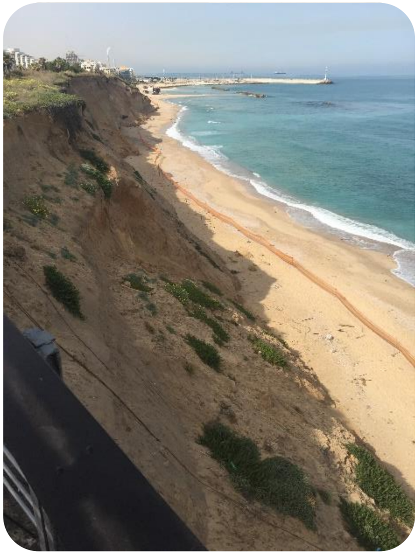

Geotextile structures for beach protection Ashkelon, Israel

Design of the marine works

DESIGN REPORT AREA 39

PROGRESS REPORT

Affaire : CORADM-73-2016
Référence du document : DES-MEM-02-5
August 2017

Document editing

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Versions and modifications

Version	Date	Description	Modifications
0	06/04/2017	Design report -progress report	Initial version
1	09/05/2017	Design report – complement progress report	Detail about scenario S1 Simulation on complementary scenarios S12 and S12bis
2	09/06/2017	Design report – complement progress report	Simulation on complementary
3	17/07/2017	Design report – complement progress report	Simulation on complementary Following the meeting with the client on 06/07/2017
4	05/08/2017	Design report – complement progress report	Simulation on complementary Following the meeting with the client on 27/07/2017
5	25/09/2017	Design report – complement progress report	Simulation on complementary Following the discussions with the client on 10/08/2017 and 24/08/2017

RÉSUMÉ

This report is a design report presenting the work carried out on area 39.

SUMMARY

TABLES

FIGURES

1 INTRODUCTION

1.1 PREAMBLE

The Mediterranean Coastal Cliffs Preservation Government Company Ltd has welcomed proposals for design and build of coastal protection schemes in the Ashqelon area (Israel), using geotextile to build shore-parallel breakwaters.

The tender have been awarded to a Joint Venture of TAAVURA, Admir technologies and TRASOMAR.

CORINTHE Engineering is the designer of the JV.

The two sites are the Field Units 38 and 39, as described in the Policy Document and National Outline Plan 13, Amendment 9A. Field Unit 38 is immediately to the north of Ashqelon marina and Field Unit 39 is about 1.5km south of the marina.

Field Unit 38 comprises some 800m of beach, backed by hotel development on the cliff top.

Field unit 39 comprises 800m of beach, backed by the archaeological remains within the roman city of Ashqelon.

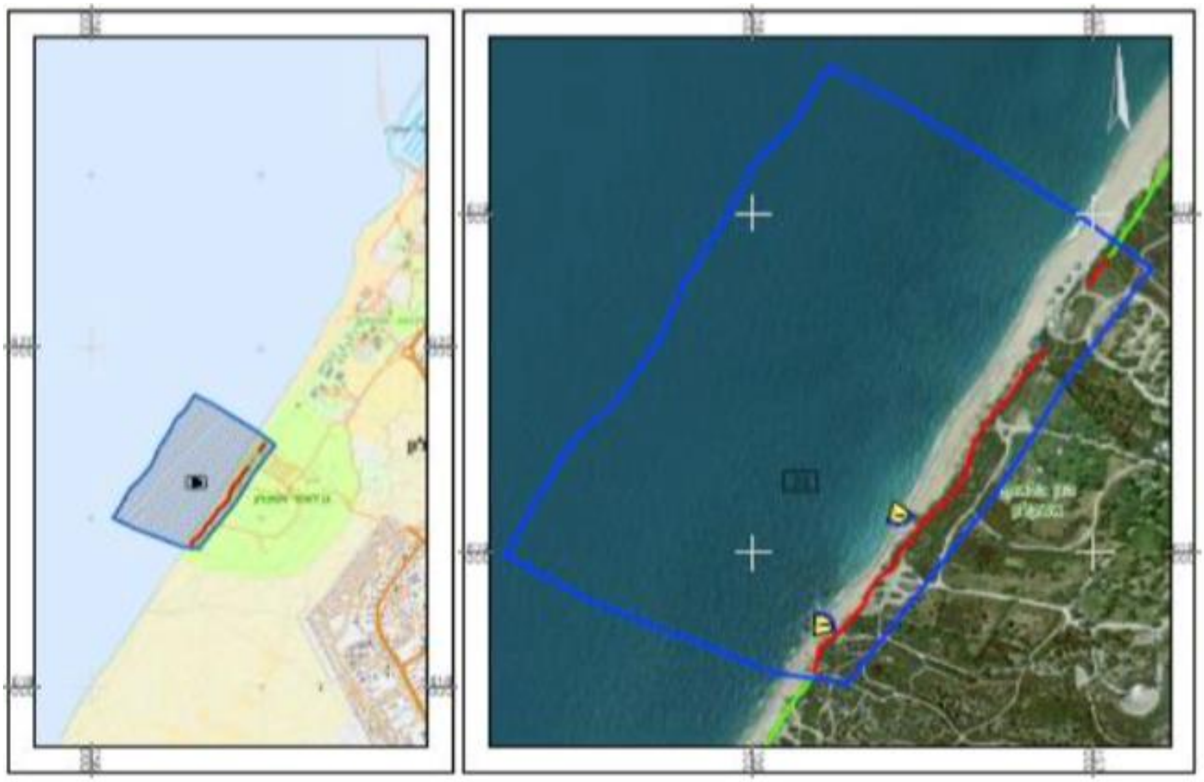


Figure 1 : Location of the Ashkelon site

Certain segments of the above coastal cliff belt are prone to erosion of cliffs. They are mainly due to natural weathering processes triggered by a combination of various factors, including: wave erosion at ridge base, ridge slope instability, runoff erosion.

1.2 INITIAL SOLUTION SET

The tender document set the main objectives for the protection of the cliff:

- Do a nourishment to protect the cliff from the impact of the waves;
- Install a breakwater to minimize the erosion of the beach.

Taking that objectives into account, the Moffat and Nichols report present a solution for area 38 and 39.

Table 1: submerged breakwater design parameters

	Area 38	Area 39
Design wave height ($H_{m0,12hrs/year}$, m)	3.2	3.2
Peak wave period (Tp, s)	11.0	11.0
1 year surge level (m)	0.3	0.3
Total length of coast (m)	1000	800
Number of breakwaters	5	5
Breakwater length per section (Ls, m)	120	120
Assumed minimum Breakwater crest width (w, m)	> 15	> 15
Gap length (G, m)	50	50
Breakwater crest level (mCD)	0.0	0.0
Seaward toe level of the breakwater (mCD)	-4.0	-4.0
Nourishment Volume (m3)	211,000	244,000
Initial berm width (width of the dry beach)	75	75
Fill slope	1V:10H	1V:10H

1.3 DESCRIPTION OF THE PROPOSED SOLUTION AND RETAINED BY CORINTHE ENGINEERING ON THE AREA 38

The calibration of the model was carried out by Corinthe Ingénierie on the study of zone 38 on the basis of studies carried out by Maffat and Nichols.

The same model has been used for studies in zone 39, including the solution proposed by Corinthe Ingénierie on zone 38, namely:

Configuration	A
Breakwater length per section(m)	120 to 105 from south to north
Assumed breakwater crest width (m)	15
Gap length (m)	50 to 75 from south to north
Breakwater crest level (mCD)	-0.2
Seaward toe level of the breakwater (mCD)	-4
Initial berm width (width of the dry beach)	≈75
Breakwater height (m)	3.8
Structure of breakwaters	Geotube®

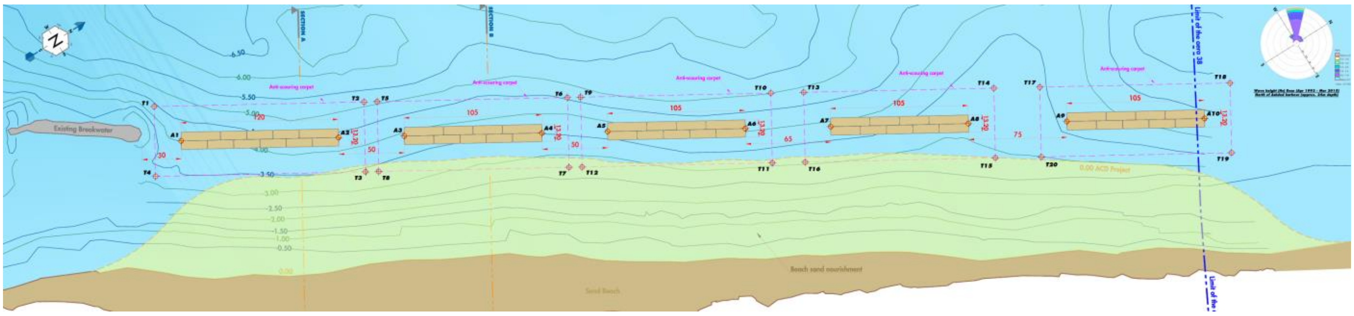


Figure 2. Plan view of the final scenario – Aera 38

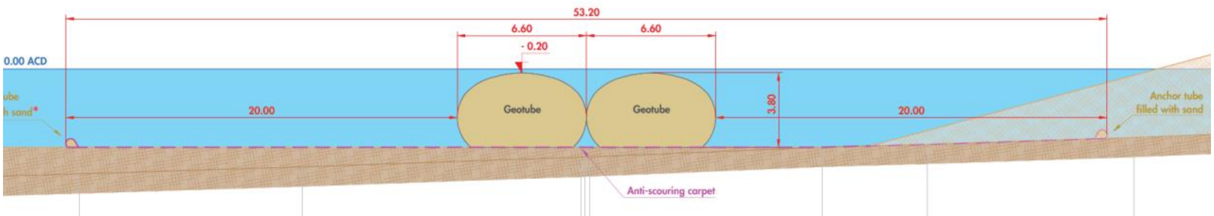


Figure 3. Typical cross-section of the geotube breakwater of the final scenario – Area 38

1.4 PURPOSE OF THE REPORT

The report states:

- A reminder of the Metocean data,
- The execution of several different scenarios to define the most significates for the design.

The report aim is to extend the studies done previously and design the final solution for the beach protection of the area 39 in Ashklelon.

It seems important to set at the beginning of the report the way the design has been performed by CORINTHE Engineering:

- The same Xbeach model used by Moffat and Nichols has been used to realize the simulations.
- The protection of the beach is to be made with geotube structure
- The design parameter is the average shoreline position after 10 years.

2 REMINDER OF THE METOCEAN DATA

2.1 WAVE DATA AND STATISTICAL APPROACH

Offshore and moreover nearshore, wave data are required to provide wave conditions to the sediment transport and coastal area morphology models, as well as extreme wave conditions to assess immediate post-storm erosion and to dimension any project.

