the simulating procedure of the North event are presented:

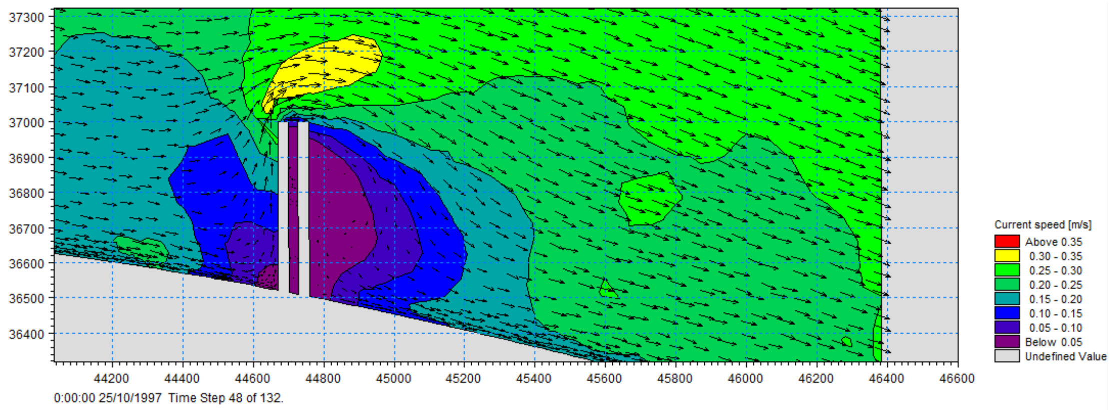


Figure 5.18: Inshore maximum current velocity – North event

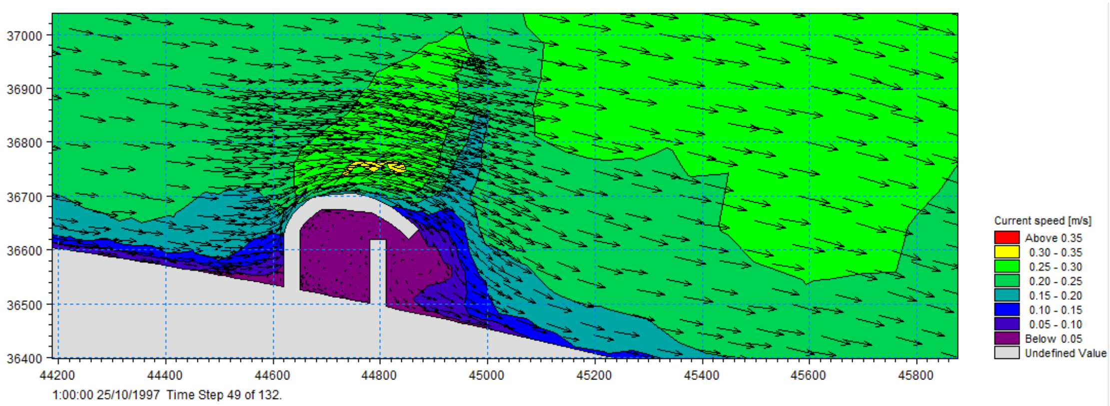


Figure 5.19: Onshore maximum current velocity–North event

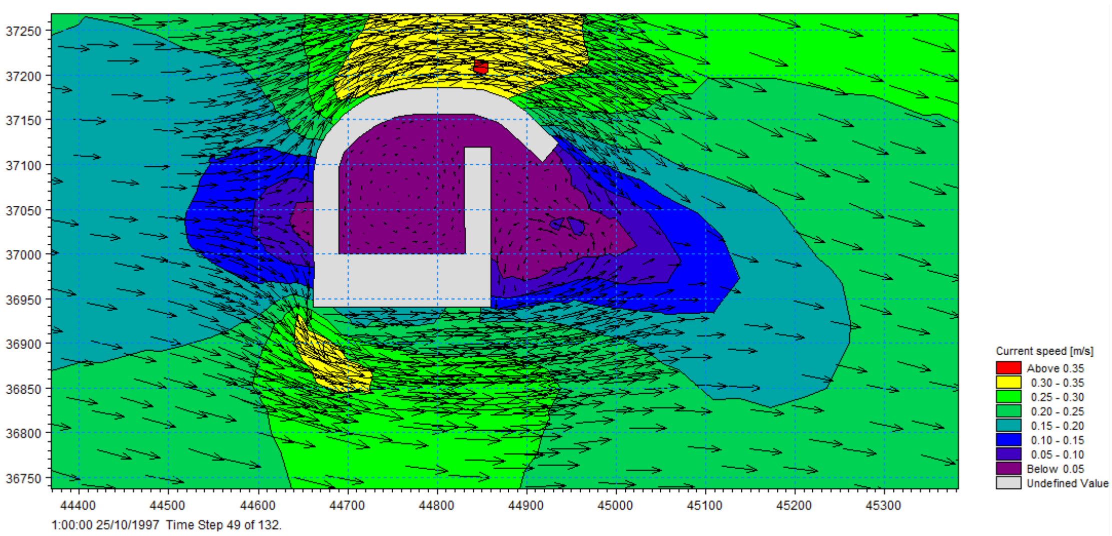


Figure 5.20: Offshore A maximum current velocity–North event

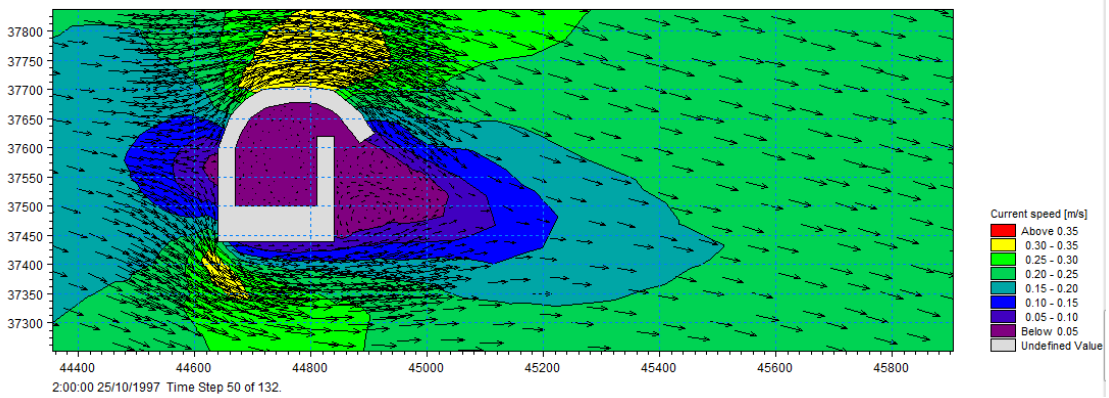


Figure 5.21: Offshore B maximum current velocity-North event

Close tho the entrance of the Inshore harbour the highest values of currents speed observed were around 0.15-0.25 m/s for the mean North event. At the entrance of the Onshore and the Offshore harbours the highest values range between 0.05 -0.15 m/s. The difference between the Inshore and the rest cases is probably due to the way of construction. The breakwaters at the Inshore do not protect the entrance as at the rest of the cases.

At the last three kind of harbours (Onshore and 2 Offshores) small eddies can be distinguished close to the entrance of the harbours with very low values.

5.3.1.2 Total Water depth

The total water depth at the end of the simulation is analyzed in order to see if depth is enough for the boats to come in or go out after the event.

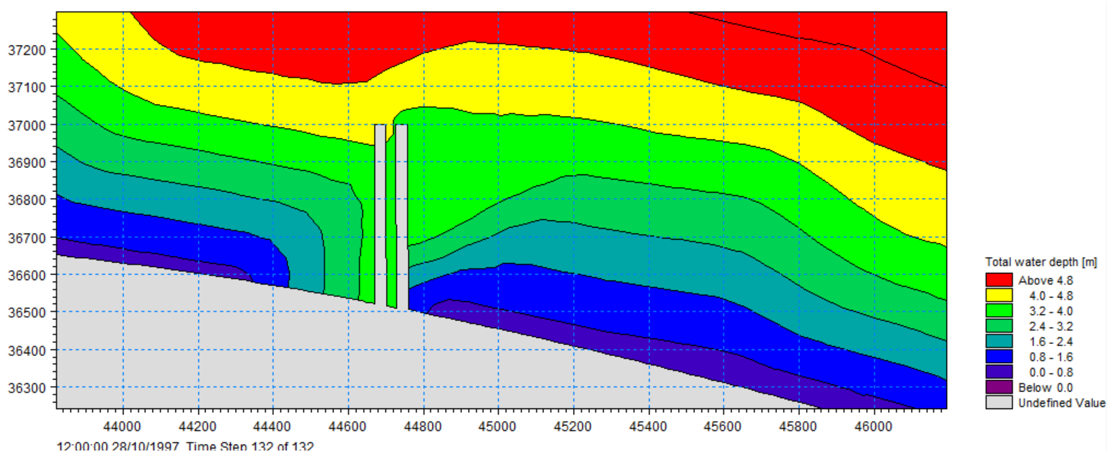


Figure 5. 22 Total water depth for North event

The total water depth after the simulation is more than 3.2m as showed on figure 5.22. There is no problem to access or exit of the boats at the channel.

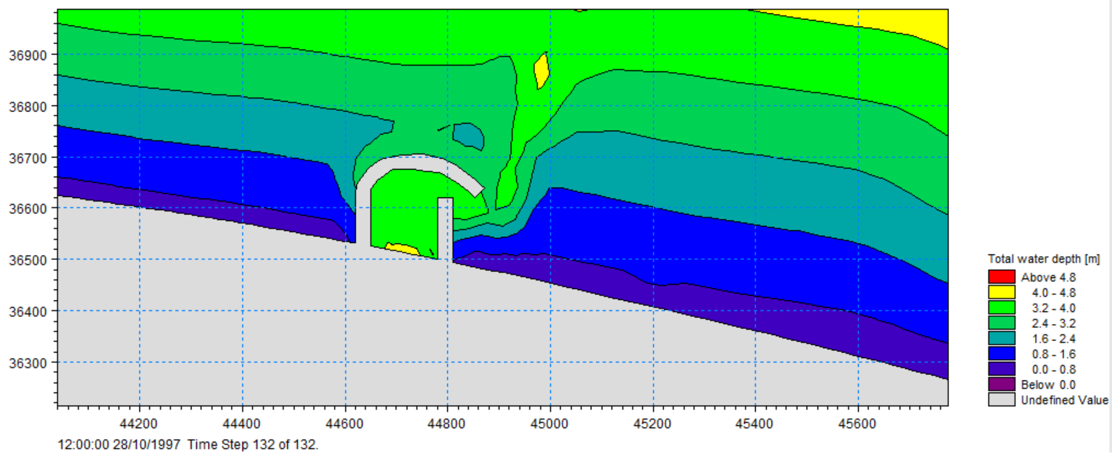


Figure 5. 23: Onshore total water depth for North event

The total water depth nearby the entrance of the onshore harbour is less than 3.2m (see figure 5.23). This would create problems to the access and exit after the North mean event.

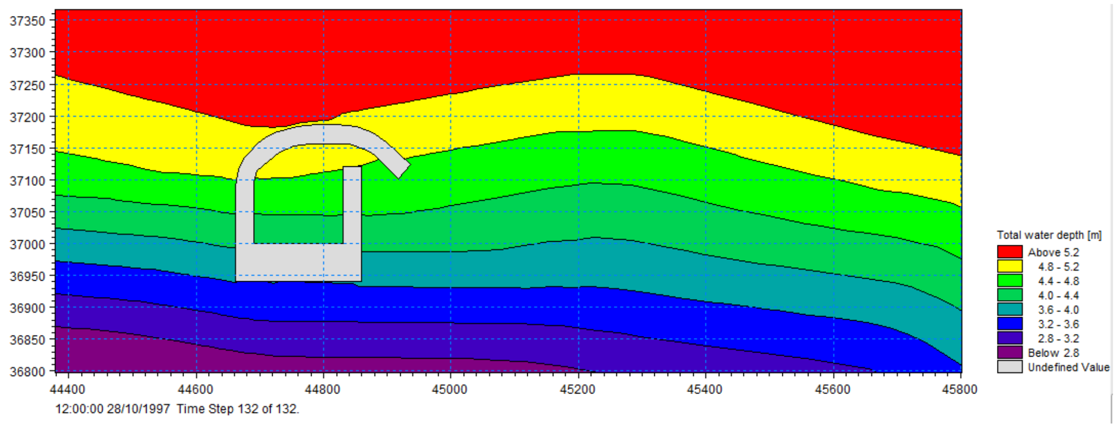


Figure 5. 24: Offshore A total water depth after North event

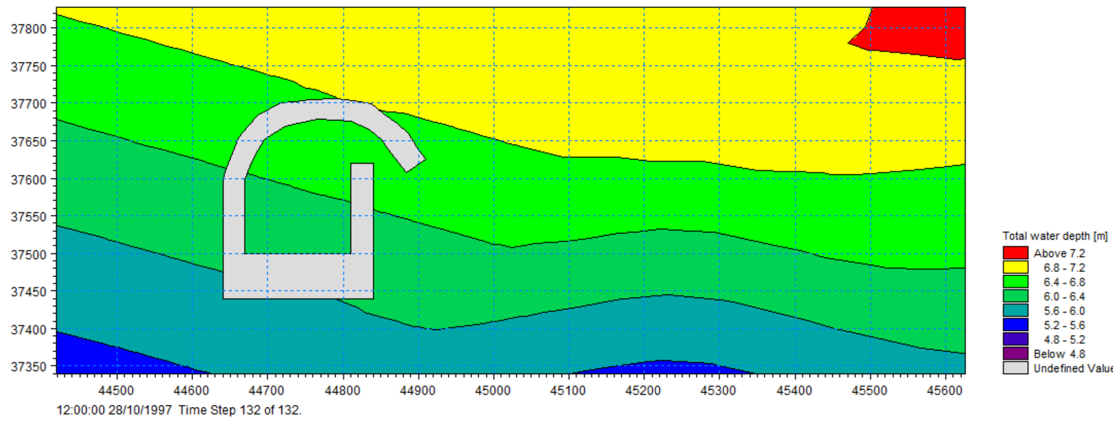


Figure 5. 25: Offshore B total water depth after North event

The Offshore occasions have total water depth higher than 3.2m (see figures 5.24-5.25) and the boats can easily access-exit or have mooring to the harbours.

5.3.2 Results for the West-mean event

5.3.2.1 Current velocities

At the graph on figure 5.26 the current speed values at points in the entrance of the harbours are presented.

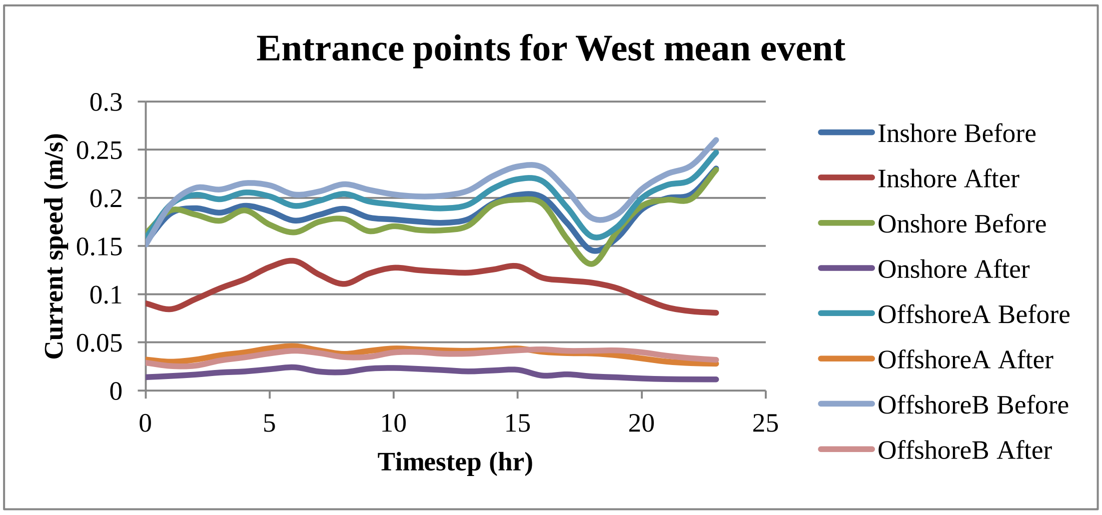


Figure 5.26: Currents pointseries nearby the harbours entrance for the West mean event

The mean value(average) of the current speed for the Inshore harbour is 0.18 before 0.08 m/s after the design of the harbour. For the Onshore it is reduced from 0.17m/s to 0.014 m/s. For the OffshoreA it is reduced from 0.19m/s to 0.02m/s. For the Offshore B it is reduced from 0.2m/s to 0.02. The design of the harbours reduced the current values at that points more than half at all cases, except for the Inshore. The reason is that the Inshore point is not protected as the rest cases.