As stated by Moffatt & Nichol in their report [1], there are no available observed (measured) wave data sets in the project vicinity of Ashqelon. MCCP has provided observed historical wave data covering a period of 23 years (Apr1992 – Mar 2015) in 3 hour intervals, recorded at a location just north of Ashdod harbor. The data includes; significant wave height (Hs), peak wave period (Tp), mean wave direction (MWD, from true north), mean wave period (Tz), directional spreading, and sea water temperature. The buoy location is -31°52.49´N, 34°38.96´E in a water depth of approximatively 24 meters.

The nearshore wave rose obtained by Moffatt & Nichol thanks to the analysis of this data is presented below. It shows that about 63% of the wave heights are higher than 0.5m, responsible for a strong littoral drift. About 62% of the waves are coming from directional sector 285 – 315 deg, responsible from a net northward littoral drift. Waves with high wave heights are having long peak periods of 10.0 – 16.0 s.

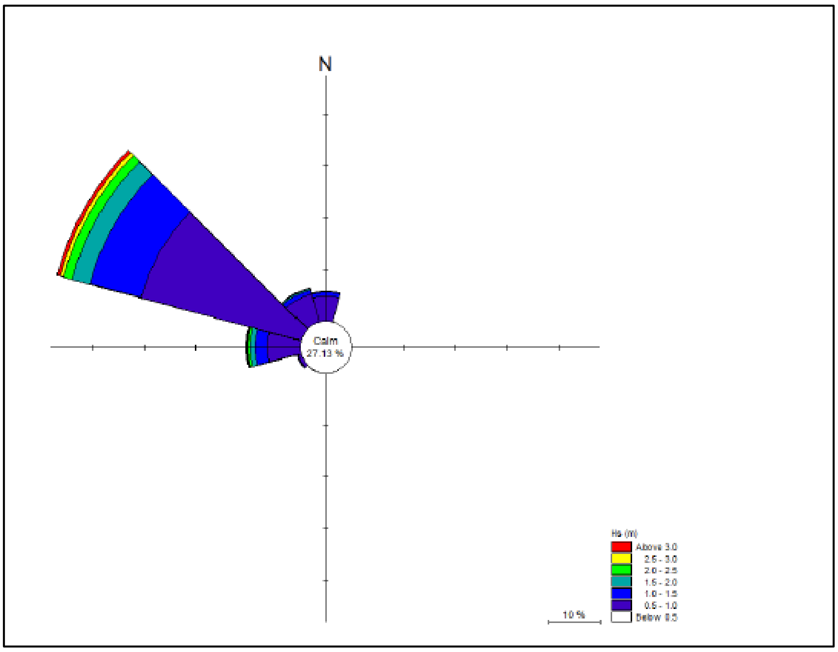


Figure 4. Wave height (Hs) rose (Apr 1992 – March 2015) north of the Ashdod harbor (approx.. 24m depth) (source : Moffatt and Nichol [1]

The Ashdod wave data were used by Moffatt & Nichol to estimate an offshore wave climate that was used as input to a wave transformation modelling approach in order undertake a statistical analysis of this data. Such data are relevant for long term beach evolution study.

For long term beach evolution purpose, a key parameter is the significant wave height exceeding 12hours per year (0.137%), used in the different formulas.

The wave exceedance curve at 5m depth provided by Moffat & Nichol is presented below. From this curve, the significant wave height exceeding 12hours per year (0.137%) was extracted
It corresponds to $H_{m0\_12hrs/year@5mdepth}$=3.2m.

And the associated Tp is 11s.

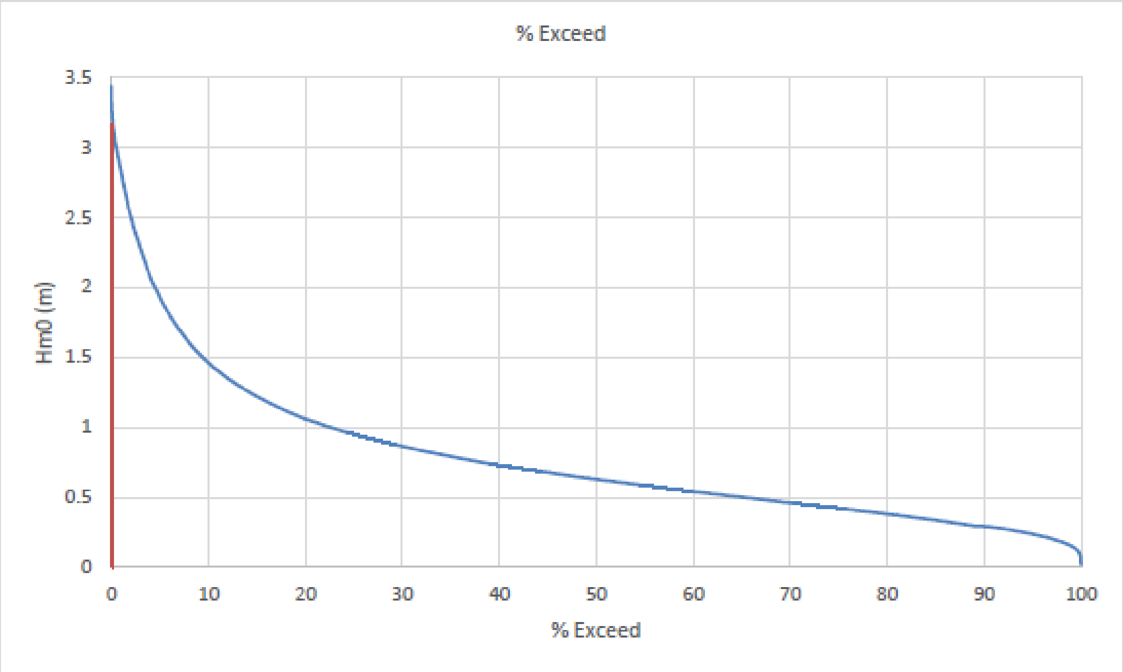


Figure 5. wave exceedance curve at 5m depth (source : Moffatt and Nichol [1])

2.2 WAVE CONDITIONS FOR STORMS

In order to assess the extreme wave climate at the site area, CORINTHE Engineering has extracted data analysis from different internal or external sources, such as:

- Internal database reports of CORINTHE Engineering
- Moffatt & Nichol report [1]
- SEATECH report from 1990 on the Ashkelon Marina design [2]
- Scientific publication by Sergiu Dov Rosen in Coastal Engineering 2012 [3].

The table below presents extreme wave data extracted from this database. It shows intensity of 4 to 6m of (significant) wave heights for "frequent" storms (1 to 5 year Return Period – RP) and 6 to more than 8m for extreme storms (10 to 100 year RP).

Table 2: comparison of extreme offshore wave conditions depending on the source

Return Period (year)	CORINTHE (2010) North of Israel		SeaTECH (<1990) Ashdod port station		Rosen(2010) Ashdod port station	
	Hs (m)	Tp (m)	Hs (m)	Tp (m)	Hs (m)	Tp (m)
1	4.4	8.7 to 10	3.7	9.6	4.8	11.5
2			5.4	11.6		
5	6	11.2 to 12.5	6.2	12.4	6.2	13
10	6.3	11.2 to 12.5	6.7	12.9	6.8	13.5
20	6.7	11.2 to 12.5			7.4	14
25			7.5	13.7		
50	7.1	12.5 to 15	8.2	14.3	8.2	15
100	7.4	12.5 to 15	8.7	14.7	8.7	15.5

Results of the analysis, undertaken on offshore wave data time series provided by M&N (generated from Ashdod port wave data) in order to determine offshore directional extreme wave data, are presented in the table below. A POT analysis was applied to estimate these values.

This shows good agreements with the above table.

Table 3: extreme wave analysis using the offshore wave provided by Moffatt&Nichol

	Significant wave height Hs (m)				
Off. wave dir. (°N)/ Return Period (year)	N195° N225°	N225° N255°	N255° N285°	N285° N315°	N315° N345°
1	0.5	1.4	3.8	4.2	2.4
10	1	2.1	5.5	6	3.7
20	1.1	2.4	6	6.7	4.1
50	1.3	2.6	6.6	7.6	4.8
100	1.4	2.8	7.1	8.2	5.2

In September 2016, MCCP provided CORINTHE Engineering with storm wave data recorded at the Ashdod port station during the period December 2015 to February 2016.

As example, the time series of wave height data is presented in the figure below for the period 27/12/2015 to 11/01/2016.

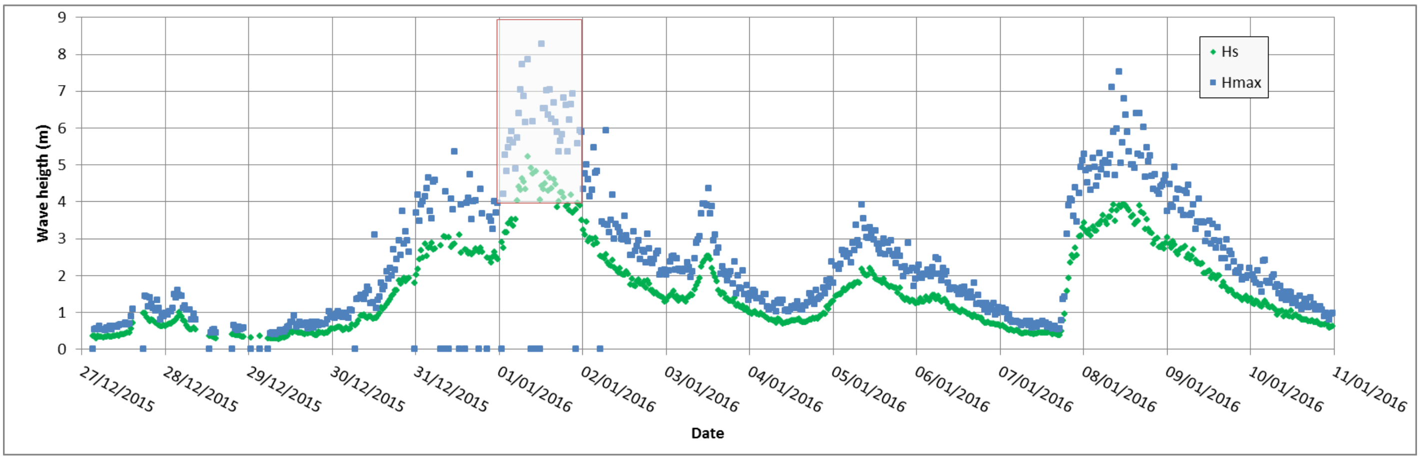


Figure 6. Wave height data recorded at Ashdod wave station

During this period, the beach experienced 5 storms with maximum significant wave heights ranging from 4m to 5m:

- This confirms the height intensity of the « frequent » storms (1 to 5 year return period).
- These records confirm the average duration of the peak storm of about 24 hours.

2.3 WATER LEVELS

As provided in the "Technical Requirement" document [4], the tide levels at Ashdod (extended in Ashkelon) are presented in the table below, with a MSL at 0.3m CD and a MHWS at 0.6m CD:

Table 4: present day Ashdod levels (source "Technical requirement" [4])

Table 2-2: Present Day Ashdod Levels

Tide	Abbreviation	Elevation (m ACD)
Highest Astronomical Tide	HAT	+0.80
Mean High Water Spring	MHWS	+0.60
Mean High Water Neap	MHWN	+0.40
Mean Sea Level	MSL	+0.30
Mean Low Water Neap	MLWN	+0.10
Mean Low Water Spring	MLWS	+0.00

Hereinafter are presented the extreme water levels extracted from different database. It shows extreme water levels from 0.6 to 1.35m depending on the intensity and the database.

Table 5: comparison of extreme water level conditions depending on the source

Return Period (Year)	CORINTHE (2010) mCD North of Israel	SeaTECH (Rosen <1981) mCD Ashdod port station	Rosen (2010) mCD Ashdod port station
1	0.55	0.9	0
5			0
10	0.65	1.15	0.1
20			0.2
25		1.25	
50	0.75	1.30	0.5
100	0.85	1.35	1.0

This data shows that, while the tendency of storm surge increase with the intensity is coherent, the values are variable between the different dataset.

In a attempt to specify the storm surge values, CORINTHE Engineering analyzed time series of water levels from the website http://ioc-sealevelmonitor.ing.org/. Extracted data at Ashkelon port station show that data is generally not available, or not exploitable, during a storm event. However, this lead to think that consequent surge might be associated with storm events. As example, the time series below correspond to the periods December 2015, January and February 2016, with storm events experienced; especially the 1st, 19th and 25th of January and the 23rd of February.

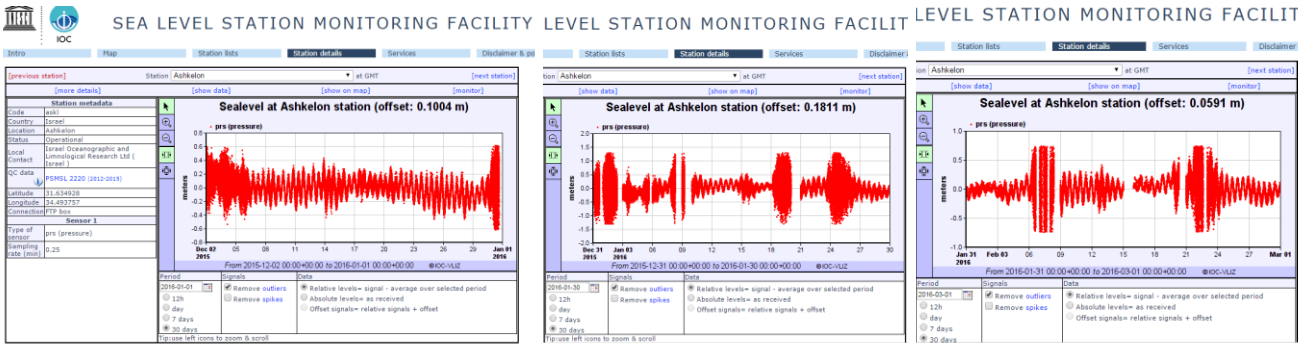


Figure 7. Recoded water levels at Ashkelon port station, period December 2015 to February 2016

Same observations (figures below) can be made from Ashdod and Hadera port station water level data, when available.

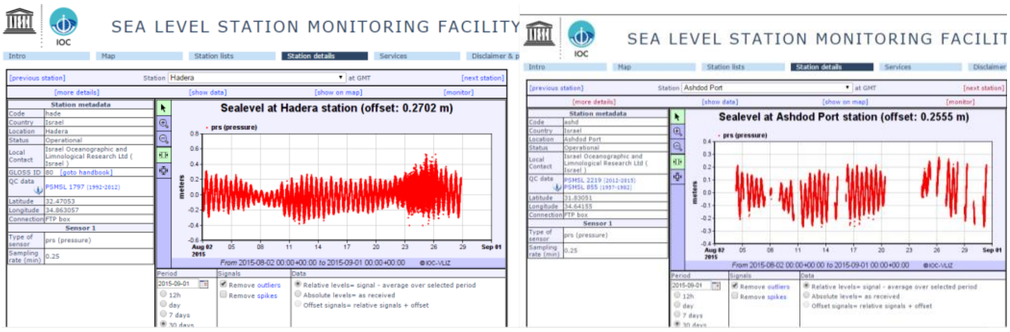


Figure 8. Recoded water levels at Hadera and Ashdod port station

2.4 EXTREME WATER LEVELS AND WAVES (PROJECT DESIGN CONDITIONS)

In order to take into account storm surge variabilities, the following water levels will be associated with the following offshore wave conditions for post storm beach erosion studies and geotextile stability calculations.

Table 6: Extreme water level and wave conditions for the project design

Return Period (Year)	Water levels (m CD)	Offshore wave conditions		
		Hs (m)	Tp (s)	Dir (°N)
1	0.6 - 0.9	4.8	11.5	290
5	0.6 - 1.0	6.2	13	290
10	0.6 - 0.8 - 1.2	6.8	13.5	290
20	0.6 - 0.8 - 1.2	7.4	14	290
50	0.6 - 1.0 - 1.3	8.2	15	290
100	0.6 - 1.0 - 1.4	8.7	15.5	290

2.5 CONSIDERATIONS REGARDING EXTREME CONDITIONS AND ASSOCIATED RISKS

In order to provide information for decision making, the table below details the percentage of risk associated with a given Return Period (RP) of a storm event. This is considering a duration of 10 years.

For a 1 year RP, it is almost certain that such a storm will happen during in 10 years and for the 10 year RP, the risk is almost 2/3.

Table 7: Extreme event and associated risks for a 10 year duration

Duration: 10 years	
Return period	Percentage of risk
1	100%
5	86%
10	63%
20	39%
50	18%
100	10%

3 SCENARIOS AND SIMULATIONS

From the already calibrated model, we had to run several scenarios of protection of the area 39.

In the following sections, the shoreline is linked to the 0mCD line.

3.1 PRESENTATION (SCENARIOS RUN IN THE MODEL)

At first, to get a good view on the effectiveness of the reef in relation to their location, we organize scenarios with different implantations of the geotubes structures.

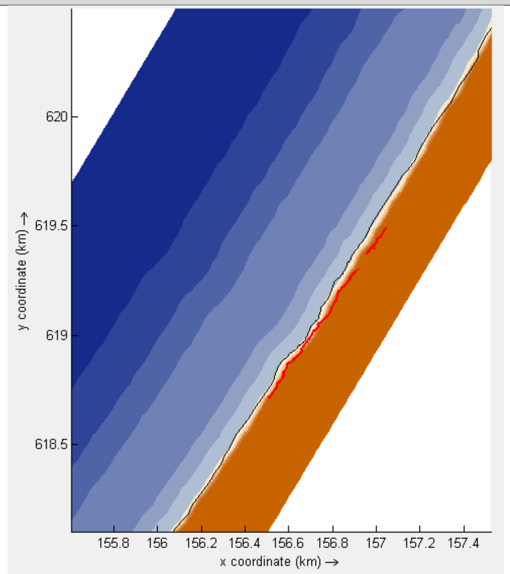
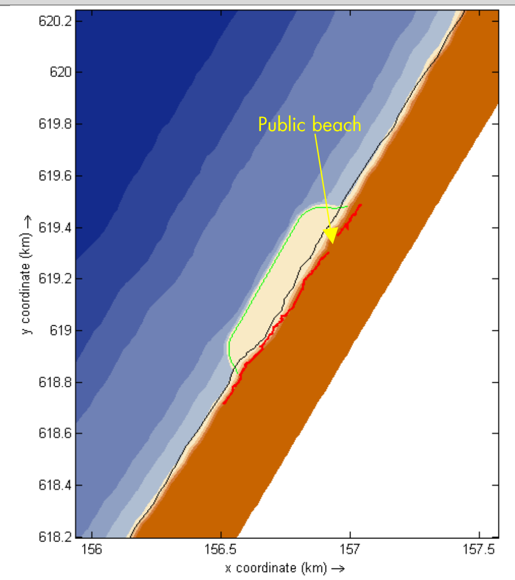
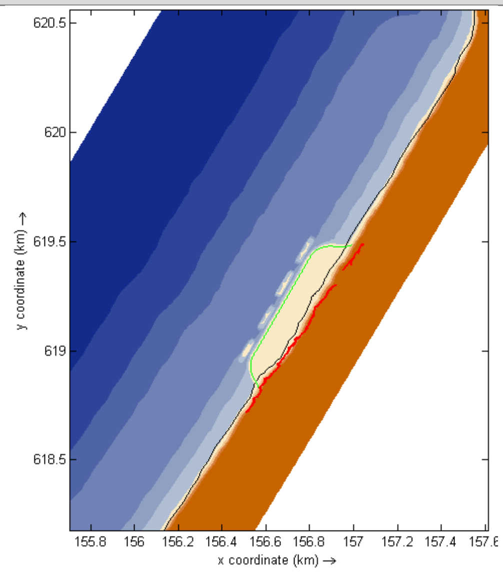
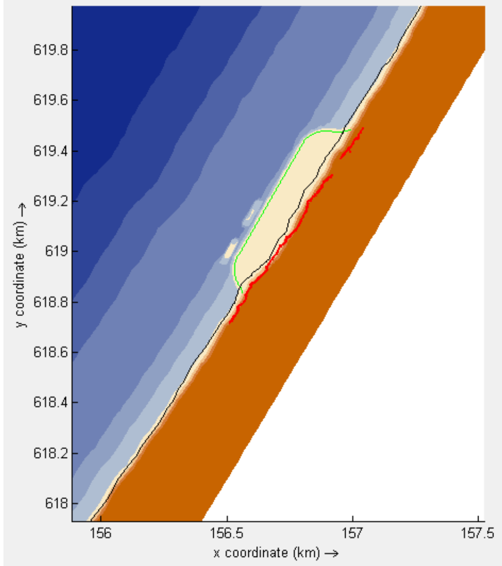
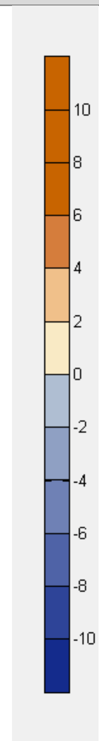
We model also two scenarios without any reef to compare with geotubes solutions.

The structures are all positioned parallel to the shoreline as in the studies carried out by Moffat and Nichols.