The figures 5.27,5.28, 5.29 and 5.30 show the maximum values observed during the simulating procedure of the West mean event:

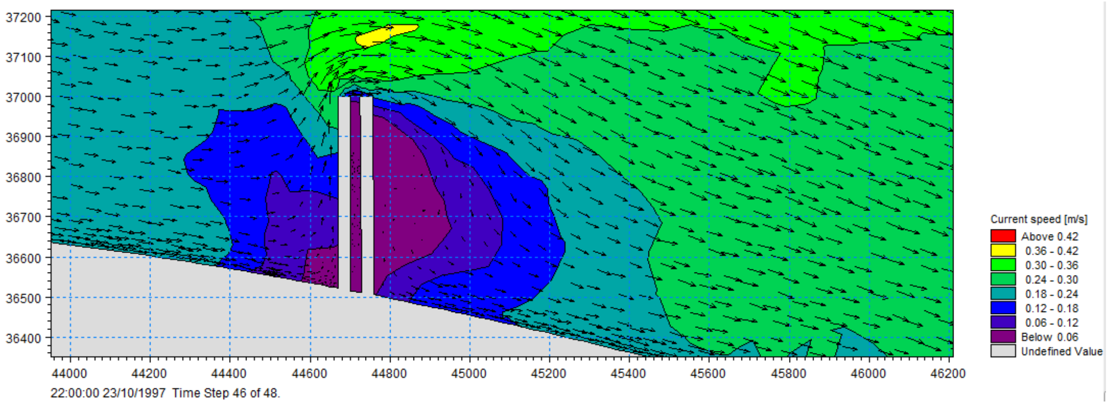


Figure 5.27: Inshore maximum current velocity–West mean event

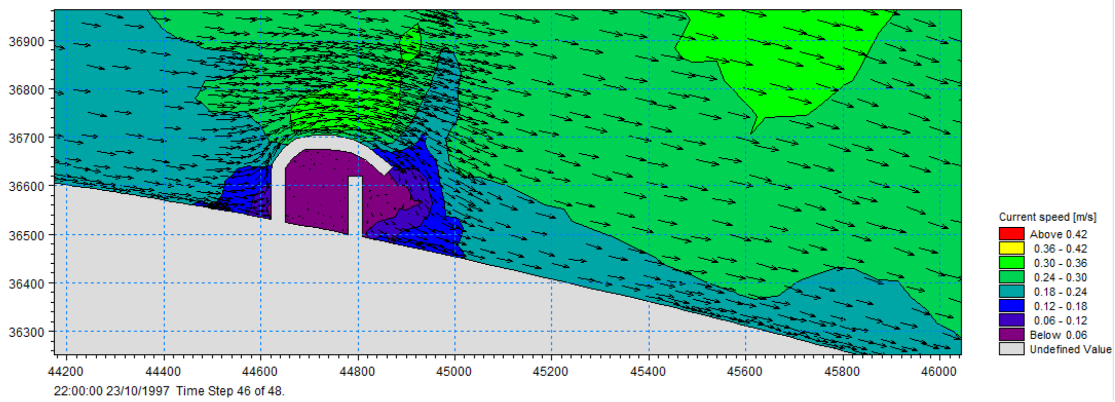


Figure 5.28: Onshore maximum current velocity–West mean event

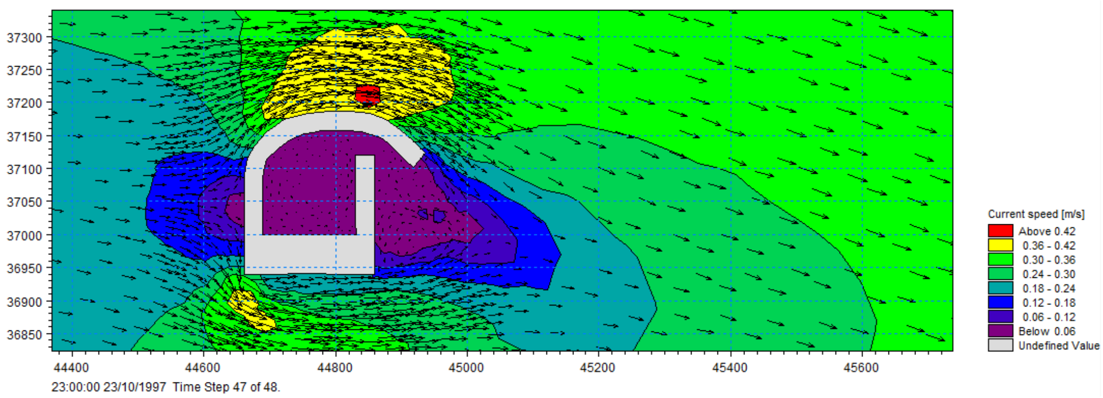


Figure 5.29: OffshoreA maximum current velocity–West mean event

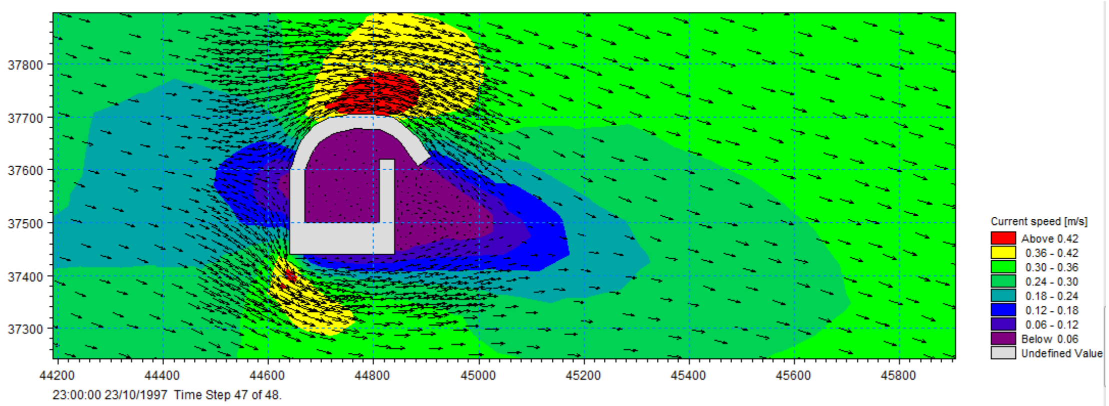


Figure 5.30: OffshoreA maximum current velocity–West mean event

Close tho the entrance of the Inshore harbour the highest values of currents speed observed were around 0.18 -0.30 m/s for the mean West event. At the entrance of the Onshore and the Offshore harbours the highest values range between 0.06 -0.12 m/s (lower than the North event).

5.3.2.2 Total water depth

The total water depth after the West mean event is showed for each occasion on figures 5.31, 5.32, 5.33 and 5.34.

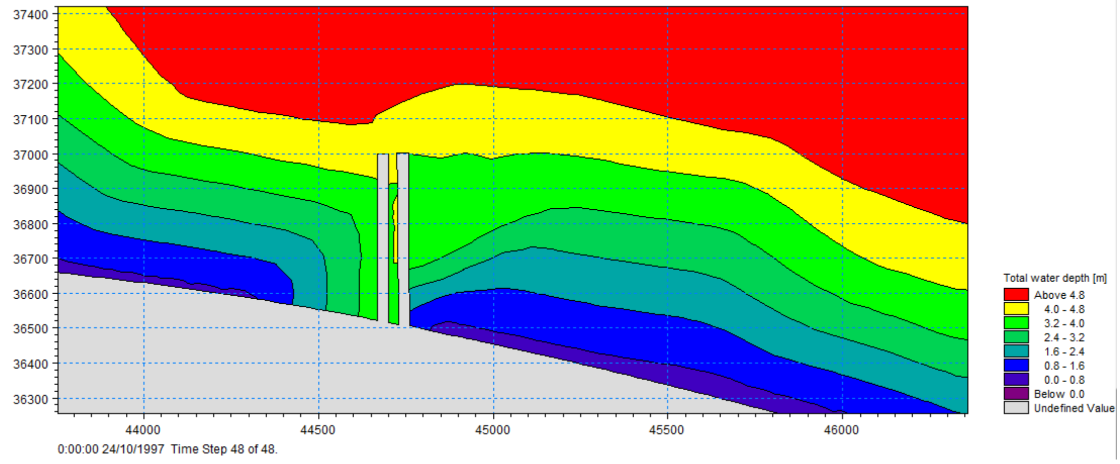


Figure 5. 31: Inshore total water depth after West mean event

Inside the harbour channel and outside the total water depth is more than the demanded. Thus, there is no problem for the boats to access or exit the basin.

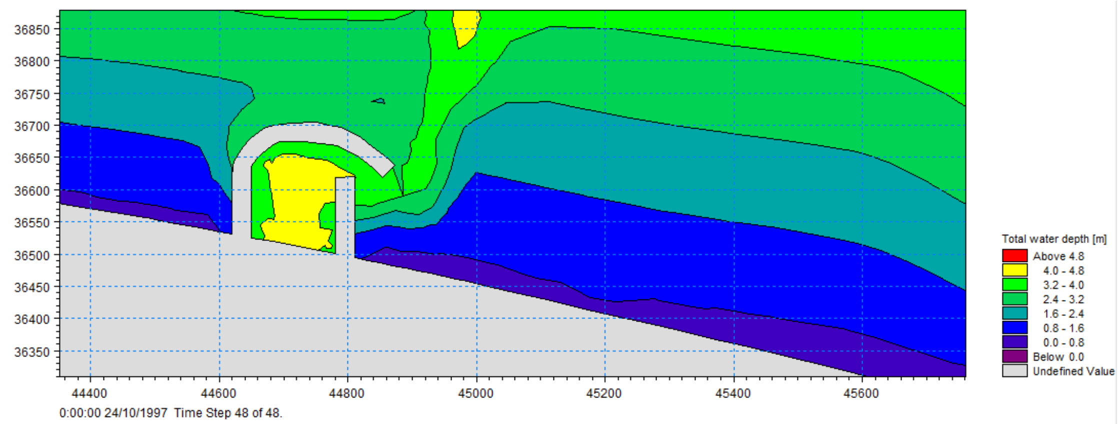


Figure 5. 32: Onshore total water depth after West mean event

Inside the harbour basin the total water depth is higher than 3.2m so there boats are safe at the mooring places. The channel driving to the harbour basin has also more than 3.2 total water depth except for a small region nearby the harbour entrance where the total water depth is observed to be less than 3.2m.

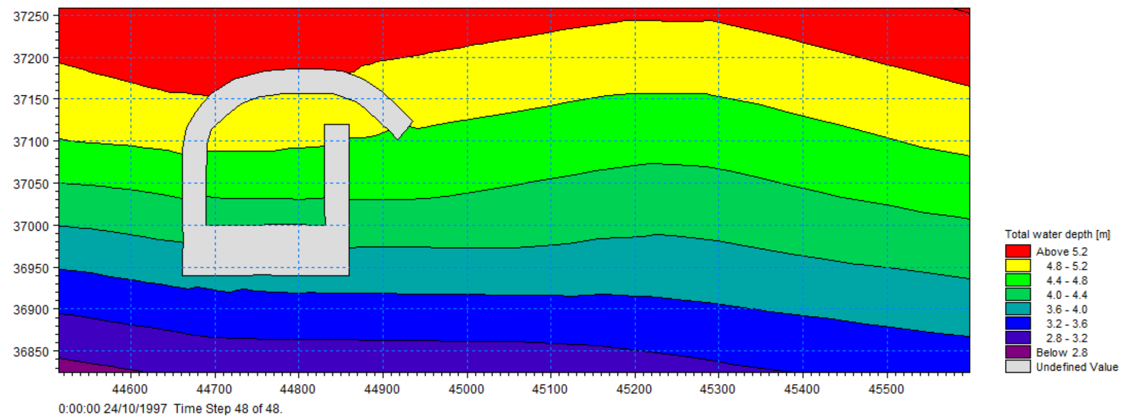


Figure 5. 33: Offshore A total water depth after West mean event

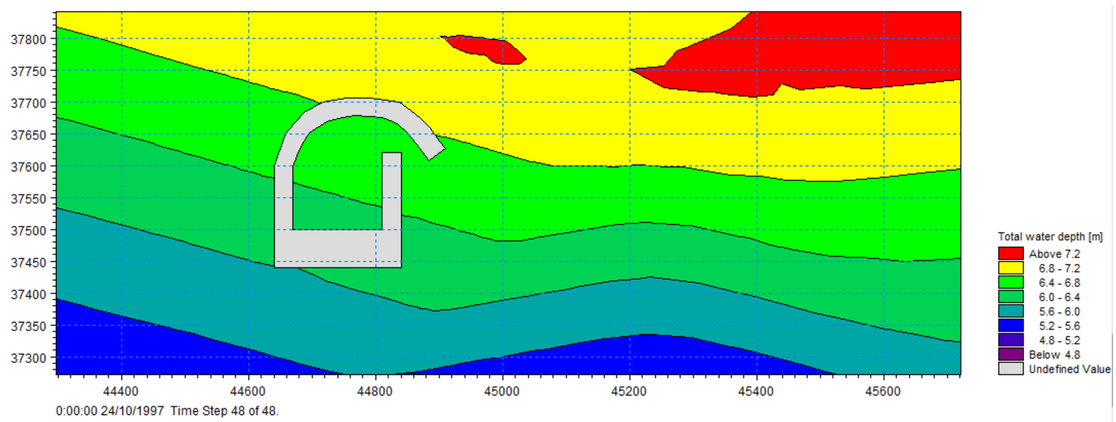


Figure 5. 34: Offshore B total water depth after West mean event

The Offshore occasions (see figures 5.33-5.34) have total water depth higher than 3.2m and the boats can easily access-exit or have mooring to the harbours.

5.3.3 Results for the West-max event

5.3.3.1 Currents

At the graph on figure 5.35 the current speed values at points nearby the entrance of the harbours are presented

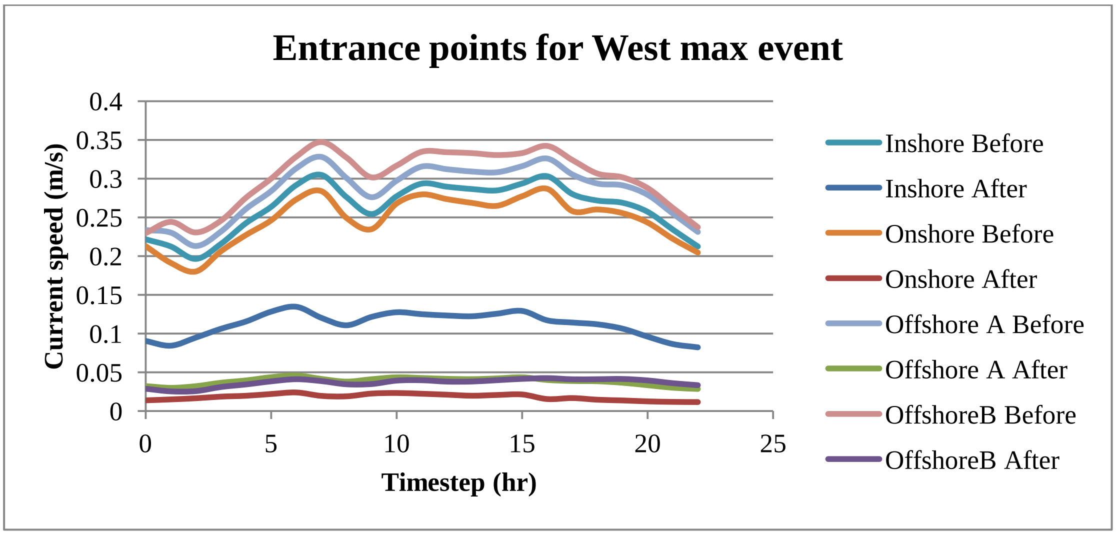


Figure 5.35: Currents pointseries nearby the harbours entrance for the North event

At the graph on figure 5.35 the current speed values at points in the entrance of the harbours are presented. The mean value (average) of the current speed before the design of the Isnhore harbour is 0.26m/s while after the design it is 0.1 m/s. For the Onshore harbour, before and after it is 0.24m/s and 0.02 m/s respectively. For both the Offshores it is 0.29 m/s before and 0.04m/s after.