Therefore, we first simulated the following solutions:

Table 8: characteristics of initial studied scenarios (Scenario 1; 2 and 3)

	Scenario 1 (C2)	Scenario 2 (C1)	Scenario 3 (C6)
Nourishment (m3)	310 000	310 000	310 000
Elevation of the beach nourishment (mCD)	+1.5	+1.5	+1.5
Number of Breakwater	0	4	2
Breakwater length (m)	-	96 to 110	96 and 100
Assumed breakwater crest width (m)	-	15	15
Gap length (m)	-	80 to 70 From south to north	80
Breakwater crest level (mCD)	-	0	0
Seaward toe level of the breakwater (mCD)	-	-4	-4
Initial berm width (width of the dry beach)	128 to 140 From south to north	128 to 140 From south to north	128 to 140 From south to north

Actual case	Scenario 1 : T0	Scenario 2 : T0	Scenario 3 : T0	Bed level (mCD)
				
— Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	— Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	— Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	— Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	

For all those solutions, we keep the d50 determined in the calibration studies: 0.25 mm.

The purpose of those simulations was to see the influence of all the parameters.

With those solutions, we saw the influence of localization of the geotubes along the shoreline.

We added some other modeling to see the influence of the other parameters:

- Orientation of the geotubes
- Depth D of the geotubes location
- Crest level C of the geotubes
- Nourishment volume of the beach
- Width of beach nourishment

For this study, the different configurations are as follow, indicating the different parameters values used for the sensitivity analysis.

Table 9: characteristics of studied configurations for sensitivity analysis purpose (scenario 4 and 5)

- Evaluation of the influence of the depth of localization of the geotubes (comparison solution 3 with solution 4)
- Evaluation of the influence of the breakwater crest elevation (comparison solution 4 with solution 5)

	Scenario 4 (C13)	Scenario 5 (C14)
Nourishment (m^3)	310 000	310 000
Elevation of the beach nourishment (mCD)	+1.5	+1.5
Number of Breakwater	2	2
Breakwater length (m)	96 and 100	96 and 100
Assumed breakwater crest width (m)	15	15
Gap length (m)	80	80
Breakwater crest level (mCD)	0	-1.0
Seaward toe level of the breakwater (mCD)	-5	-5
Initial berm width (width of the dry beach)	128 to 140 From south to north	128 to 140 From south to north

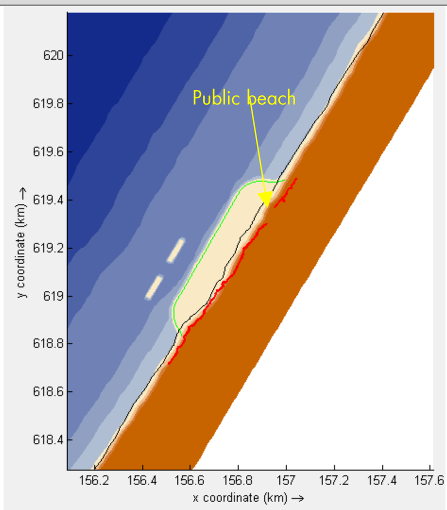
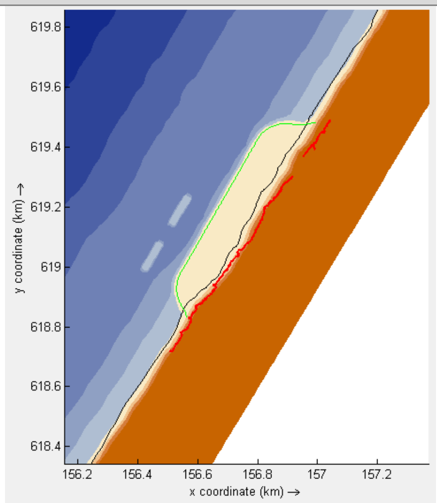
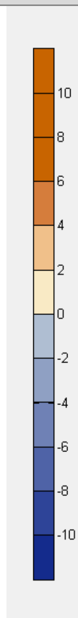
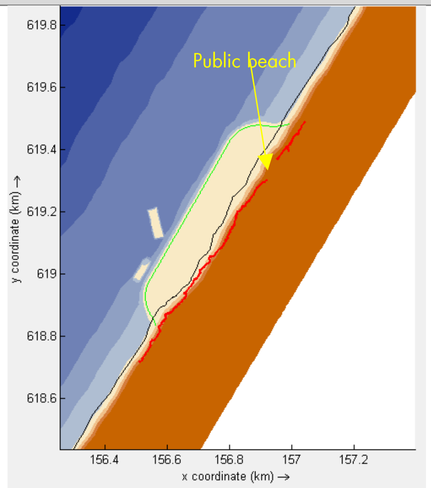
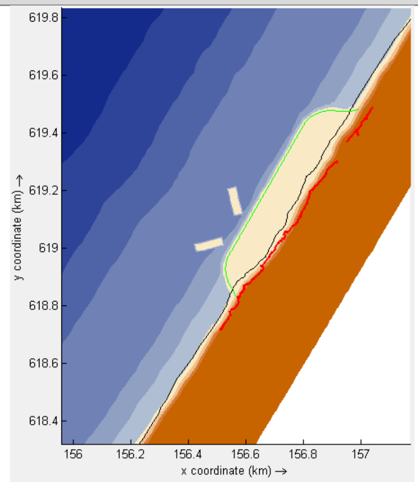
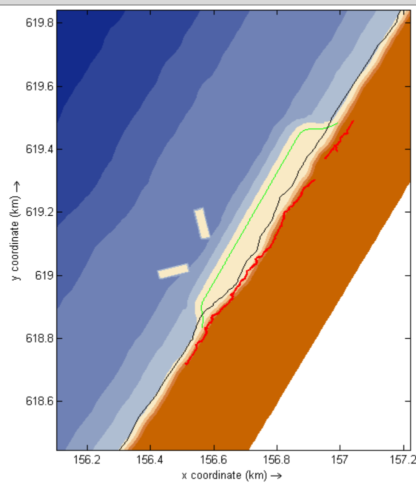
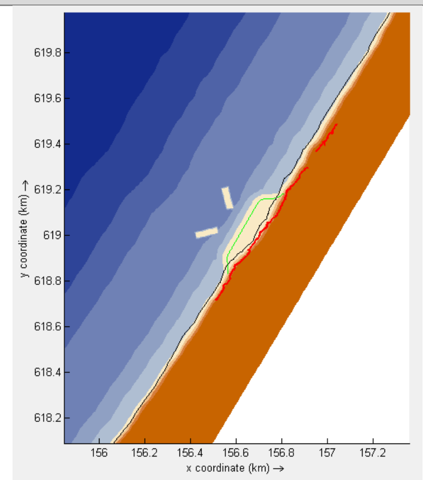
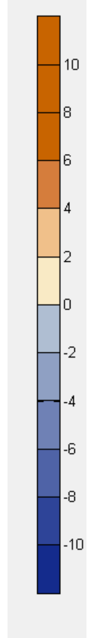
Scenario 4 : T0	Scenario 5 : T0	Bed level (mCD)
 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	

Table 10: characteristics of studied configurations for sensitivity analysis purpose (scenario 6; 7; 8 and 9)

- Evaluation of the influence of the geotubes orientation: (comparison solution 3, solution 6 and solution 7)
- Evaluation of the influence of the nourishment volume beach : (comparison solution 7, solution 8, solution 9)

	Scenario 6 (C9)		Scenario 7 (C16)		Scenario 8 (C15)		Scenario 9 (C18)	
Nourishment (m³)	310 000		310 000		206 000		142300	
Elevation of the beach nourishment (mCD)	+1.5		+1.5		+1.5		+1.5	
Number of Breakwater	2		2		2		2	
Breakwater length (m)	South 96	North 90	South 90	North 90	South 90	North 90	South 90	North 90
Assumed breakwater crest width (m)	15	23	23	23	23	23	23	23
Gap length (m)	80		96		96		96	
Breakwater crest level (mCD)	0		0		0		0	
Seaward toe level of the breakwater (mCD)	-4	-4 to -5	-4 to -5	-4 to -5	-4 to -5		-4 to -5	
Initial berm width (width of the dry beach)	128 to 140 From south to north		74 to 88 From south to north		74 to 88 From south to north		74 to 88 From south to north	

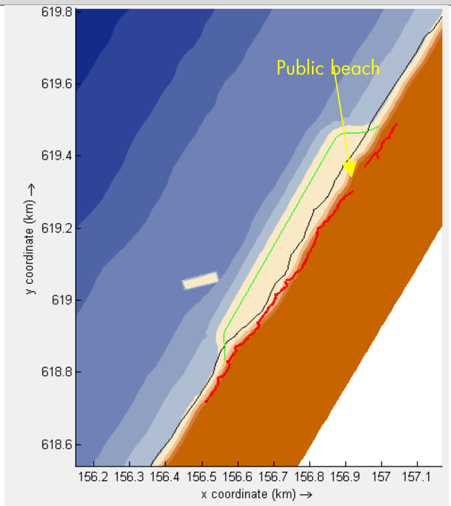
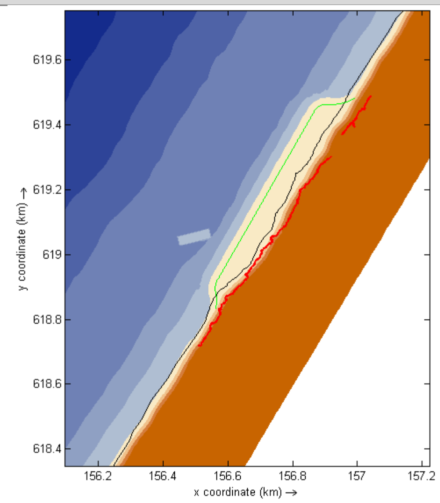
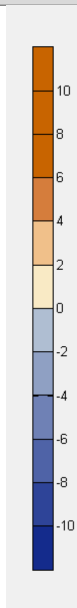
Scenario 6 : T0	Scenario 7 : T0	Scenario 8 : T0	Scenario 9 : T0	Bed level (mCD)
 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	

Finally, a scenario consisted in the placement of a single reef immersed in a geotube positioned at the right of the most critical zone to be protected with a nourishment of the most suitable beach in view of the results previously obtained and presented in the following, in this report.