As it is seen the values are in general higher than both the West and North mean events. The table 5.2 shows the average values of the currents at the pointseries of the entrance of each harbour after the design.

Table 5. 2 Average current values for the pointseries at the entrance of the harbours

	Currents (m/s)		
	North mean	**West mean**	**West max**
Inshore	0.04	0.08	0.26
Onshore	0.04	0.14	0.10
Offshore A	0.02	0.02	0.02
Offshore B	0.02	0.02	0.02

In general it is observed that the West wind creates currents with higher values than the North. This can be more easily seen at the Inshore case which is more representative due to lack of protection arround the point in comparison with the rest cases where the points are nearby the entrance and protected due to the design shape.

On figures 5.36, 5.37, 5.38 and 5.39 the highest values of the max event that were observed during the simulating procedure are showed:

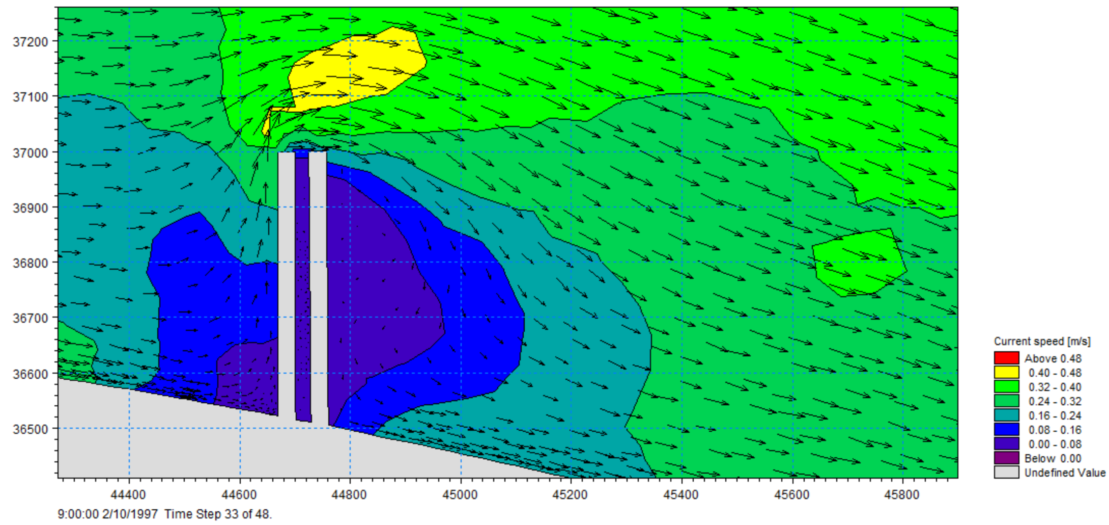


Figure 5.36: Inshore maximum current velocity–West max event

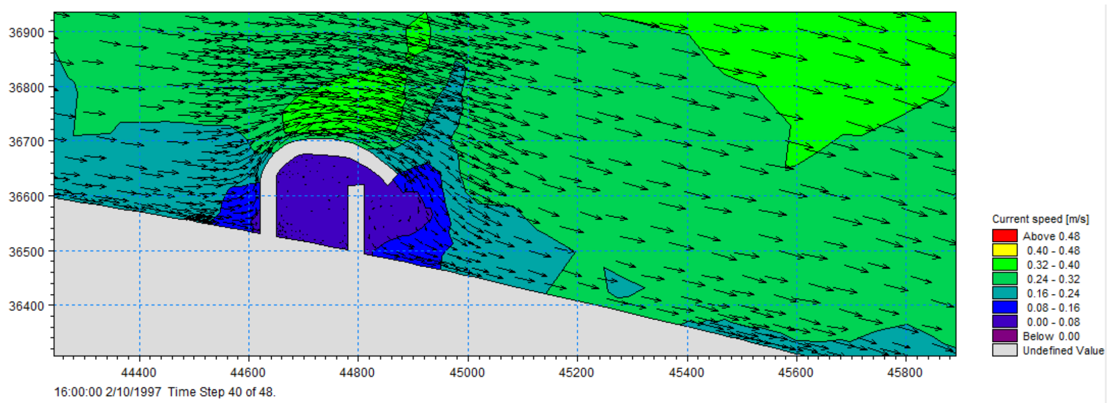


Figure 5.37: Onshore maximum current velocity–West max event

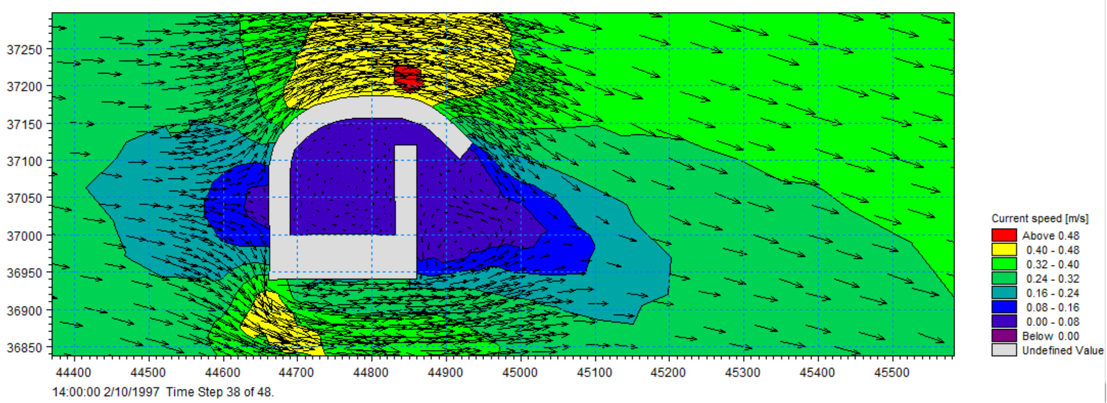


Figure 5.38: OffshoreA maximum current velocity–West max event

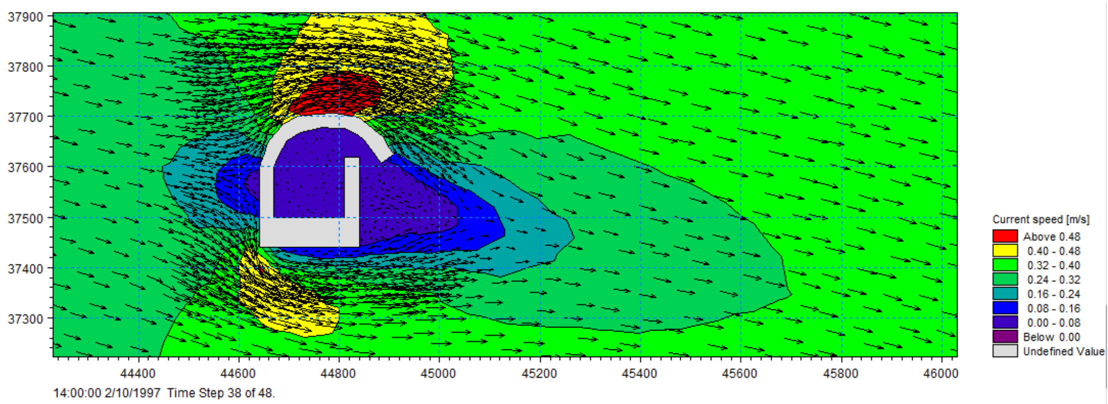


Figure 5.39: OffshoreB maximum current velocity–West max event

Close to the entrance of the Inshore harbour the highest values of currents speed observed were around 0.16-0.32 m/s for the mean West event.Nearby the entrance of the Onshore and the Offshore harbours the highest values range between 0.0-0.16 m/s.

5.3.3.2 Total water depth

On figures 5.40, 5.41, 5.42 and 5.43 the total water depth after the simulation of the West max event is presented.

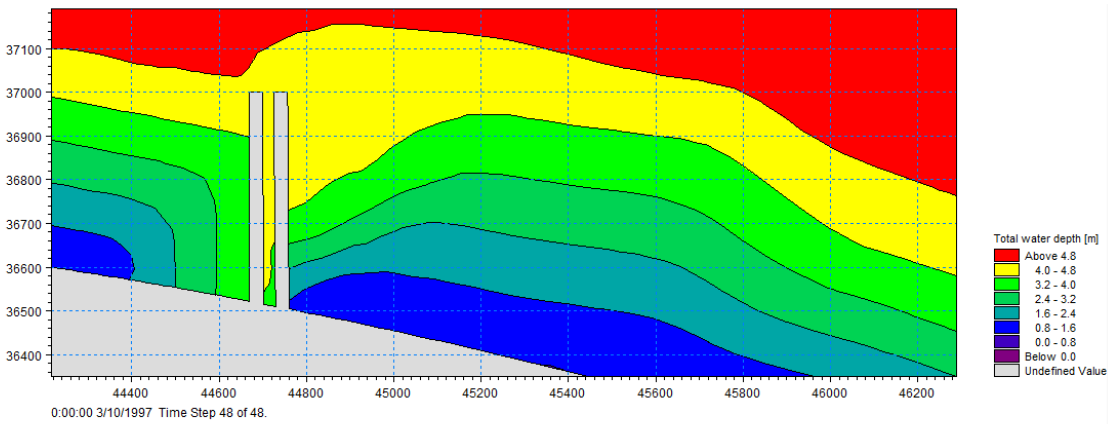


Figure 5. 40: Inshore total water depth after West max event

The total water depth is more than 4m after the West max event more than the demanded.

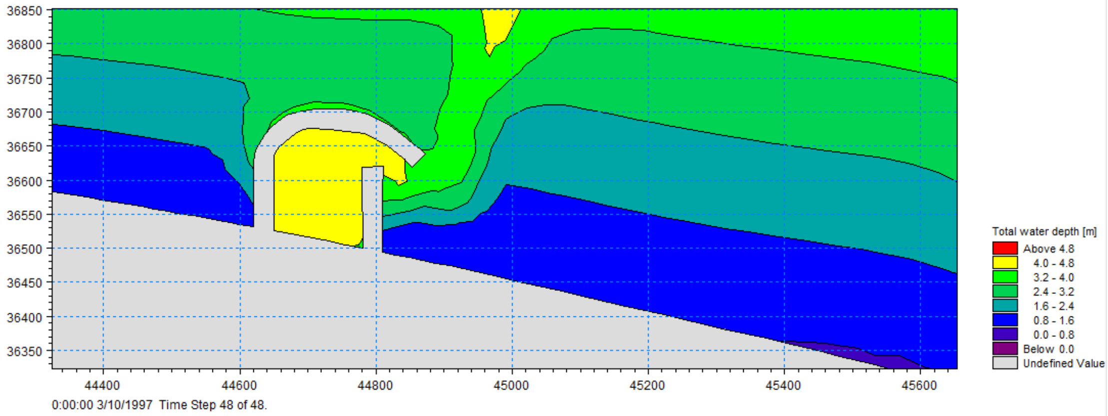


Figure 5. 41: Onshore total water depth after West max event

Inside the harbour basin the total water depth is higher than 3.2m so there boats are safe at the mooring places. The channel driving to the harbour basin has also more than 3.2 total water depth so the boats can have safe access or exit after the event.

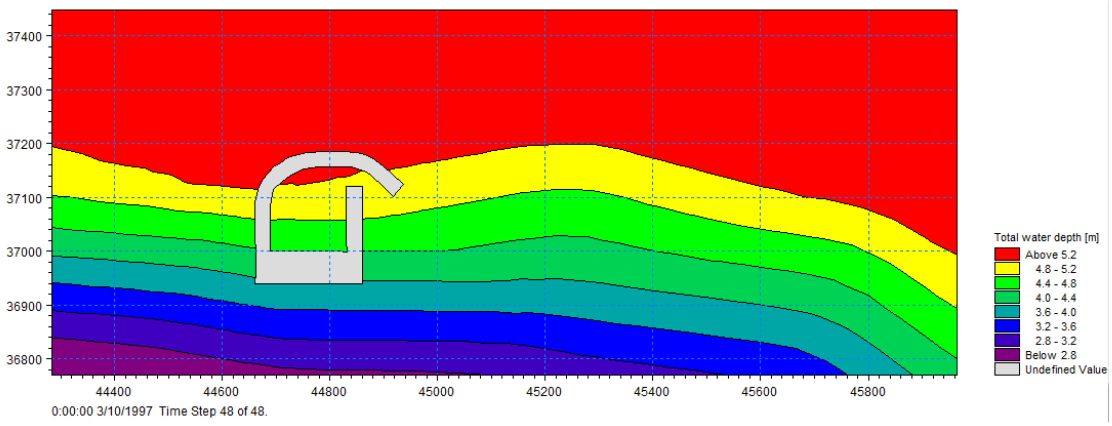


Figure 5. 42: Offshore A total water depth after West max event

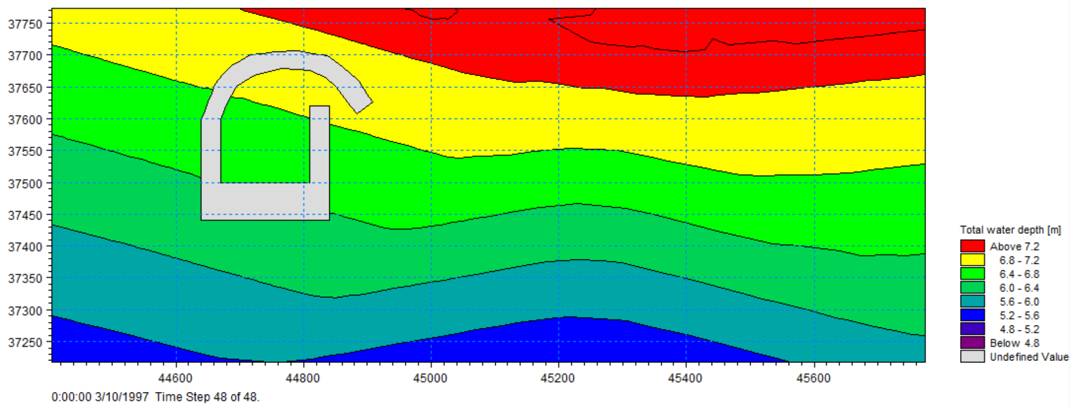


Figure 5. 43: Offshore B total water depth after West max event

The total water depth at the entrance of the two Offshore harbours is not affected from the West wind event and the boats can safely access the harbours.

According to the total water depth, the harbours are not affected when the wind is coming from west. The Onshore harbour is affected from the North wind and creates problems to boats which have to access or exit the harbour.

5.4. Sand Transport model–Results and comments

At this part the results of the sand transport model will be presented. Specifically, the bed level before and after the simulation is showed in order to get an initial feeling about the areas of deposit and accumulation for each case for each event.