Table 11: characteristics of studied configurations for sensitivity analysis purpose (scenario 10 and 11)

- Evaluation of the installation of a single breakwater and evaluation influence of the level of the crest of this breakwater : (comparison solution 10 with solution 11)

	Scenario 10 (C20)	Scenario 11 (C21)
Nourishment (m^3)	206 000	206 000
Elevation of the beach nourishment (mCD)	+1.5	+1.5
Number of Breakwater	1	1
Breakwater length (m)	90	90
Assumed breakwater crest width (m)	23	23
Gap length (m)	/	/
Breakwater crest level (mCD)	0	-0.2
Seaward toe level of the breakwater (mCD)	-4 to -5	-4 to -5
Initial berm width (width of the dry beach)	74 to 88 From south to north	74 to 88 From south to north

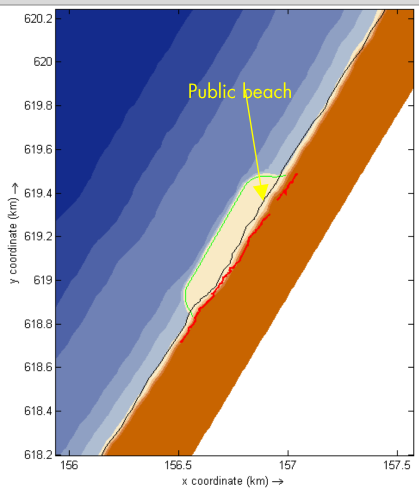
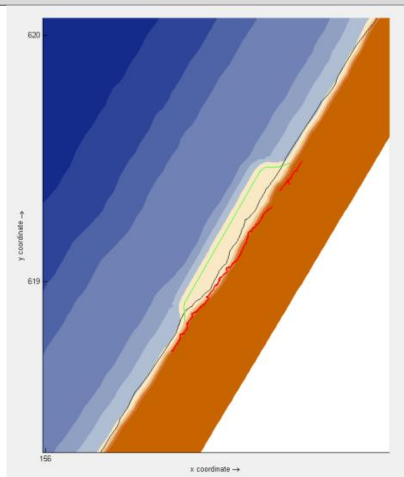
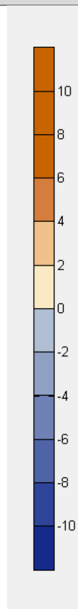
Scenario 10 : T0	Scenario 11 : T0	Bed level (mCD)
 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	

<u>Special case of beach nourishment without the installation of protective structures</u>

A sensitivity study was carried out on the particular case of a nourishment of the beach with different nourishment volumes in order to evaluate the impact on maintaining the coastline.

Table 12: characteristics of studied configurations for sensitivity analysis purpose (scenario 1 and 12)

- Evaluation of the influence of the nourishment volume beach without the installation of protective structures: (comparison solution 1 with solution 12)		
	Scenario 1 (C2)	Scenario 12 (C3)
Nourishment (m³)	310 000	206 000
Elevation of the beach nourishment (mCD)	+1.5	+1.5
Number of Breakwater	0	0
Breakwater length (m)	-	-
Assumed breakwater crest width (m)	-	-
Gap length (m)	-	-
Breakwater crest level (mCD)	-	-
Seaward toe level of the breakwater (mCD)	-	-
Initial berm width (width of the dry beach)	128 to 140 From south to north	74 to 88 From south to north

Scenario 1: T0	Scenario 12 : T0	Bed level (mCD)
 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	

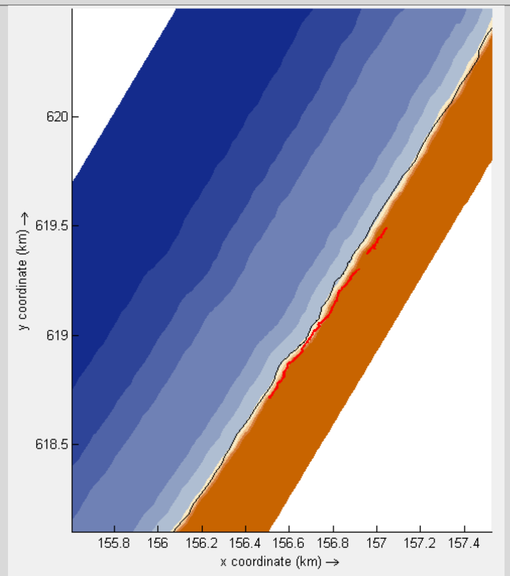
Moreover, a sensitivity study on the size of the sand grains was carried out on scenario 12 with a d50 taken equal to 0.36 mm.

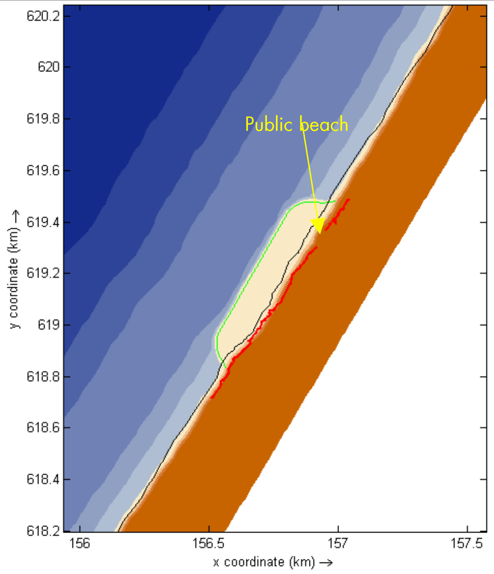
3.2 RESULTS AND SUM-UP

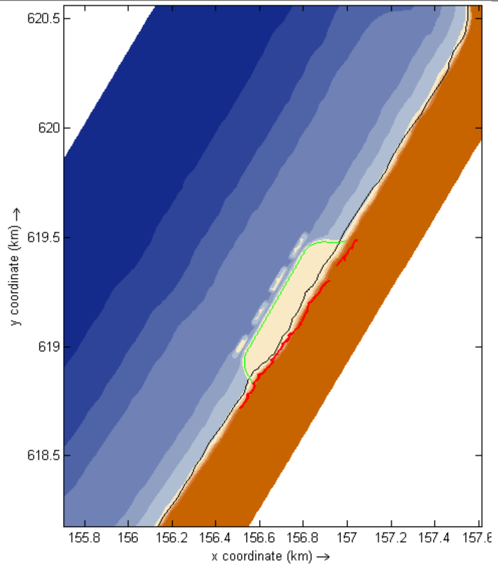
3.2.1 Localization of the breakwaters along the coast line

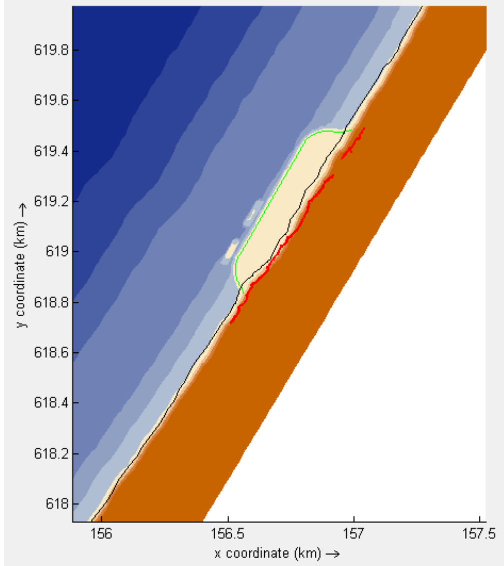
The simulations of scenarios 1, 2 and 3 made it possible to realize the influence of the positioning of breakwaters along the shoreline on the behavior of the beach.

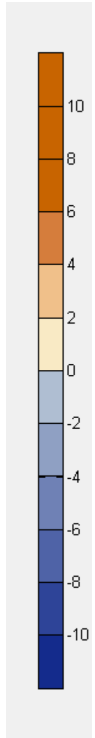
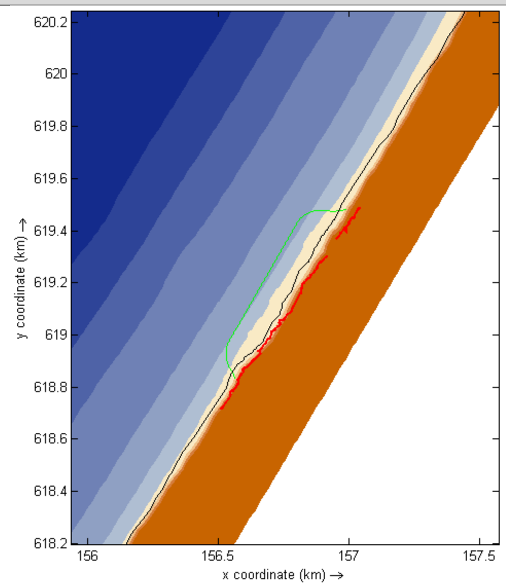
In the table below, the results of the simulations are reported, after 10 years of simulation and in particular the evolution of the beach nourishment.

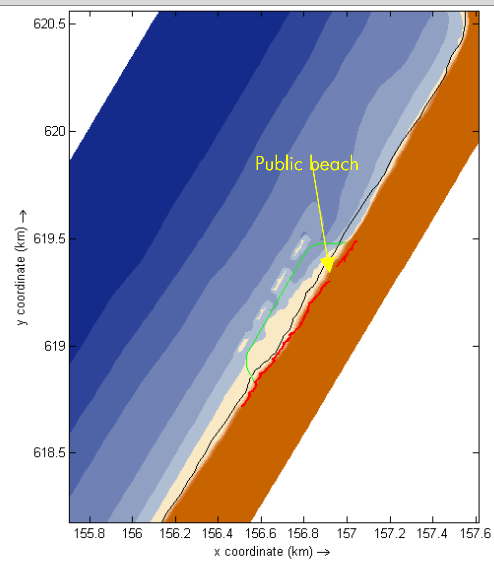
<table>
<tr><th>Actual case</th><th>Scenario 1 : T0
(C2)</th><th>Scenario 2 : T0
(C1)</th><th>Scenario 3 : T0
(C6)</th><th>Bed level
(mCD)</th></tr>
<tr>
<td>

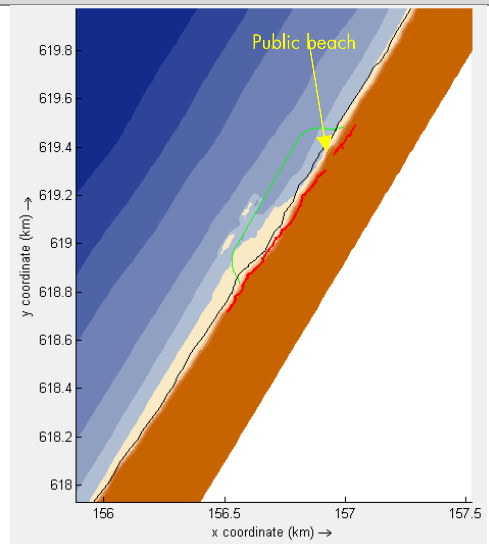
— Initial coastline T0
— Cliffs</td>
<td>

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
<td>

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
<td>

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
<td rowspan="3">
</td>
</tr>
<tr><td></td><td>Scenario 1 : T0+10 years</td><td>Scenario 2 : T0+10 years</td><td>Scenario 3 : T0+10 years</td></tr>
<tr>
<td></td>
<td>

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
<td>

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
<td>

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
</tr>
</table>

Figure 9. Simulations results: scenarios 1, 2 and 3

Observations :

Scenario S1:

A retreat of the coast line, at the recharge zone (initial width beach and after 10 years of simulation are shown in the below table).

A slight nourishment of the beach south of the initial nourishment zone by sediment transit (initial width beach and after 10 years of simulation are shown in the below table).

Scenario S2:

A retreat of the coast line, at the recharge zone (initial width beach and after 10 years of simulation are shown in the below table).

A significant decline of the coast line north of the recharge zone.