5.4.1 Results for North-mean event

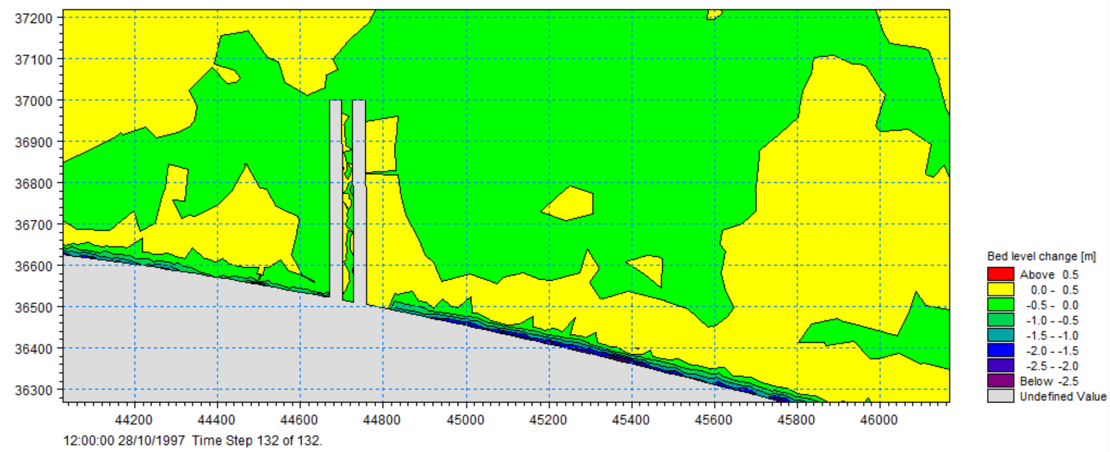


Figure 5. 44: Bed Level change for the Inshore harbour after the North event

From figure 5.44 a tendency for erosion at the West part of the West breakwater and accumulation at the Eastern part of the East breakwater is observed. Moreover, tendency of erosion is also observed along the shoreline

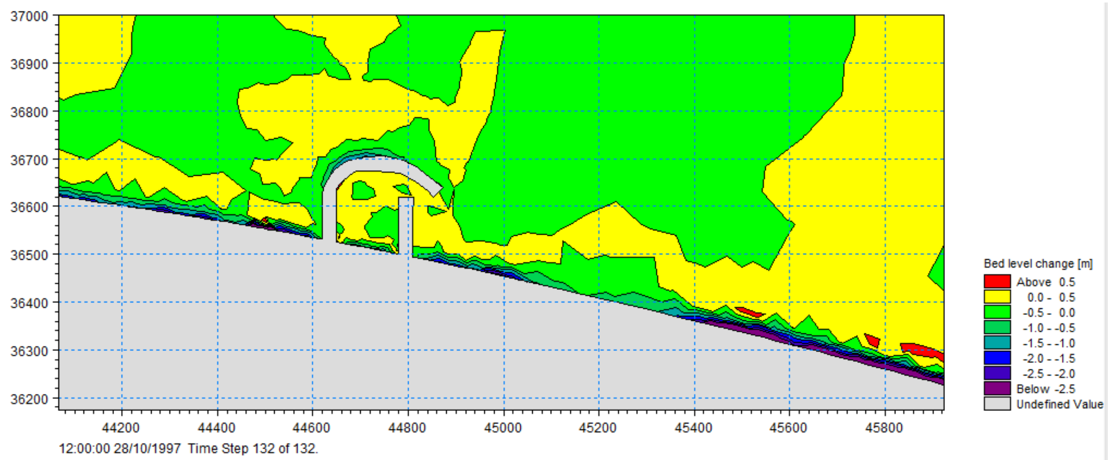


Figure 5. 45: Bed level change for the Onshore harbour after the North event

From figure 5.45 the tendency for erosion at the North part of the harbour as well as along the coastline can be observed. Nearby the entrance there is tendency for accumulation which would probably create problems to the access or exit of the boats. Inside the harbour basin there is a tendency for accumulation at the northern part and tendency for erosion at the southern part.

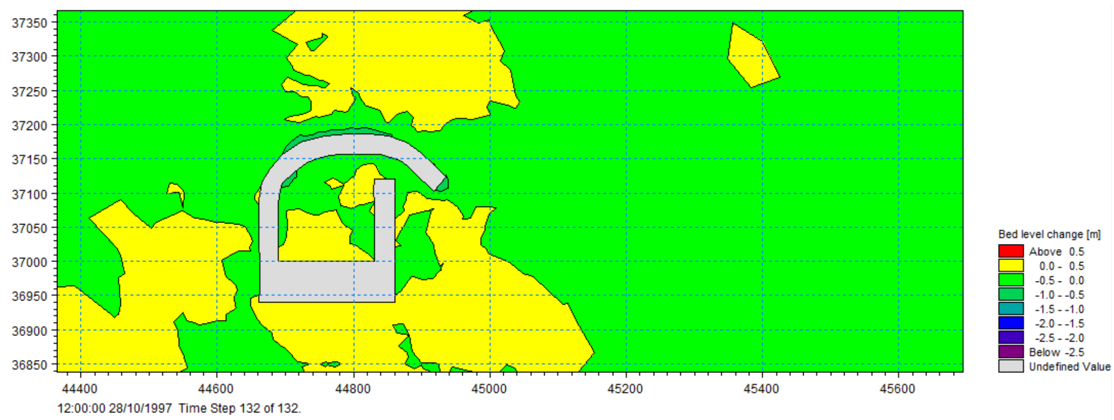


Figure 5. 46: Bed level change for the Offshore A harbour after the North event

Outside of the harbour there is observed high erosion at the northern part and accumulation at the southern as showed on figure 5.46. Inside the harbour basin there is tendency for erosion at the northern part and accumulation at the sourthern. Meanwhile, tendency for erosion is observed close to the entrance of the harbour.

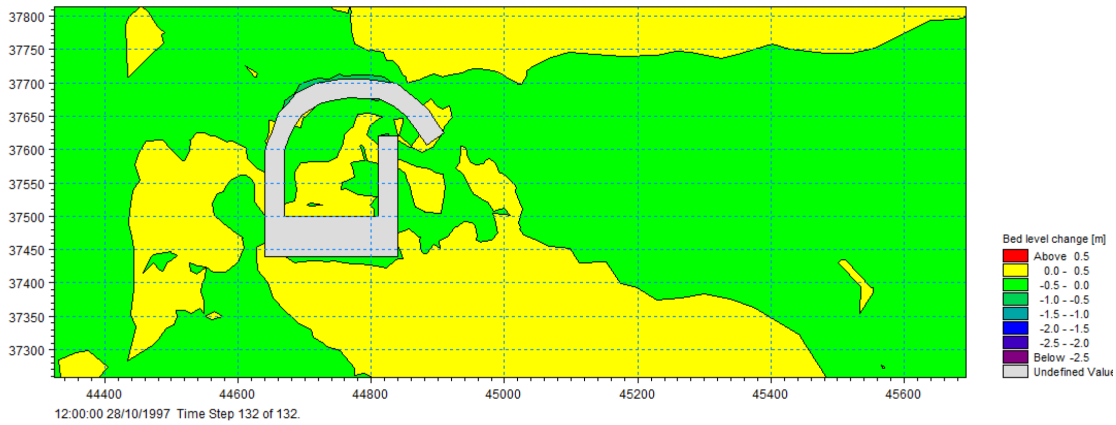


Figure 5. 47: Bed level change for the Offshore B harbour after the North event

Outside of the harbour it's observed high erosion at the northern part and tendency for erosion at the southern (see figure 5.47). Inside the harbour basin there is tendency for erosion at the northern part and accumulation at the sourthern.

5.4.2 Results for the West-mean event

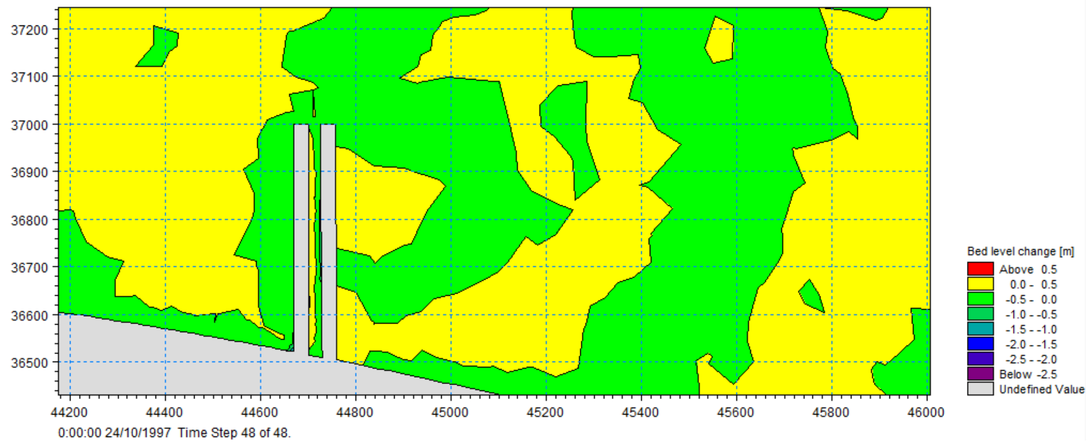


Figure 5. 48: Bed level change for the Inshore harbour after the West mean event

On figure 5.48 there is the tendency for erosion at the western part of the West breakwater while the opposite happens on the East part of the Eastern breakwater.

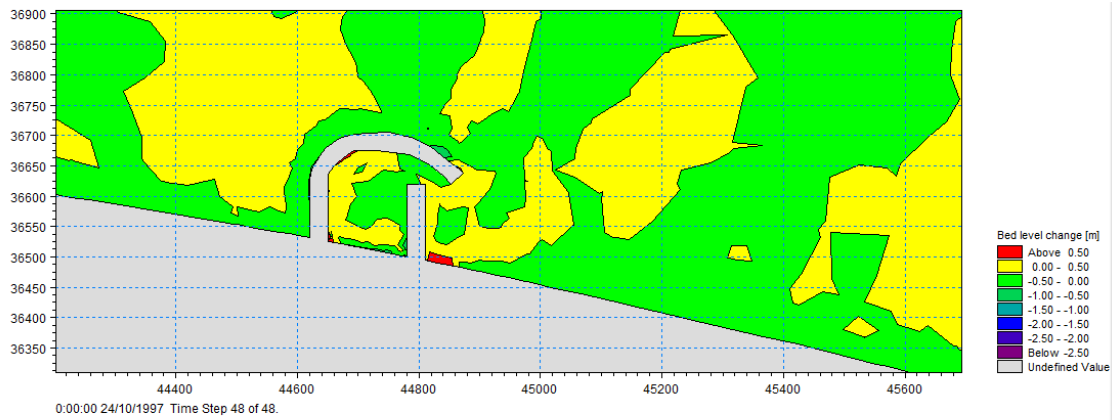


Figure 5. 49: Bed level change for the Onshore harbour after the West mean event

From figure 5.49 it is observed that after the West mean event nearby the entrance of the onshore harbour there is the tendency for deposition. Specifically for the Onshore harbour that is designed in very shallow water accumulation at the entrance would create problems for the total water depth. Accumulation is also observed at the bottom of the eastern part of the east breakwater and in some parts inside the basin which is important for the mooring places.

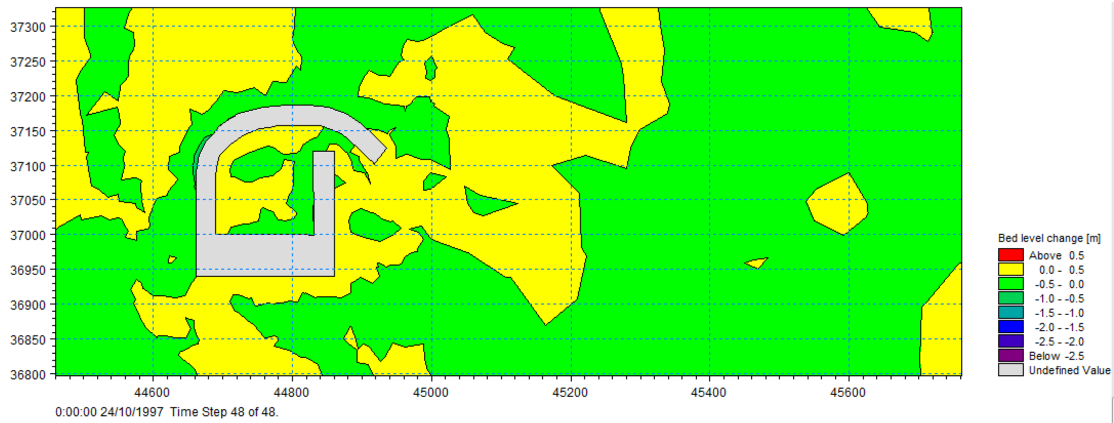


Figure 5. 50 Bed level change for the Offshore A after the West mean event

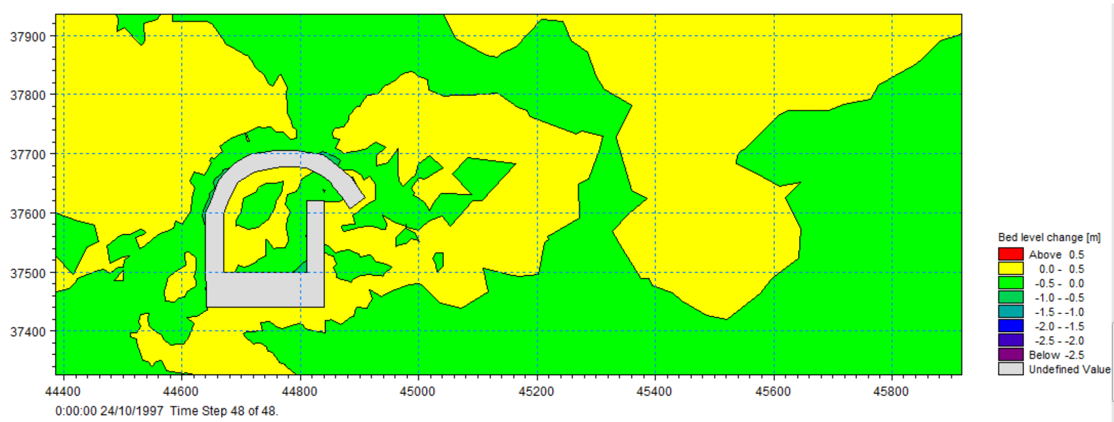


Figure 5. 51: Bed level change for the Offshore B after the West mean event

The two Offshore harbours (see figures 5.50 and 5.51) give a similar picture. Erosion at the North and West part outside of the harbours and deposit at the Southern part. Nearby the entrance there is the tendency for deposit. Inside the harbour basin there area also changes of the bed but they are not so important for mooring places as the water are deep enough.

Both the Offshore harbours are not affected a lot from the West mean event. The level that they are affected does not create any problems to the entrance or mooring places. At the North part of both harbours erosion is observed and accumulation at the South part of the harbours.

5.4.3 Results for the West-max event

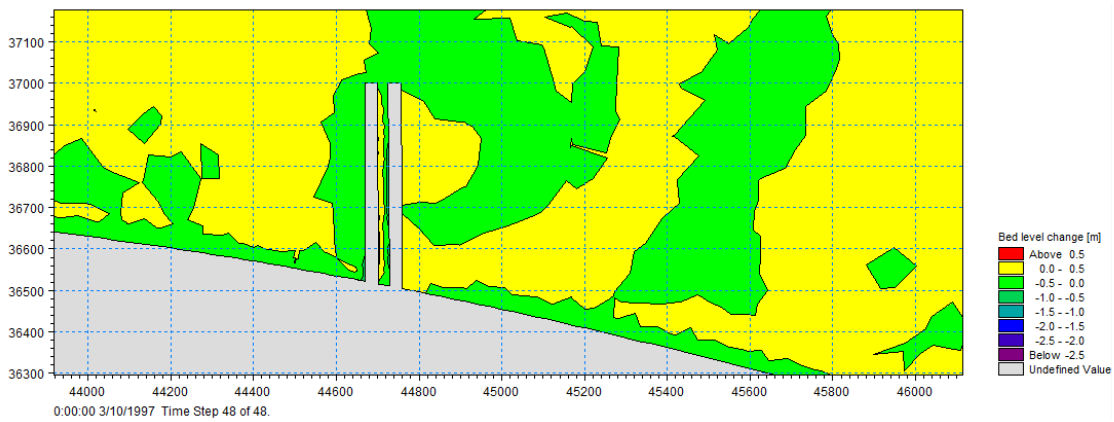


Figure 5. 52: Bed level change for the Inshore harbour after the West max event

At the western part of the West breakwater erosion is more prevalent (see figure 5.52). At the Eastern part of the East breakwater there it the tendency for accumulation.