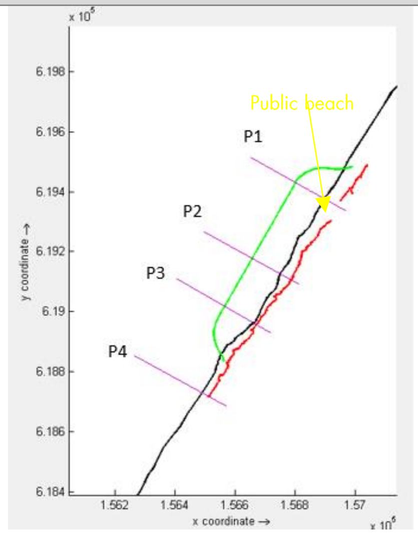
A nourishment of the beach south of the initial nourishment zone by sediment transit (initial width beach and after 10 years of simulation are shown in the below table).

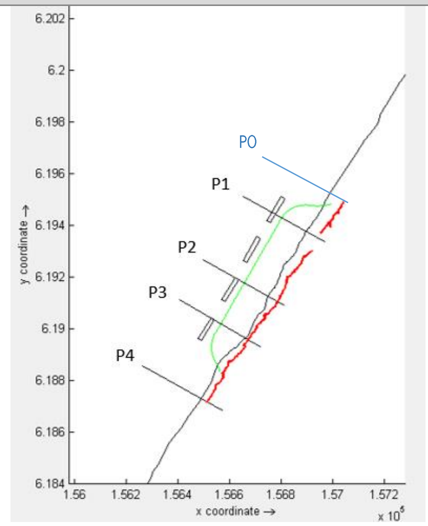
Scenario S3:

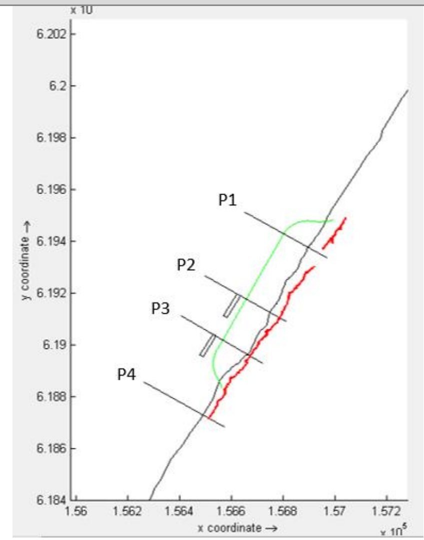
Total sediment loss over the entire recharged area but not protected by breakwaters.

A nourishment of the beach south of the initial nourishment zone by sediment transit (initial width beach and after 10 years of simulation are shown in the below table).

Four profiles were drawn along the recharge zone on each scenario, in order to be investigate the evolution of the coastline. The values obtained are also reported in the table below.

<table>
<tr><th colspan="12">Comparison of the evolution of beach profiles S 1; 2 and 3</th></tr>
<tr><th colspan="4">Scenario 1
(C2)</th><th colspan="4">Scenario 2
(C1)</th><th colspan="4">Scenario 3
(C6)</th></tr>
<tr><td colspan="4">

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
<td colspan="4">

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
<td colspan="4">

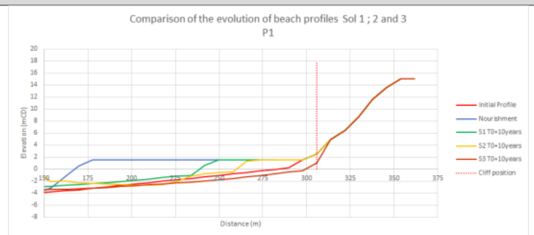
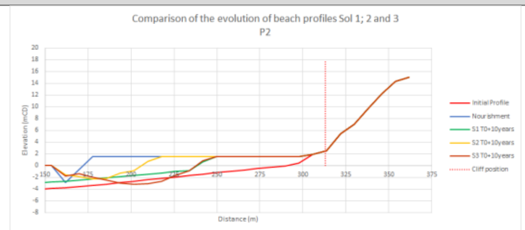
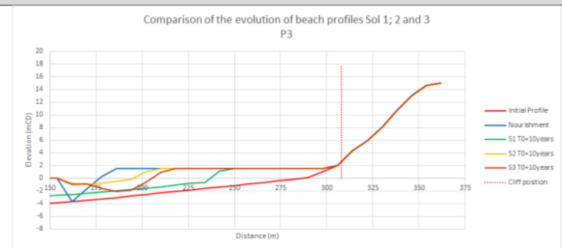
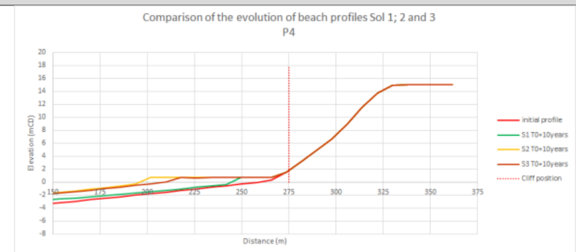
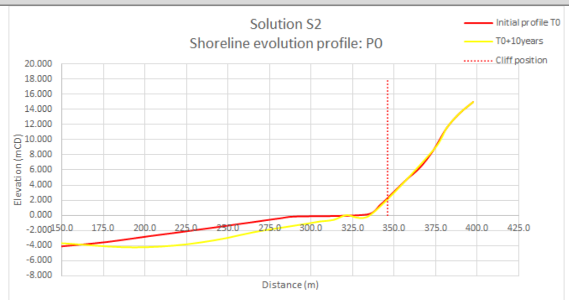
— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td></tr>
<tr><th colspan="3">Profile P1</th><th colspan="3">Profile P2</th><th colspan="3">Profile P3</th><th colspan="3">Profile P4</th></tr>
<tr><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><th colspan="3">Profile P0 (scenario 2)</th><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">
</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
</table>

Figure 10. Simulation results: scenarios 1, 2 and 3 – comparison of the evolution of beach profiles (P1, P2, P3, P4 and P0 on the scenario 2)

Table 13: table of comparison between the scenarios 1, 2 and 3

Aera	Case	Layout description	Nourishment volume (m³)	Initial beach berm width (m) from the cliff toe line				Beach berm width after 10 years (m) from the cliff toe line				Receding coastline out of protected area
				P1	P2	P3	P4	P1	P2	P3	P4	P0
39	S1	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 0 D50 0.25mm	310 000 m³	140m Elevation E≥+1.5mCD	140m Elevation E≥+1.5mCD	128m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	56m Elevation E≥+1.5mCD	64m Elevation E≥+1.5mCD	56m Elevation E≥+1.5mCD	30m Elevation E≥ 0.0mCD	/
	S2	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 4 Elevation of berm structures: 0.0mCD Depth of implantation: -4.0mCD Breakwaters length (m): 96 to 110 Gap : 80 to 70 (From south to north) D50 0.25mm	310 000 m³	140m Elevation E≥+1.5mCD	140m Elevation E≥+1.5mCD	128m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	40m Elevation E≥+1.5mCD	96m Elevation E≥+1.5mCD	96m Elevation E≥+1.5mCD	80m Elevation E≥ 0.0mCD	**Localization:** North of the protected area. **Initial beach berm width:** 32m E≥ 0.0mCD **Beach berm width after 10 years:** 24m E≥ 0.0mCD
	S3	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 2 Elevation of berm structures: 0.0mCD Depth of implantation: -4.0mCD Breakwaters length (m): 96 and 110 Gap: 80m D50 0.25mm	310 000 m³	140m Elevation E≥+1.5mCD	140m Elevation E≥+1.5mCD	128m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	0m Erosion up the cliff	64m Elevation E≥+1.5mCD	88m Elevation E≥+1.5mCD	64m Elevation E≥ 0.0mCD	/

Conclusion on scenarios 1, 2 and 3:

These simulations show that the location of the submerged breakwaters along the coast plays a significant role.

Indeed:

- With the installation of 4 breakwaters (scenario 2), there is an erosion of the beach in the North. Probably by extending the nourishment area of the beach on this area, the closeness with the cliff would be less important. In the area protected by the breakwaters, the beach width (width where the elevation remains of the order of +1.5mCD) is maintained between 40m and 96m approximately, after 10 years.
- With the installation of two breakwaters in the southern zone and a reloading identical to scenario 2 (scenario 3), we also observe a shrinkage of the beach, compared to the initial beach width with the nourishment, in particular on the northernmost zone (P1 profile), where the coastline after 10 years reaches the cliff.
  In the area protected by the breakwaters, the beach width (width where the elevation remains of the order of + 1.5mCD) is maintained between 64m and 88m approximately.
- In the absence of breakwaters and with an identical initial beach nourishment to scenarios 2 and 3, there is a general loss of sediment over the entire recharged area with beach widths after 10 years of simulation (beach width berm between 56m and 64m). Nevertheless, the Xbeach model does not take into account of the reflective phenomena, which occurs at the level of profile P3 with the presence at the right of this profile of a wall, it is probable that at this point the phenomena of reflection which induce to a more marked loss of sediment than presented by the modelling.

In each simulated scenario, a portion of the beach nourishment is transited southward (profile P4) with a relocation of the coast line to the sea.

Finally, in general, it is preferable to maintain the location of the geotubes closest to the zone to be protected in the South and more particularly to the right of the 400 ml of zone to be protected

These simulations show the evolution of the coastline after 10 years of simulations and the climatology retained. At this stage, no simulation of independent wave events was carried out.

3.2.2 Depth of the geotubes installation and crest elevation

By comparing the simulations of scenarios 3 and 4, it's possible to realize the influence of the depth positioning of breakwaters.

In addition, scenarios 4 and 5 evaluate the influence of breakwater berm elevation on the maintenance of the coastline.

In the table below, the results of the simulations are reported, after 10 years of simulation and in particular the evolution of the beach recharge.