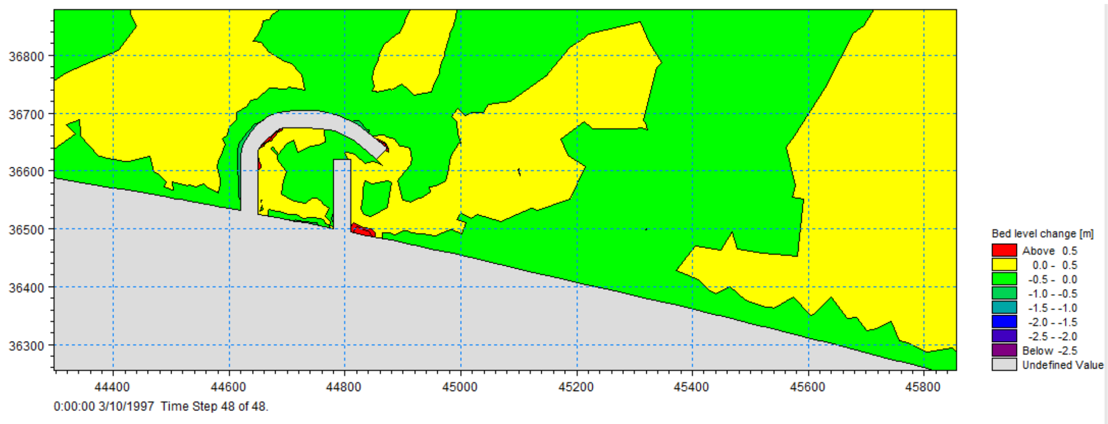


Figure 5. 53: Bed level change for the Onshore harbour after the West max event

The figure 5.53 is very similar with the West mean event. After the West max event nearby the entrance of the harbour there is the tendency for deposition. For the Onshore harbour accumulation at the entrance is observed and this would create problems to the access or exit of the harbours under investigation.

Accumulation is also observed at the bottom of the eastern part of the east breakwater and in some parts inside the basin which is important for the mooring places.

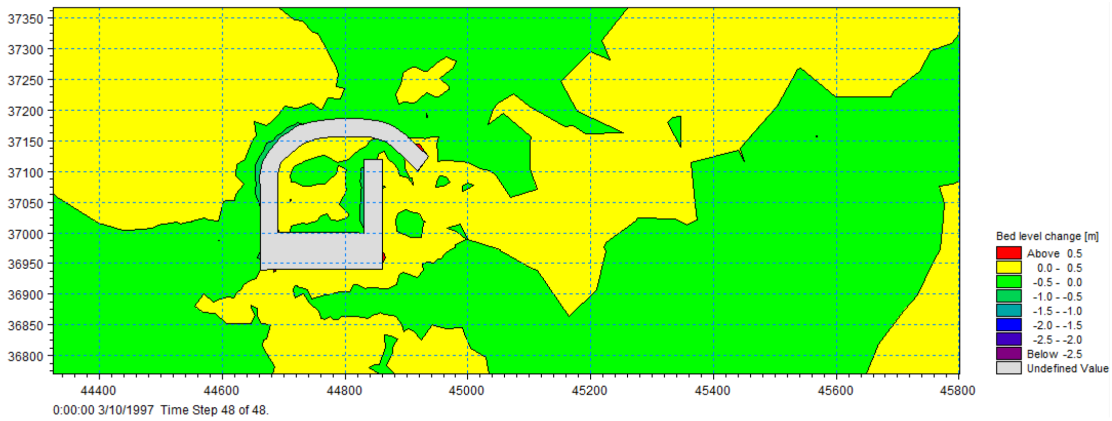


Figure 5. 54: Bed level change for the Offshore A harbour after the West max event

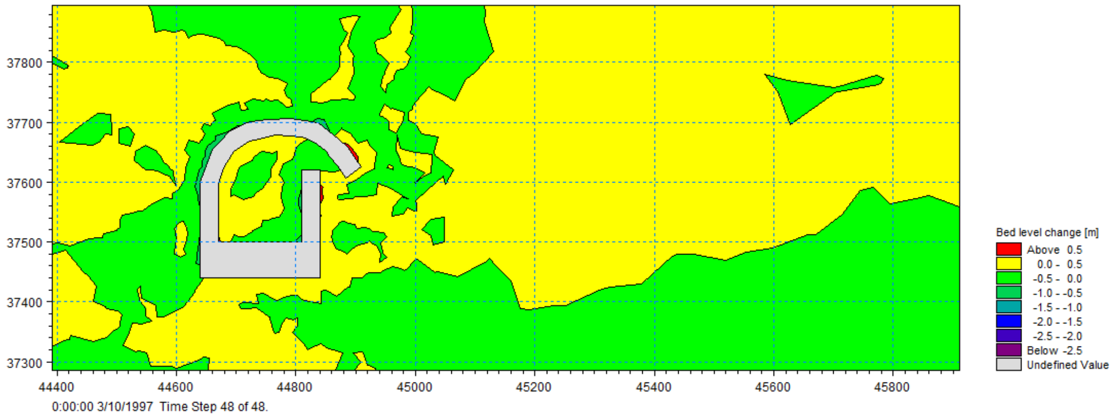


Figure 5. 55: Bed level change for the Offshore A harbour after the West max event

The Offshore harbours on figures 5.54 and 5.55 have a similar picture as after the West mean event. There is the tendency for erosion at the West and North part outside of the harbours. There is the tendency for accumulation nearby the entrance and at the Southern part outside ot the harbour. Inside the harbour basin there is the tendency for accumulation at the western part and erosion at the eastern. Those changes do not affect the mooring places as the water are already deep enough.

Chapter 6: Conclusions

From the wave model in general it was concluded that that the maximum values of the mean North event are much higher than those of the two West events before and after the design of harbours. Moreover, the values of the West events do not change in a significant way when the West event represents mean or extreme values of wind. This created the first assumptions that the harbours are not so sensitive to the West winds as they are to the North.

The values of the West events especially at the Onshore and Offshore cases are much lower than the Inshore and this has to do with the shape of the construction which protects the entrance in comparison with the channel entrance. The shape of the Onshore and Offshore harbours protects the entrance from the prevalent North and West winds. The channel entrance driving to the Inshore mooring places is the one which is totally exposed to all kind of winds mainly due to its shape. This is the reason why the values at the Inshore are in general higher than the remaining kind of harbours.

In general the significant wave height is less than 0.6m at harbour entrances over the 90% of time simulation and less than 0.3m at harbour mooring places over the 90% of time simulation so the design criteria are fully covered for all the simulated events.

From the Flow model FM it was observed that the West wind creates currents with higher values than the North. This could be observed at the Inshore case which is more representative due to lack of protection arround the point nearby the entrance in comparison with the rest cases where the points are nearby the entrance and protected due to the design shape. Designing the harbours affected a lot the initial values of the currents in the area. Inside the harbour basins the currents are pretty small (less than 0.05m/s) during the whole procedure.

According to the total water depth, the harbours are not affected when the wind is coming from west. However, from the North wind affected the Onshore harbour creating problems to boats which have already moored at that places or want to access the harbour.

The North wind affected the Onshore harbour creating accumulation and erosion inside the harbour basin rendering it unsafe for the boats mooring. Accumulation was also observed at the entrance of the harbour.

The rest cases of the harbours were not affected from the events in a level that big problems close to the entrance or mooring places can be observed. However, at the Offshore harbours the common characteristic was the tendency for erosion at the northern and eastern part outside of the harbours.

Taking into account the results of the models and the so far pre-study two options of harbours are proposed; the Inshore or the OffshoreA harbour. Both cover the criteria investigated so far. The final choice will depend on a further more detailed study.

The Onshore harbour has been rejected as the proposed location for the harbour. First of all, dredging is assumed in order to create that kind of harbour as the water depth is very low. Secondly, the Onshore harbour seems sensitive to the North event and the boats cannot have access or exit . Moreover, they are not safe in mooring places due to changes on the bed level inside the harbour.

The Inshore harbour does not show basic problems during and after the events at significant wave height, the total water depth and bed level change even if the entrance is exposed to all wind directions. As it was seen from the results, the Hmo and the currents have been significantly higher at Inshore harbour than the rest of the cases but still covering the criteria. As a result the Inshore harbour could be one option.

The two Offshore cover the design criteria for safety during access or mooring according to CEM. The currents close to the entrance are very low. There are no problems with the total water depth as it they are designed in deep water. From the hydrodynamic point of view, the differences between the two Offshore are not important. Hence the OffshoreA is preferred as it is covers completely the criteria so the option of the Offshore B is not needed.

The proposed options cover the criteria of the significant wave height at the entrances and mooring places and the total water depth after the events. The choice between the two is depending on further studies for which hints are given on the next chapter.

Chapter 7 Proposals for further steps

A project in these dimensions needs many years of statistical analysis. Hence a more detailed study with larger timeseries over 10 years is of high need. This study could define which storm events are the most critical and which are not. Moreover, a full sediment transport study should be applied nearby Prerow.

Gauging stations close to Prerow are of a high need. Measurements nearby Prerow will give the opportunity for calibration of the wave and flow models. The models and the results of the simulations would be more reliable and more intergrated conclusios will be made.

From this pre-study it was concluded that the harbours seem sensitive to the North mean event. For further investigation the simulation of an extreme North[7] event is necessary and would give a better overview of the picture.

Moreover, at the northern and eastern part of the harbours tendency for erosion was observed which gives hints for further detailed research about the level of erosion after the events. This will ensure the security or not of the construction during time.

The final option will also depend on environmental, social and economical studies. For example, if the touristic development of Prerow is to be achieved then the Inshore harbour would be a better option. On the other hand, the Offshore harbour would not change a lot the landscape along the shoreline.

Further studies should be applied to find the optimal way of navigation of the boats in order to access the harbours.

For the proposed inshore harbour, the optimal direction of the breakwaters should be further investigated. For the proposed Offshore A case the optimal bridge which connects the harbour with the shoreline is also a factor which should be under further research (for example a closed construction).

Physical modeling in a laboratory would give another opinion about further investigation. Moreover, the use and comparison of different simulation models is also an idea which could be implemented.

[7] Due to the restriction in data an extreme North event could not be identified at the months data provided.

Limitations

This case is a simple pre-study. The provided three months of data do not give an overall picture about the conditions that predominate in the area. Thus, it is not possible to know whether the events simulated are the typical of a year or not. However, the proposals given and the final conclusions have been made with the assumption that the events simulated are the typical of the year.

Moreover, important is to be mentioned that a full sediment transport study was out of the goal of this thesis. The sediment transport was checked only from the qualitative point of view and not from the quantitative as there was no data to calibrate or verificate the sand transport model.

Another important factor has to be mentioned. During the simulating procedure the license of the programme changed. The initial big models (Ruegen Overall, WP2, Ruegen West and Gellen Bight) have a restriction on number nodes so the generation of the mesh was with the thought "as many nodes as possible". The rest models in Prerow do not have restriction on nodes as the dongle key with unlimited number of nodes was provided from DHI for this thesis. The models in the beginning were between 2500-3500 nodes while at the second part (models inside Prerow) were between 3500-5000 nodes. The first models lack in accuracy in comparison with the smaller models which are smaller in domain and have higher number of nodes.

Moreover, the measured data used from the boyes of GKSS and BSH were far away from the local Prerow model. During the downscaling procedure followed for the models it is possible that mistakes may have been done. Those mistakes could have been transferred to the local Prerow models. By the use of the uncalibrated Wave model and the Flow model coming from the downscaling procedure (which may includes some errors) the errors on the last Sand Transport model could have been bigger.

According with the 3 Gauging stations which provided measurements the calibration was done on the Flow model. However, the initial models were big. As a result, calibrating with gaugin stations on the East part of the Ruegen West model does not ensures that the model is also calibrated on the West and especially at the small local Prerow model.

At the Gellen Bight model the Boundaries used for the West event are the measurements provided from GKSS. The West boundary for the West wind was defined as constant along line and varying in time. The assumption of constant along line is not the best as the bed level changes along the line towards the coast and the wave characteristics cannot be the same.

Output from the Spectral Wave model was a NON-UTM dfsu file (varying in time and domain). This file was supposed to be used at the Sand Transport model as an input for the wave forces. Unfortunately, this file could not be read from the programme. The problem could be in the data, in the handling of the tools by misunderstanding of the software documents or a bug or fixed precondition in the software which needs further investigations. A pointseries (dfs0) file was extracted from the same dfsu file and used as an input only varying in time and assumed constant in domain assumed to represent the reality.

The design of the harbours are a coarse approach as the design details were out of the scope of this thesis. For sure there could have been better approaches covering with more details the design criteria.

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Annexes

Annex A: German organizations for seadata

This is a brief report about the German organizations for seadata and the ISO19115. Extensively are analyzed at the original site: (http://www.coastalwiki.org/coastalwiki/NOKIS_-_Information_Infrastructure_for_the_North_and_Baltic_Sea).

NOKIS

The project NOKIS (German title: Nord- und Ostsee-Küsteninformationssystem) was first created due to the lack of an infrastructure for the exchange of geodata across administrative boundaries between the German Wadden sea national parks and other governmental administrations (e.g. water management and administration of waterways and navigation) on the federal and state levels. Today, around 20 partners from administration, research and industry are cooperating within NOKIS. The focus of the participants changed from the goal of an information system to the shared internet-based use of existing geodata. The technologies and concepts of NOKIS reflect the common objectives of the participating partners, but they also have expanded due to alternate interests, problems and tasks. Some of the discussed topics in the project have to do with data and privacy protection, criteria for the distribution of data and the handling of the copyright of data.

Use of ISO Standards

Within NOKIS, a profile of the ISO 19115 has been developed, which meets the needs of the coastal community. To enable the documentation of time series and research projects within the same system, metadata schemas have been extended in order to include the necessary information.

ISO 19115 "Geographic Information - Metadata" from ISO/TC 211, is the current standard for geospatial metadata, as it is defined in the original webpage for International Organization for standardization (http://www.iso.org/iso/home.html).

ISO 19115:2003 defines the schema required for describing geographic information and services. It provides information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference, and distribution of digital geographic data.

ISO 19115:2003 is applicable to:

- the cataloguing of datasets, clearinghouse activities, and the full description of datasets;
- geographic datasets, dataset series, and individual geographic features and feature properties.

ISO 19115:2003 defines:

- mandatory and conditional metadata sections, metadata entities, and metadata elements;
- the minimum set of metadata required to serve the full range of metadata applications (data discovery, determining data fitness for use, data access, data transfer, and use of digital data);
- optional metadata elements - to allow for a more extensive standard description of geographic data, if required;
- a method for extending metadata to fit specialized needs.

However, ISO 19115:2003 is applicable to digital data, its principles can be extended to many other forms of geographic data such as maps, charts, and textual documents as well as non-geographic data.

To ensure that the spatial data infrastructures of the Member States are aggreable and usable in a Community and transboundary context, the Directive requires that common Implementing Rules (IR) are adopted in a number of specific areas (Metadata, Data Specifications, Network Services, Data and Service Sharing, Monitoring and Reporting). These IRs are adopted as Commission Decisions or Regulations, and are binding in their entirety. The Commission is assisted in the process of adopting such rules by a regulatory committee composed of representatives of the Member States and chaired by a representative of the Commission (this is known as the Comitology procedure).

NOKIS Applications

The NOKIS Editor is the central tool for the generation and maintenance of metadata records. This software helps the user in creating valid ISO 19115/19119 metadata by signifying missing or wrong elements and by giving aids for the editing of certain elements. It supports the user by offering template mechanisms for the generation of metadata for similar data sets as well as offering the possibility to insert metadata from other applications.

Background of NOKIS

NOKIS, the North and Baltic Sea Information System, has the goal to establish an information infrastructure for the German coast, driven by metadata. The system uses the international standard ISO 19115 for metadata and realizes a working environment for the production of metadata with an editor; which was developed for this purpose, and a map-based search, which brings up existing metadata.

Since the end of 2005, a concrete concept for the data contents has been developed and implemented for test areas during the course of 2006. Obtaining the data was done with different procedures, from data transformation to data source evaluation, up to field work. The variety of the material is used for critical examination of the present gazetteer concept and also to evaluate the difference between the data-model and services.

MUDAB - Marine Environmental Database Germany

The Marine Environmental Data Base (MUDAB) is a joint project of the Federal Maritime and Hydrographic Agency (BSH) in Hamburg and of the Federal Environmental Agency (UBA) in Berlin. MUDAB is the primary database for marine environmental monitoring data which are collected by German federal states and state agencies. MUDAB data are used to fulfill Germany's reporting obligations as part of international treaties and conventions targeting the protection of the North Sea and the Baltic Sea. The data cover physical variables such as temperature and salinity, chemical variables like, e.g. O2, nutrients, and the organic, inorganic and radiochemical components of sea water, and physical and chemical variables in sediment.

CONTIS – Continental Shelf Research Information System Germany

CONTIS is a novel ocean data base developed by the Federal Maritime and Hydrographic Agency (BSH) which shows the wide range of present and future uses of the marine environment. The CONTIS geodata, e.g. on shipping, exploitation of resources, planned offshore wind farms or environmentally sensitive areas, are available as digital maps providing concentrated information. The system visualizes, the areal extent of individual uses and interfaces with other users as well as sea areas which are still free of any uses. In other words, CONTIS is an optimal tool allowing early identification of possible conflicts of interest among different uses. The Continental Shelf Information System CONTIS focuses on the German continental shelf and Exclusive Economic Zone.

Sea Geo-Information which come from BSH, are very important for the Sea and the protection of the coast, for the insurance of the boats and for all the activities done offshore, like a Marine. The various problems that show up can be treated only if there is a standardized and cross-disciplinary access to the different spartial data.

Marine Environment Reporting System

MURSYS (Meeresumwelt-Reportsystem - Marine Environment Reporting System) is a regularly published report which gives information on physical and chemical parameters (weather, sea surface temperatures, water levels, current conditions, nutrient concentrations, oxygen situation) and biological parameters (occurrence of algae and toxic algae, blue mussel stocks, fish stocks etc.) in the area of the North and Baltic Seas. MURSYS also deals with special topics (e.g. "black spots", mass mortality of sea birds, flood etc.). MURSYS reports are published in German except for some abstracts in English. MURSYS is not a data base. MURSYS is published by the BSH (Federal Maritime and Hydrographic Agency of Germany), Hamburg. It contains written and oral information provided by scientific institutions in the North Sea and Baltic Sea areas, the German Meteorological Service, and by other states bordering the North and Baltic Seas (Denmark, Sweden, Norway, Finland, Poland), and also data provided by the BSH itself.

CoastDat Database

First of all, CoastDat is NOT an observational data base. It does not contain any in-situ or other measurements. Instead, coastDat gathers coastal analyses and scenarios for the future which obtained from numerical models. The objective is to provide a consistent meteorological-marine data set that best represents past conditions in order to complement the existing but restricted observations. Based on model results coastDat may provide information over long time spans, at high spatial and temporal detail, and at places and for variables for which no observations have been taken. As an addition step, coastDat also provides consistent coastal scenarios for the near future allowing for an assessment of expected future changes relative to changes obsereved over the past few decades.

CoastDat is a project of Helmholtz Zentrum Geesthacht, Institute of Coastal Research. An accummulation of coastal weather analyses and climate change scenarios for the future for Northern Europe from various sources is presented. They contain no direct measurements but results from numerical models that have been driven either by observed data in order to achieve the best possible representation of observed past conditions or by climate change scenarios for the near future. A comparison with the limited number of observational data points to the good quality of the model data in terms of long-term statistics such as multi-year return values of wind speed and wave heights. These model data provide a unique combination of consistent atmospheric, oceanic, sea state and other parameters at high spatial and temporal detail, even for places and variables for which no measurements have been made. In addition, coastal scenarios for the near-future complement the numerical analyses of past conditions in a consistent way. The data are based on regional wind, wave and storm surge hindcasts and scenarios mainly for the North Sea. The way to obtain these data, their quality and limitations in comparison with observations are briefly analyzed in the website (http://www.coastdat.de/about/index.html.en). Moreover, a variety of coastal offshore applications which use the data is presented by CoastDat.

Annex B Particle tracking module

The particle tracking model was set up for the North mean and West mean events in order to see how the floaters move for sources located at the entrance of the harbours. This was done as a task in order to see how a boat without s would move if it opened the sails without using the engine. One particle was released every one timestep (450sec). The results are presented on the next figures.