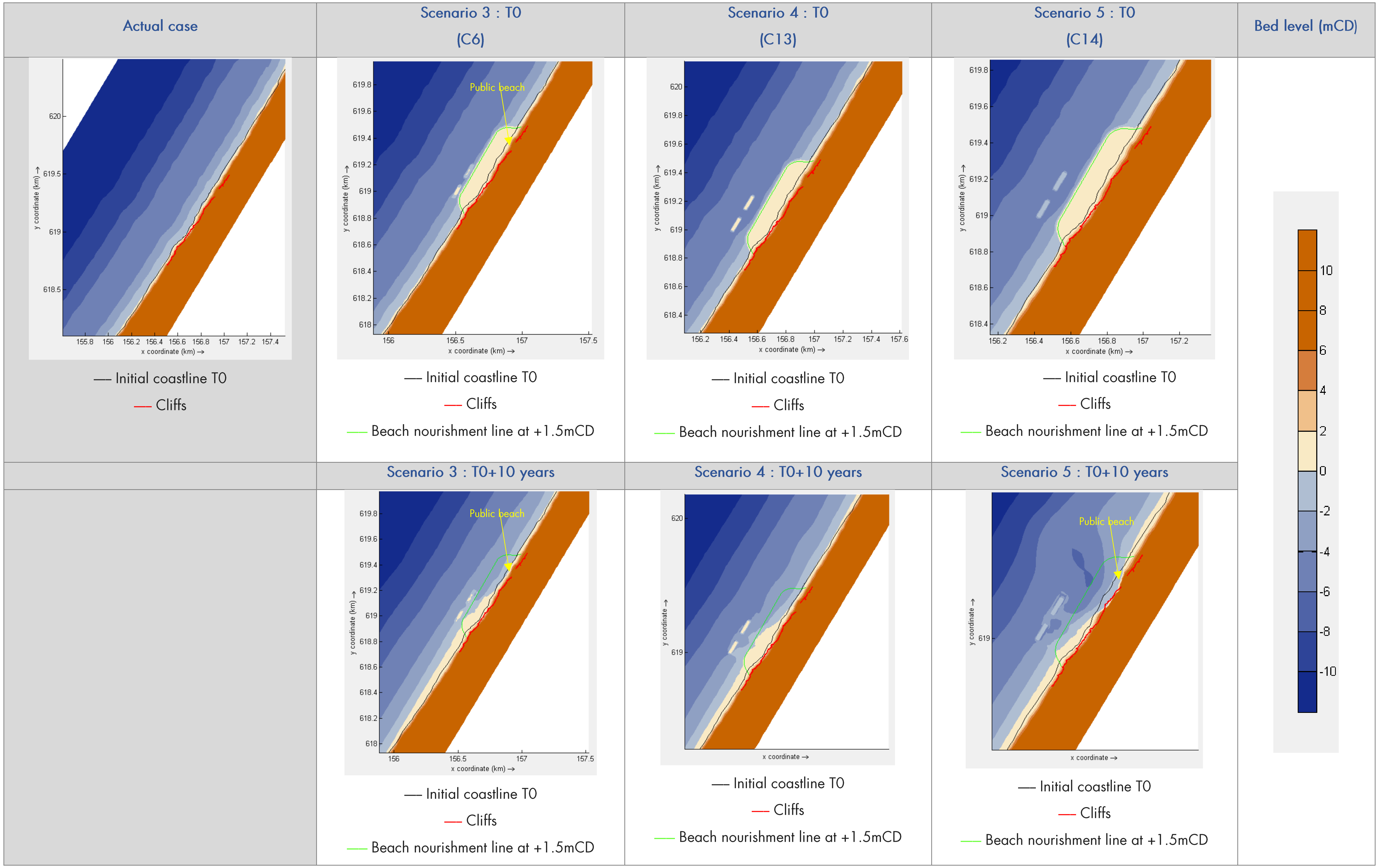


Figure 11. Simulations results: scenarios 3, 4 and 5

Observations:

Scenario S3 and S4:

Total sediment loss over the entire recharged area but not protected by breakwaters.

A nourishment of the beach south of the initial nourishment zone by sediment transit (initial width beach and after 10 years of simulation are shown in the below table).

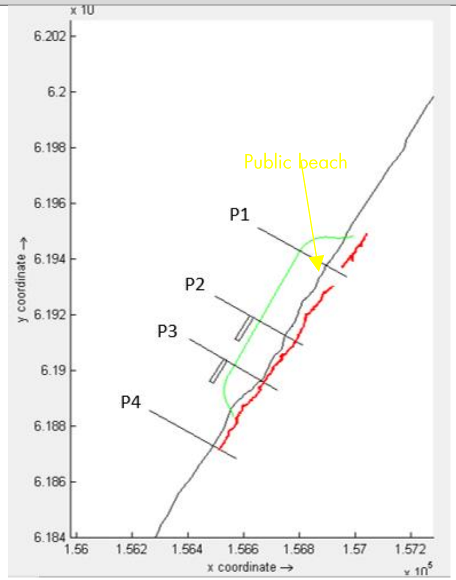
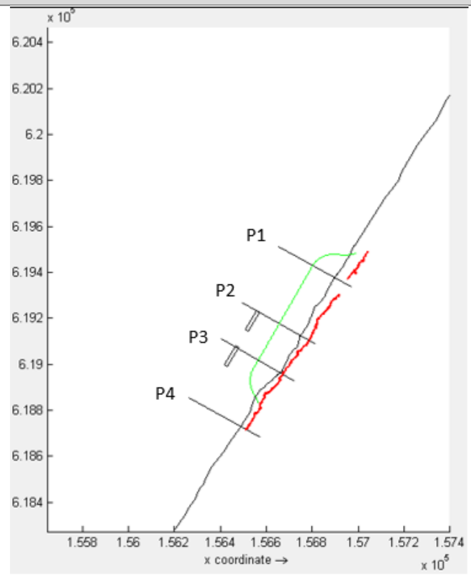
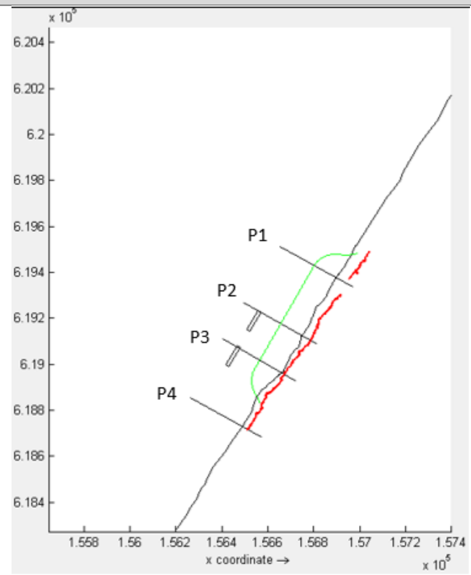
Scenario S5:

A retreat of the coast line, at the recharge zone (initial width beach and after 10 years of simulation are shown in the below table).

A significant decline of the coast line north of the recharge zone.

A nourishment of the beach south of the initial nourishment zone by sediment transit (initial width beach and after 10 years of simulation are shown in the below table).

Four profiles were drawn along the recharge zone on each scenario, in order to be aware of the evolution of the coastline. The values obtained are also reported in the table below.

Comparison of the evolution of beach profiles 3; 4 and 5		
Scenario 3 (C6)	Scenario 4 (C13)	Scenario 5 (C14)
 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD

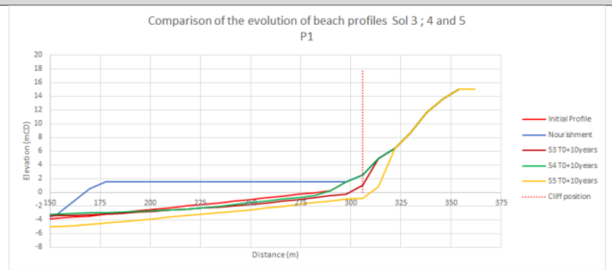
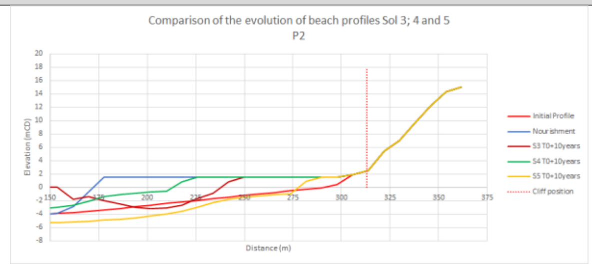
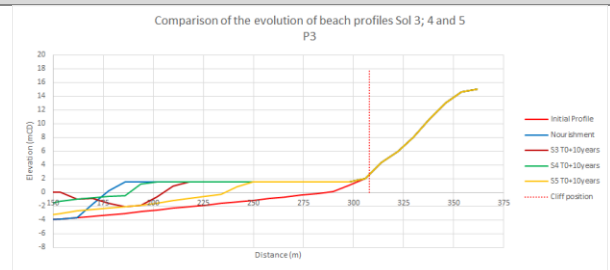
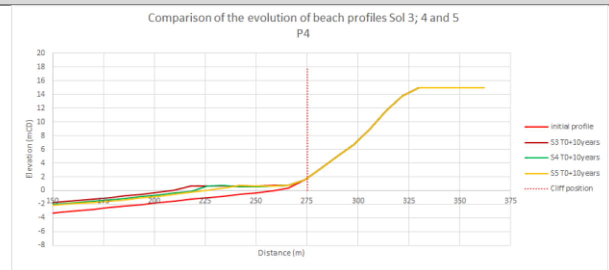
Profile P1	Profile P2	Profile P3	Profile P4
			

Figure 12. Simulation results: scenarios 3, 4 and 5 – comparison of the evolution of beach profiles (P1, P2, P3, P4)

Table 14: table of comparison between the scenarios 3, 4 and 5

Aera	Case	Layout description	Nourishment volume (m^3)	Initial beach berm width (m) from the cliff toe line				Beach berm width after 10 years (m) from the cliff toe line				Receding coastline out of protected area
				P1	P2	P3	P4	P1	P2	P3	P4	P0
39	S3	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 2 Elevation of berm structures: 0.0mCD Depth of implantation: -4.0mCD Breakwaters length (m): 96 and 110 Gap: 80m D50 0.25mm	310 000 m^3	140m Elevation E≥+1.5mCD	140m Elevation E≥+1.5mCD	128m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	0m Erosion up the cliff	64m Elevation E≥+1.5mCD	90m Elevation E≥+1.5mCD	64m Elevation E≥ 0.0mCD	/
	S4	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 2 Elevation of berm structures: 0.0mCD Depth of implantation: -5.0mCD Breakwaters length (m): 96 and110 Gap : 80 D50 0.25mm	310 000 m^3	140m Elevation E≥+1.5mCD	140m Elevation E≥+1.5mCD	128m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	8m Elevation E≥+1.5mCD	88m Elevation E≥+1.5mCD	106m Elevation E≥+1.5mCD	56m Elevation E≥ 0.0mCD	/
	S5	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 2 Elevation of berm structures: -1.0mCD Depth of implantation: -5.0mCD Breakwaters length (m): 96 and110 Gap : 80 D50 0.25mm	310 000 m^3	140m Elevation E≥+1.5mCD	140m Elevation E≥+1.5mCD	128m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	-8m to -12m Erosion of the cliff	24m Elevation E≥+1.5mCD	58m Elevation E≥+1.5mCD	48m Elevation E≥ 0.0mCD	/

Conclusions:

- Influence of depth of implantation of submerged breakwaters:

Between scenario 3 and scenario 4, it is observed that the distance of the positioning of the breakwaters by depths of the order of -5.0mCD (scenario 4) instead of -4.0mCD (scenario 3) maintaining an elevation from the crest of the structure to the 0.0mCD coast, improves the shoreline stability in the protected area.