<u>North event</u>

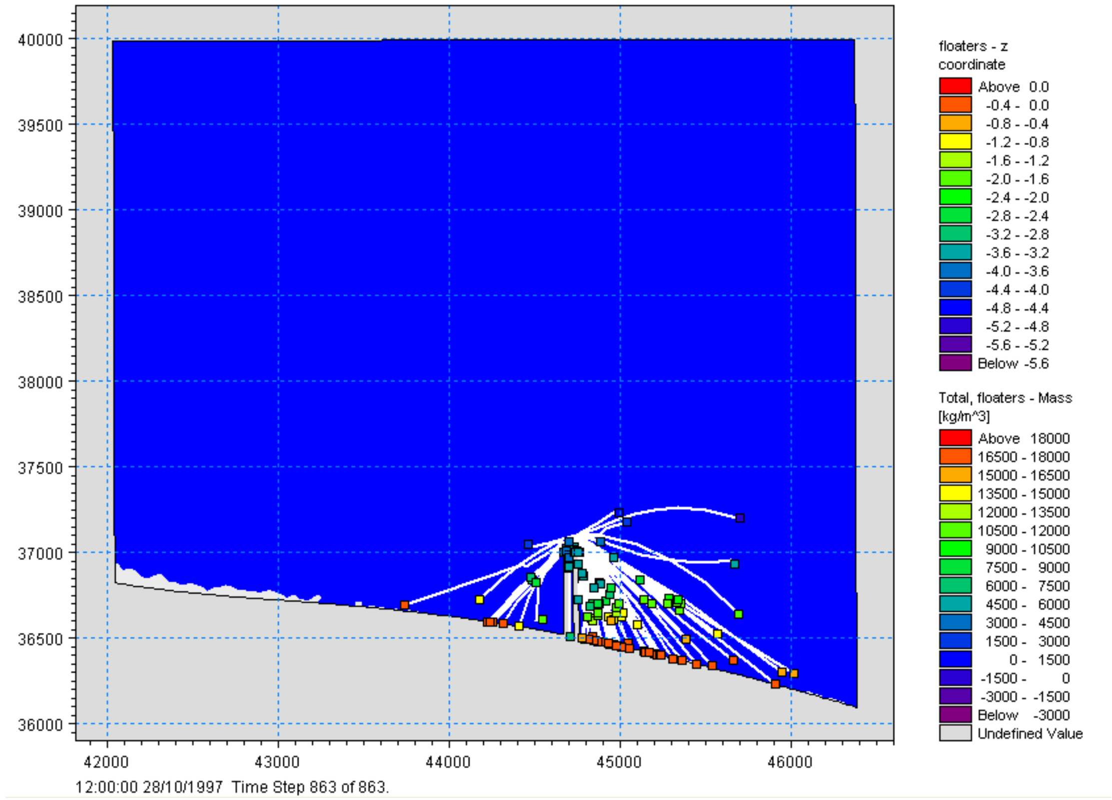

Figure B1: Inshore harbour North event

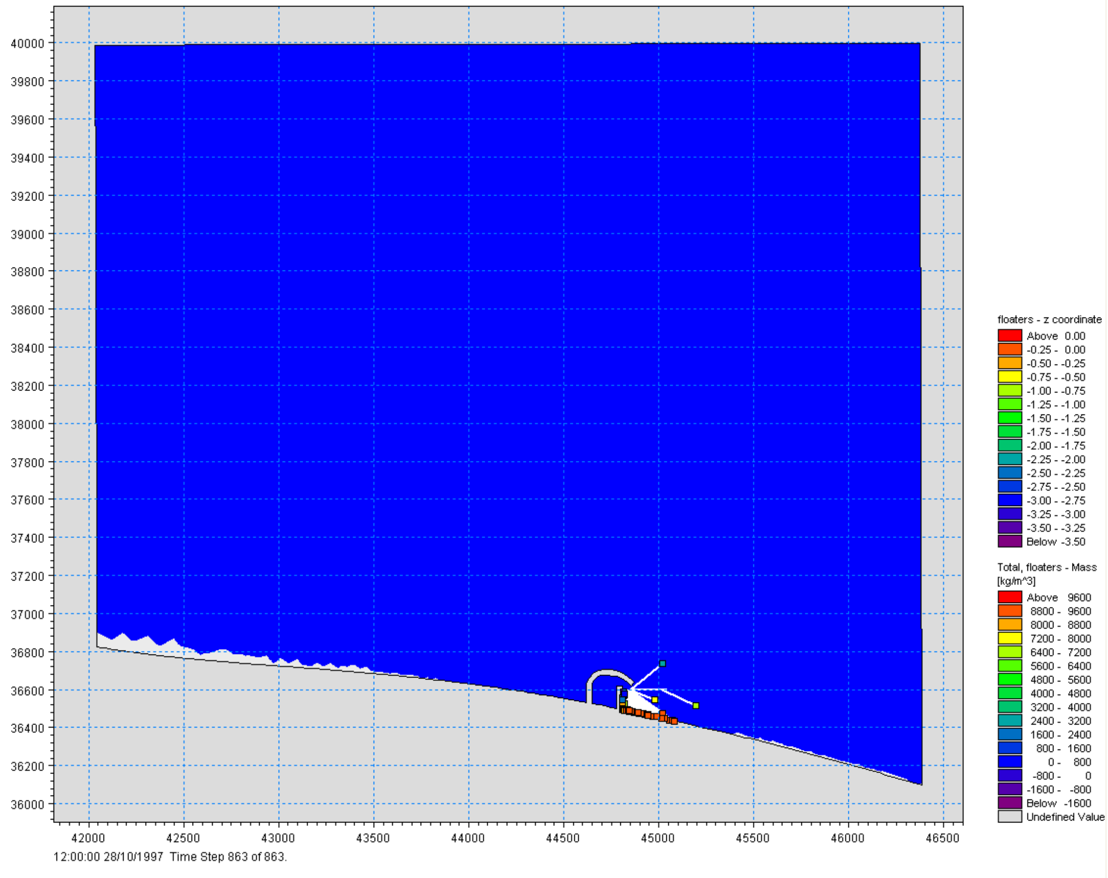

Figure B2: Onshore harbour – North event

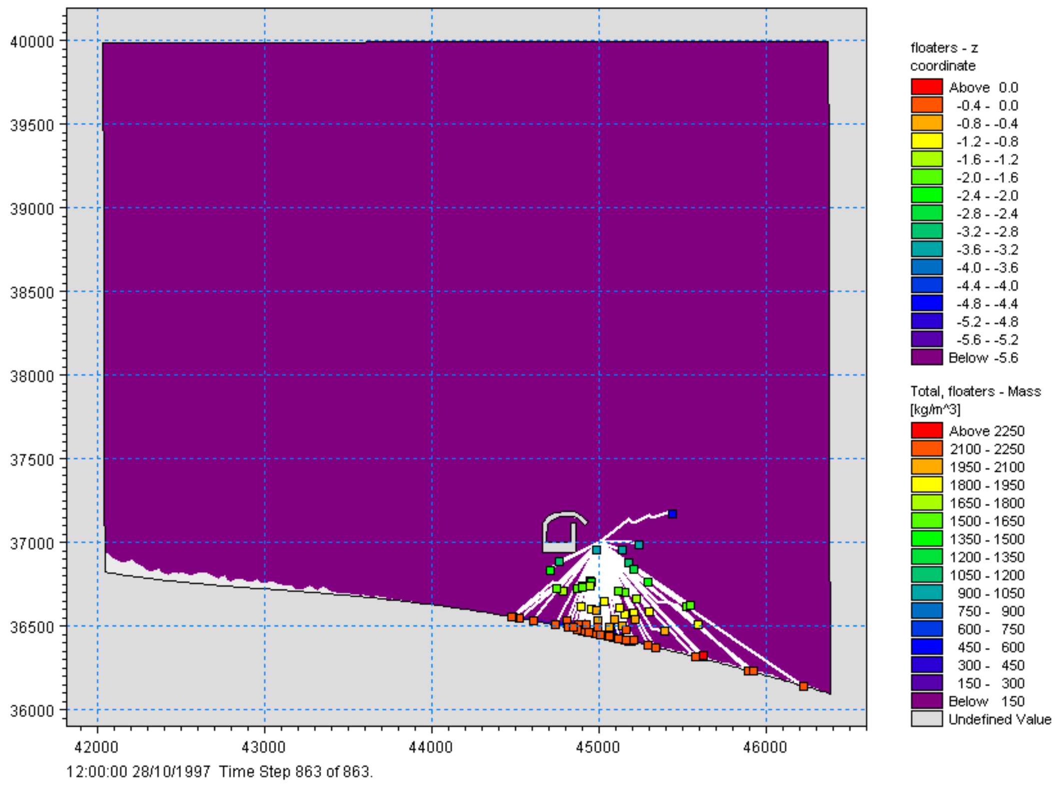

Figure B3: Offshore A – North event

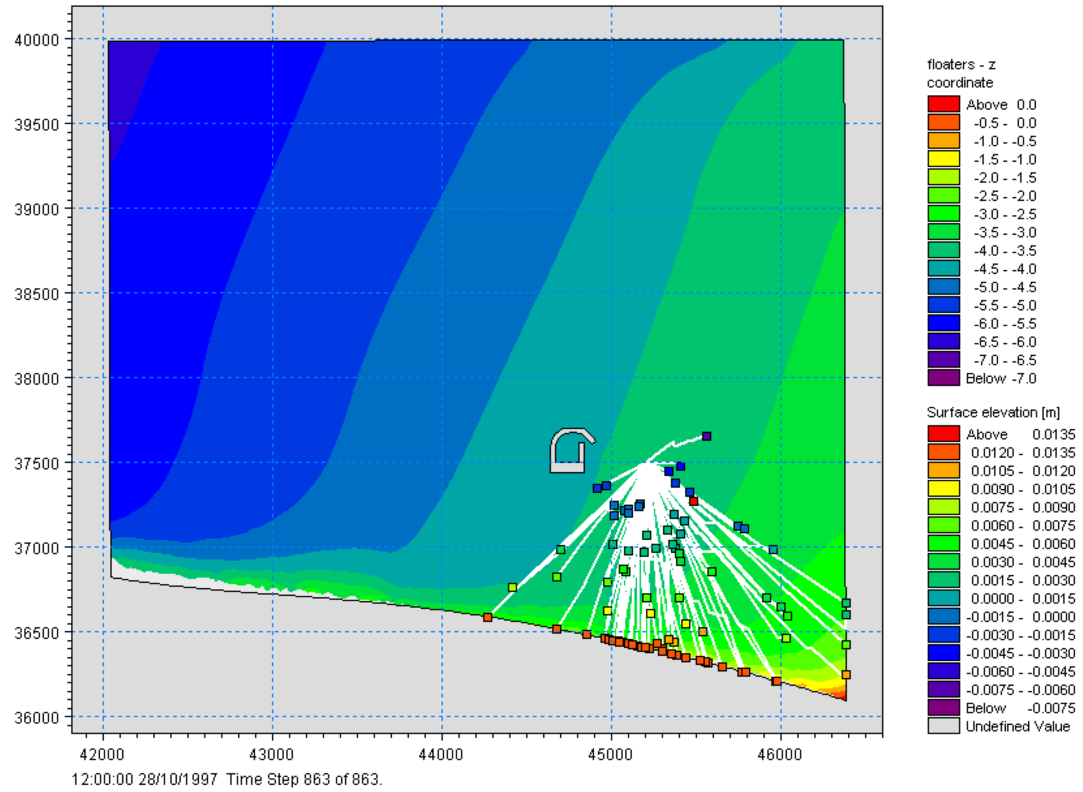

Figure B4: Offshore B – North event

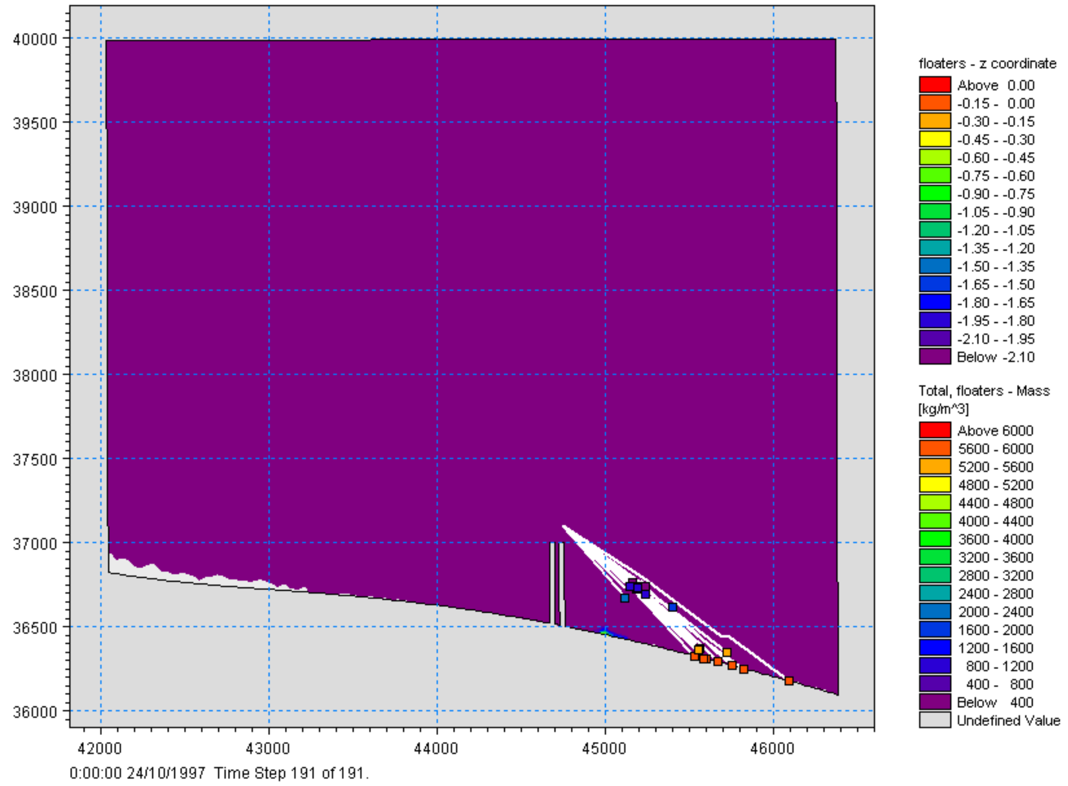

Figure B5:Inshore harbour-West mean event

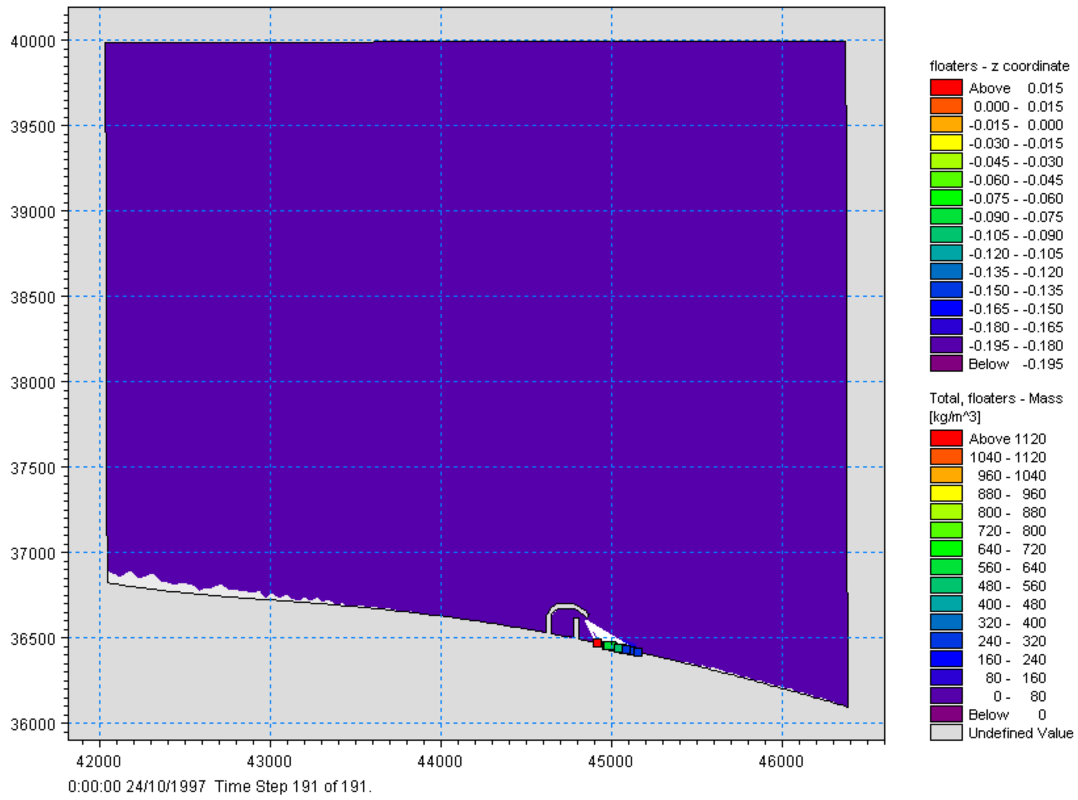

Figure B6: Onshore harbour – West mean event

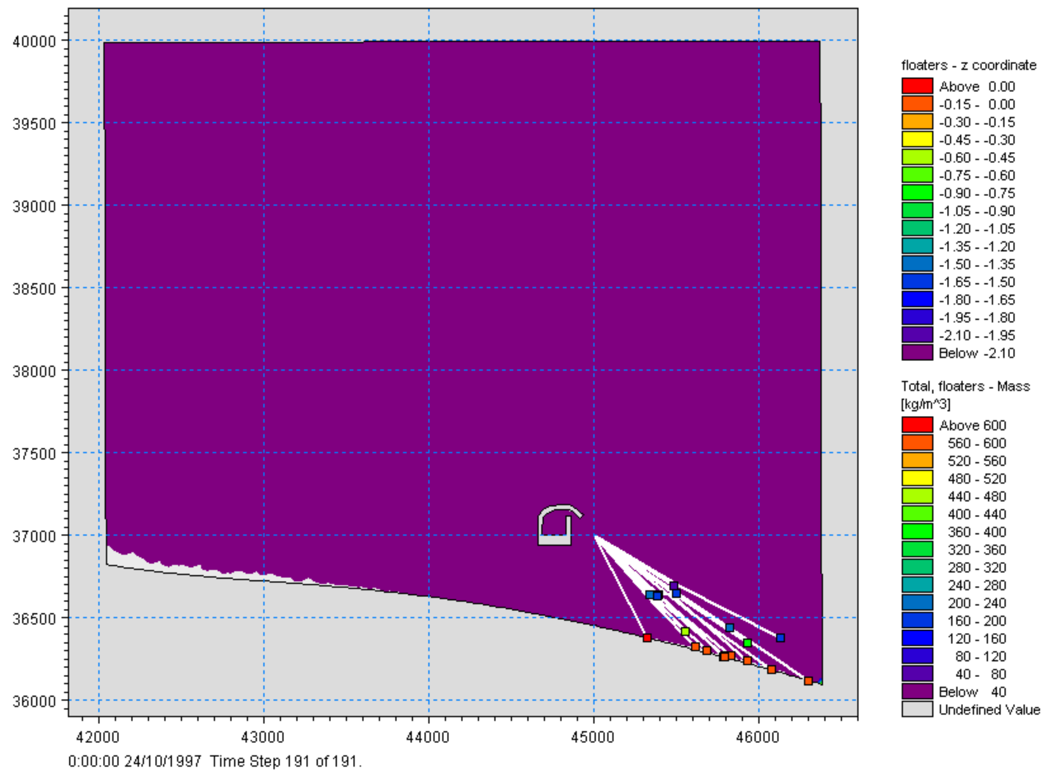

Figure B7: Offshore A-West mean event

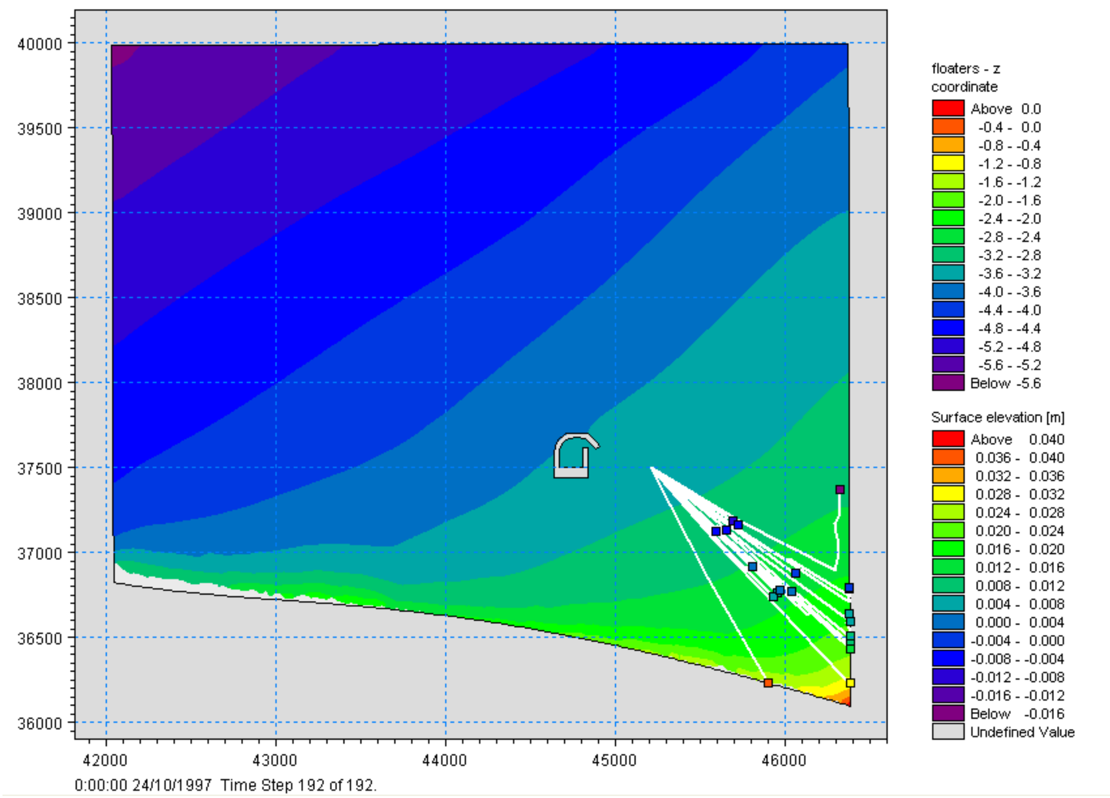

Figure B8: Offshore B – West mean event

Annex C: Theory of the statistical methods used at the Shev programme.

The used statistical methods of calculation

1 The EPR (End Point Rate) Method

This method is the most simple method used to predict a future coastline. It only uses two coastlines, usually the most recent and the oldest one.

Way of calculation:

The rate of change is calculated by dividing the distance between two coastlines to the years between. This is done by creating cross sections between two coastlines. The cross sections usually have stable length (approximately 50m). As a result:

$$P.M._{EPR} = \frac{\left(\frac{D}{\Delta T}\right)_{d1} + \left(\frac{D}{\Delta T}\right)_{d2} + \ldots + \left(\frac{D}{\Delta T}\right)_{dv}}{v}$$

$\mathbf{d_1\, d_2 \ldots d_V}$: is the distance between two coastlines at the specific cross section

D: distance between two cross sections at the specific cross section

ΔT: is the time between two coastlines

v: the number of cross sections

It is assumed a linear equation between the points so an equation y=ax+b is used in order to provide a point of the future coastline. For each cross section is provided a diagram as the one follows:

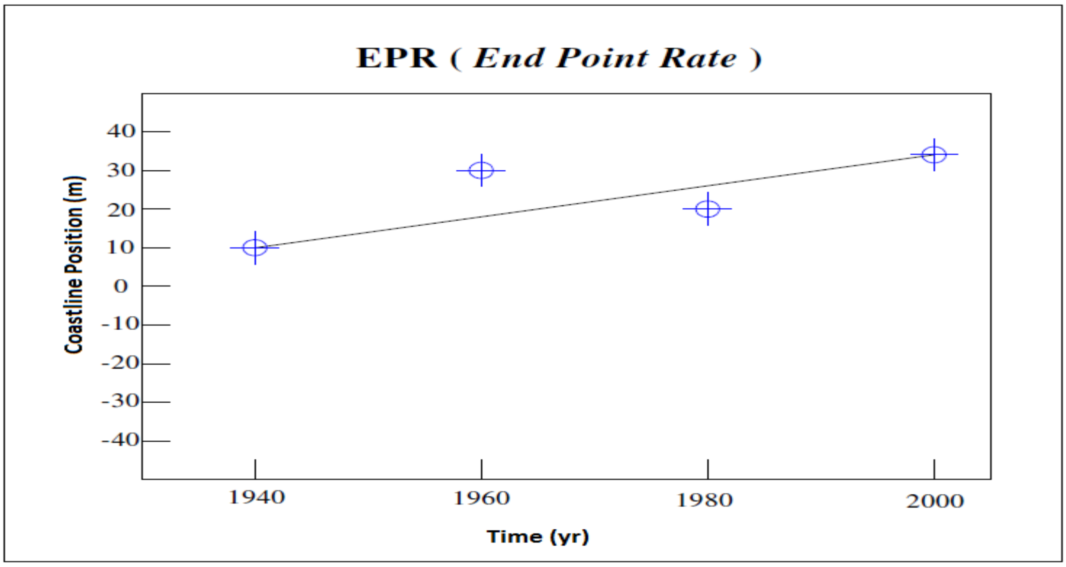

Figure C1: EPR Method (source:Doukakis 2012)

In this diagram only 1940 and 2000 coastlines are taken into account.

The biggest advantage of EPR method is that it is a very easy procedure without the need of a lot of data for the area.

The biggest disadvantage of the method is that it doesn't take into account information for the rest of the years.

2 The AOR (Average of rates) Method

This method is based on the EPR method. The EPR method is used for each pair of coastlines. At the end there are many rates for each pair. The average of all those rates defines the rate of AOR.

Moreover, there is the Tmin criterion, which is used in order to "filter" the pairs at which EPR is used. In case that those pairs are not accurate, then they are not taken into account. If any pair is able to pass then Tmin criterion, then the method cannot be used.

<u>Way of calculation</u>:

As it is already referred, this method is based on EPR method. The Tmin criterion is analyzed below:

$$\mathrm{T}\min = \sqrt{\frac{\left(E_1^{\,2} + E_2^{\,2}\right)}{R_1}}$$

E_1 E_2 : the errors between one point at the coastline and the exact same point at the other coastline respectively

R_1 : is the EPR between the coastlines with the biggest difference between the years (oldest and youngest coastline)

$$\mathrm{P.M.}_{AOR} = \frac{1}{v}\left[\left(\frac{\left(\frac{D}{\Delta \mathrm{T}}\right)_{c1} + \left(\frac{D}{\Delta \mathrm{T}}\right)_{c2} + \ldots + \left(\frac{D}{\Delta \mathrm{T}}\right)_{cn}}{n}\right)_{d1} + \left(\frac{\left(\frac{D}{\Delta \mathrm{T}}\right)_{c1} + \left(\frac{D}{\Delta \mathrm{T}}\right)_{c2} + \ldots + \left(\frac{D}{\Delta \mathrm{T}}\right)_{cn}}{n}\right)_{d2} + \ldots + \left(\frac{\left(\frac{D}{\Delta \mathrm{T}}\right)_{c1} + \left(\frac{D}{\Delta \mathrm{T}}\right)_{c2} + \ldots + \left(\frac{D}{\Delta \mathrm{T}}\right)_{cn}}{n}\right)_{dv}\right]$$

or else..

$$\mathrm{P.M}_{AOR} = \frac{1}{v}\left[\left(\frac{\mathrm{P.M}_{EPR_{C1}} + \mathrm{P.M}_{EPR_{C2}} + \ldots + \mathrm{P.M}_{EPR_{Cn}}}{n}\right)_{d1} + \left(\frac{\mathrm{P.M}_{EPR_{C1}} + \mathrm{P.M}_{EPR_{C2}} + \ldots + \mathrm{P.M}_{EPR_{Cn}}}{n}\right)_{d2} + \ldots + \left(\frac{\mathrm{P.M}_{EPR_{C1}} + \mathrm{P.M}_{EPR_{C2}} + \ldots + \mathrm{P.M}_{EPR_{Cn}}}{n}\right)_{dv}\right]$$

$\mathbf{d_1\, d_2 \ldots d_V}$: cross sections

$\mathbf{c_1\, c_2 \ldots c_n}$: combination of coastlines which satisfy the Tmin criterion

n: number of combinations which satisfy the Tmin criterion

D: distance between two cross sections for a specific cross section

ΔT: is the time between two coastlines

v: the number of cross sections

In this method there is the assumption that the change of the coastline is linear.

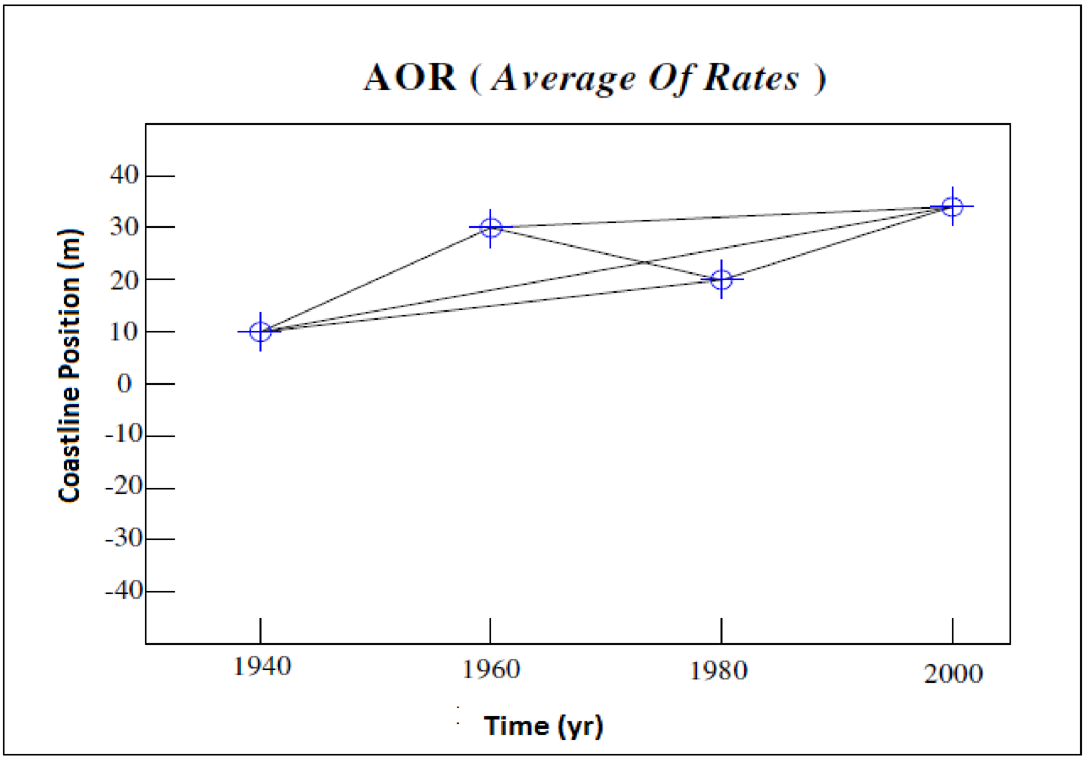

Figure C2: The AOR Method (source: Doukakis 2012)

At the diagram above all the combinations of the coastlines are represented.

The advantage of this method is that it collects information from different sources with different accuracy (ex. Maps, aerial photos). It also has the advantage of rejecting the coastlines with big error of calculations due to the Tmin criterion.

Disadvantage is that the E_1 and E_2 errors are defined from the researcher the experience and the measurements is another negative point cause those issues define which are values will be rejected.

3 The AER (Average of Eras Rates) Method

This method is also based on EPR method. That means that are also used measurements between two coastlines of two different ages. The final rate is determined by the average rate of each cross section.

<u>Way of calculation:</u>

At the beginning the calculation based on EPR method between successive coastlines is done. As a result, for each cross section there is a rate which is the average rate of the combinations for this cross section. The final rate is defined by the average change of the coastline for each cross section.

$$P.M_{AER} = \frac{1}{v}\left[\begin{array}{l}\left(\frac{P.M_{EPR_{C1}} + P.M_{EPR_{C2}} + \ldots + P.M_{EPR_{Cn}}}{n}\right)_{d1} + \left(\frac{P.M_{EPR_{C1}} + P.M_{EPR_{C2}} + \ldots + P.M_{EPR_{Cn}}}{n}\right)_{d2} + \ldots \\ \ldots + \left(\frac{P.M_{EPR_{C1}} + P.M_{EPR_{C2}} + \ldots + P.M_{EPR_{Cn}}}{n}\right)_{dv}\end{array}\right]$$

$\mathbf{d_1\, d_2 \ldots d_V}$: cross sections

$\mathbf{c_1\, c_2 \ldots c_n}$: Time between two coastlines (successive to each other)

n: number of time space between two coastlines

D: distance between two cross sections for a specific cross section

ΔT: is the time between two coastlines

v: the number of cross sections

Once more, it is assumed that the change of the coastline is linear.

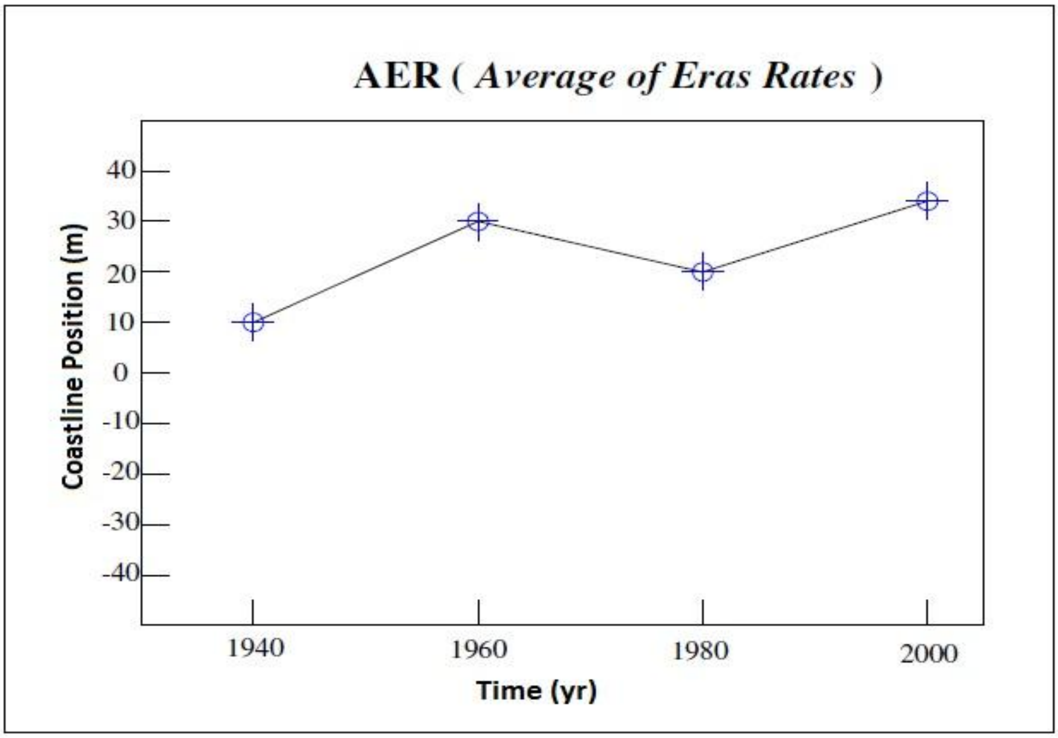

Figure C3: The AER Method (Source: Doukakis 2012)

Advantage of the method is that it is able to give a lot of statistical values.

Disadvantage is the lack of a ‘filter’ to avoid the wrong values to be incorporated.

Shev interface

The Shev programme is mathematical programme which is using simple and not a lot time consuming calculations. The user is able to choose all the methods and choose the better one in comparison with the results.

The interface of the programme is showed at the following pictures (Figure C4):

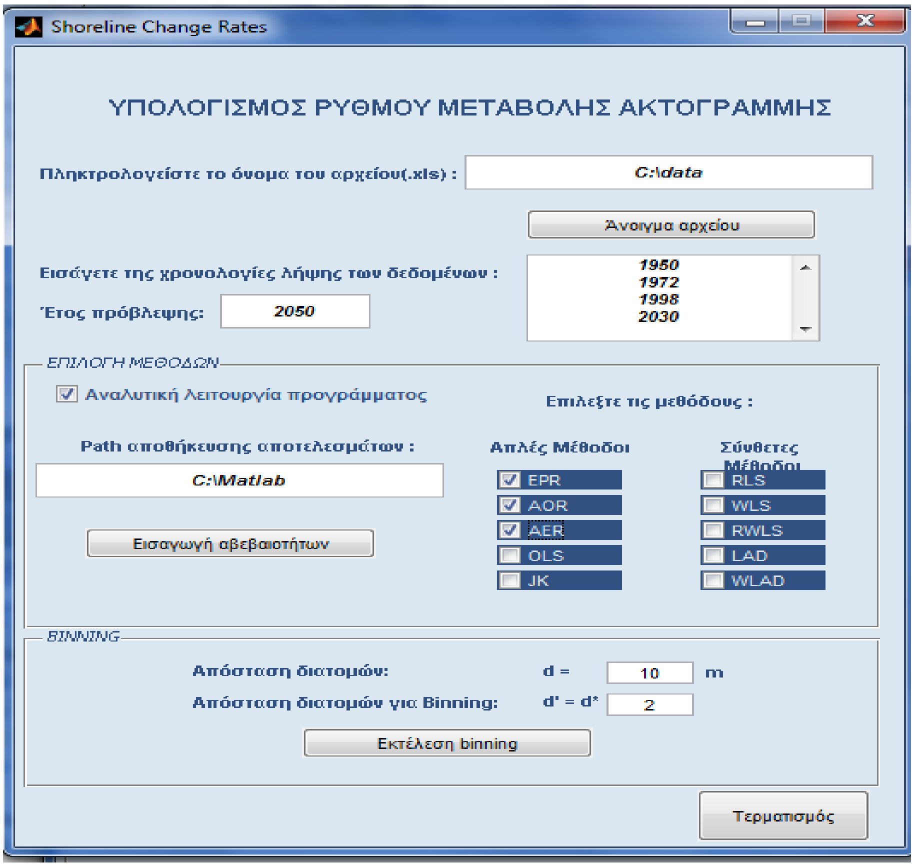

Figure C4: Interface of Shev Programme

At the first part the user chooses the file that the distances between the coastlines of different years. Then the years included are also inserted to the programme as well as the year of the prediction. (Figure C5)

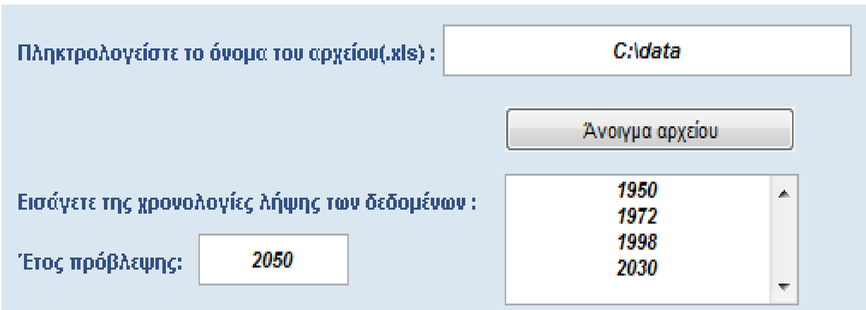

Figure C5: Shev part1

At the second part the methods are chosen. The errors can be introduced for each year. There is also the ability to chose the analytical solution of the programme which will give analytical rates for each crosssection of each method.

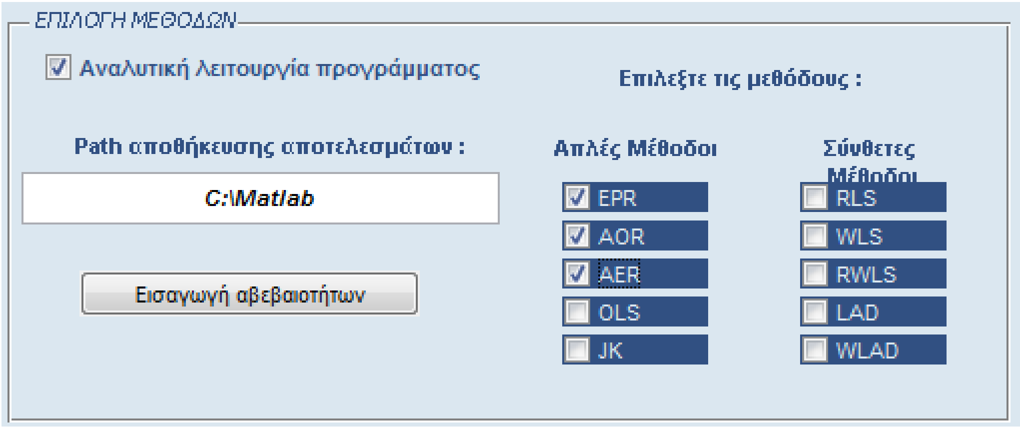

Figure C6: Second part of the programme

At the last part the Binning method can be implemented. This can give results for the rate of the coastline at all of it's length. If there are sub areas of the coastline with different rates, then those areas will be exported if the Binning has been chosen.

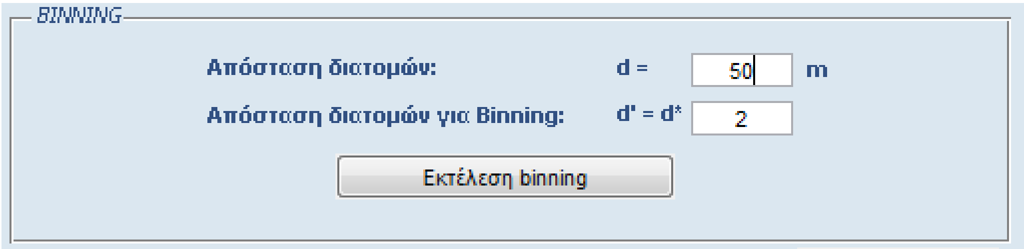

Figure C7: Last part of the programme

The Shev programme works under the environment of MATLAB by introducing the routines of the Shev programme to MATLAB.