In the unprotected zone to the north (towards profile P1), erosion remains of the same order of magnitude with a beach width after 10 years of the order of 8m for scenario 4 (with a berm elevation than or equal to 1.5mCD) against 0m for scenario 3 (with a berm elevation than or equal to 1.5mCD and less than 4m wide if we consider a beach berm elevation greater than 0.0mCD)

- Influence of the crest elevation of the breakwater:

Between Scenarios 4 and 5, with a lowering of the level berm of the breakwater at -1.0mCD, there is a significant increase in beach erosion. The protection structure does not allow the effective detention of the sediments. At the level of the profile P1 the cliff is directly reached with an erosion of it from 8m to 12m after 10 years.

In each simulated scenario, a portion of the beach nourishment is transited southward (profile P4) with a relocation of the coast line to the sea.

In general, it will be remembered that if it is desired to maintain breakwaters parallel to the coastline, it is necessary to implant them to a depth around -5.0mCD.

Those simulations show the evolution of the coastline after 10 years of simulations and the climatology retained. At this stage, no simulation of independent wave events was carried out.

3.2.3 Orientation of the breakwaters and volume of the nourishment

By comparing the simulations of scenarios 3, 6 and 7 made it possible to realize the influence of the orientation of the breakwaters relative to the incident wave and the coastline.

In addition, scenarios 7, 8 and 9 evaluate the influence of breakwater crests elevation on the maintenance of the nourishment volume beach on the maintenance of the shoreline.

In the table below, the results of the simulations are reported, after 10 years of simulation and in particular the evolution of the beach recharge.

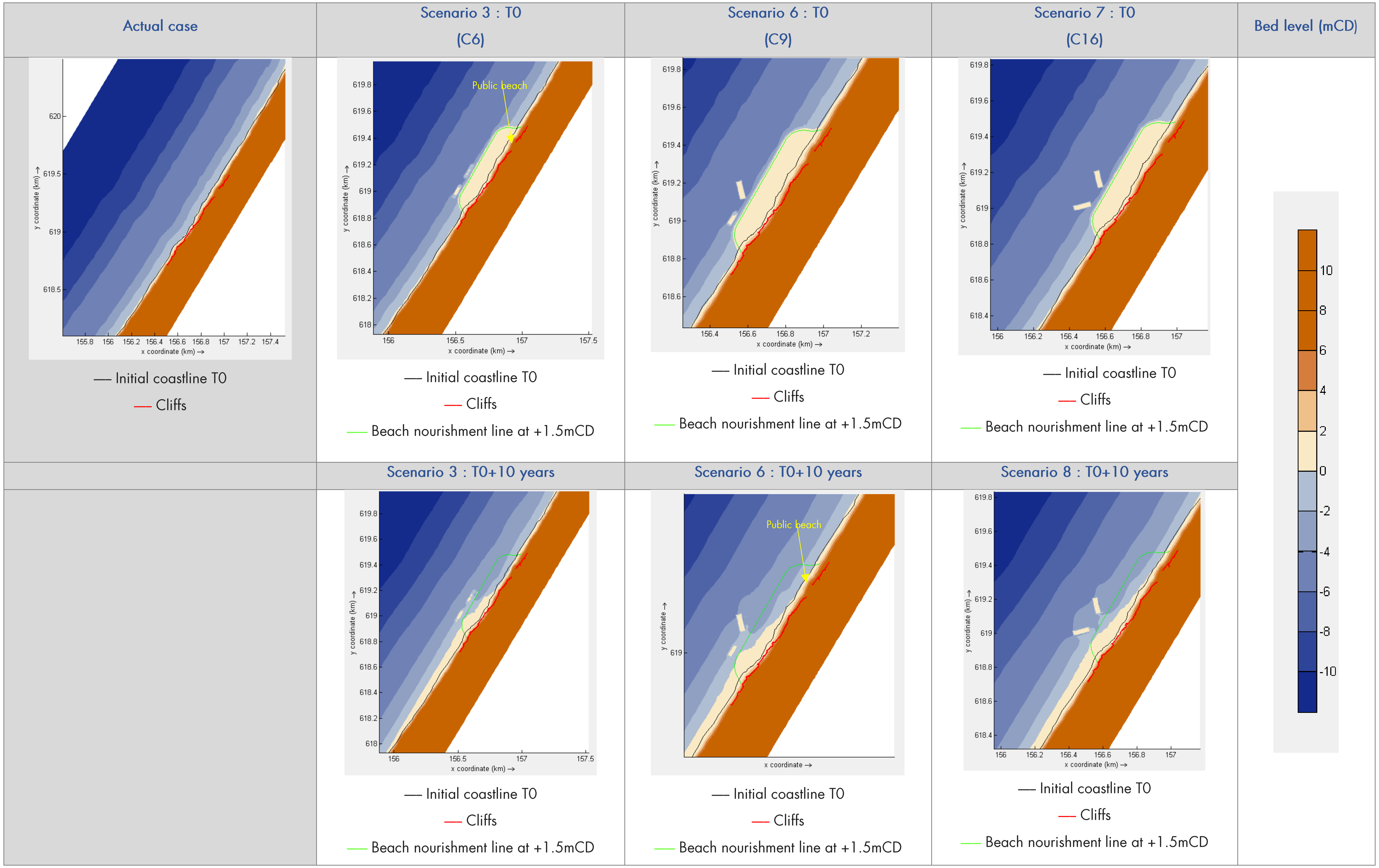


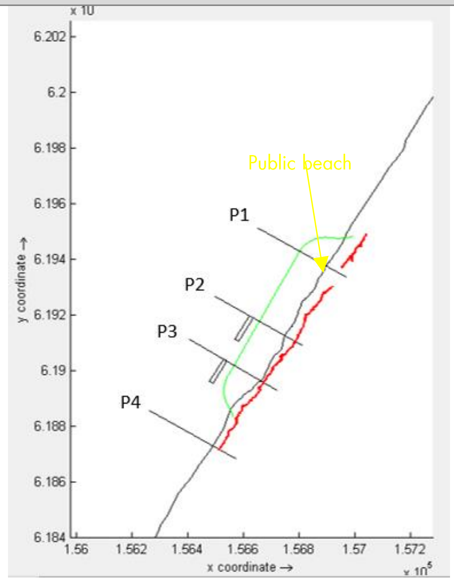
Figure 13. Simulations results: scenarios 3, 6 and 7

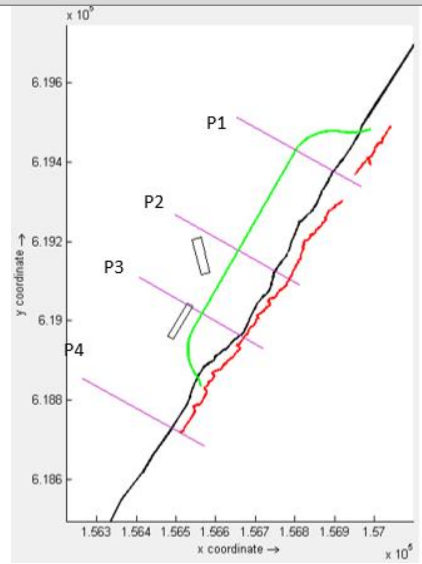
Observations:

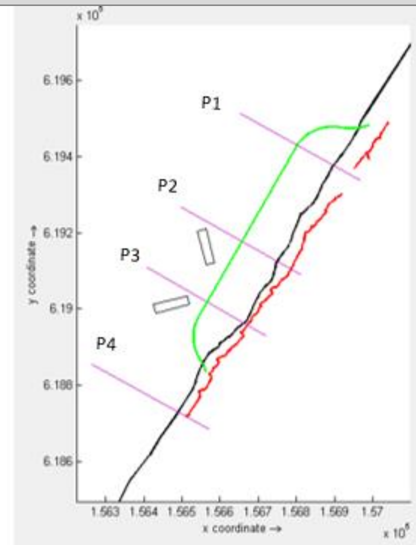
By comparing the three simulations, it can be seen that the inclination of the submerged breakwaters improves the stability of the coastline in the sensitive and unprotected zone.

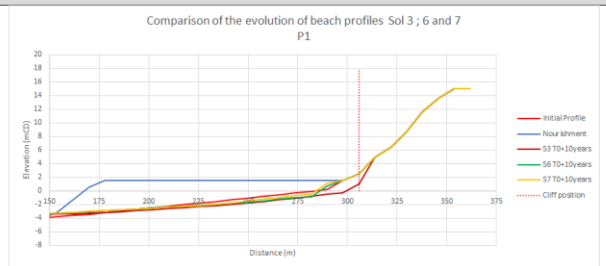
The comparison of the profiles P1, P2, P3 and P4 should allow to quantify this improvement.

Four profiles were drawn along the recharge zone on each scenario, in order to be aware of the evolution of the coastline. The values obtained are also reported in the table below.

<table>
<tr><th colspan="4">Comparison of the evolution of beach profiles 3; 6 and 7</th></tr>
<tr><th>Scenario 3
(C6)</th><th colspan="2">Scenario 6
(C9)</th><th>Scenario 7
(C16)</th></tr>
<tr>
<td>

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
<td colspan="2">

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
<td>

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
</tr>
<tr><th>Profile P1</th><th>Profile P2</th><th>Profile P3</th><th>Profile P4</th></tr>
<tr>
<td>
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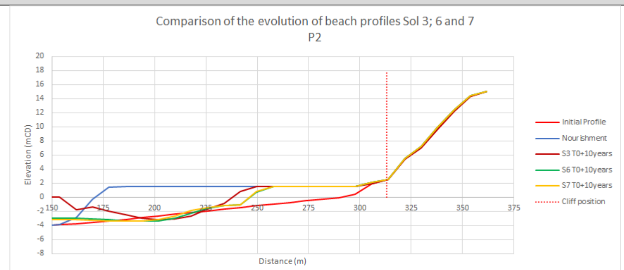
<td>
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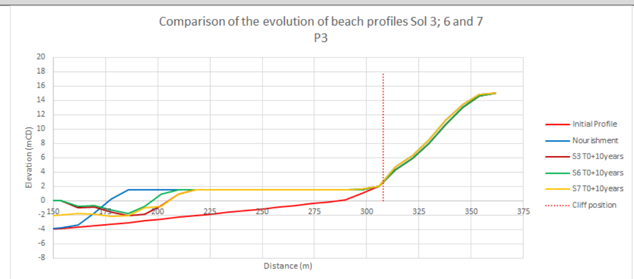
<td>
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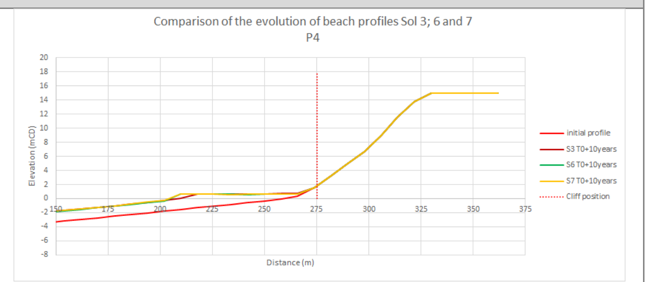
<td>
</td>
</tr>
</table>

Figure 14. Simulation results: scenarios 3, 6 and 7 – comparison of the evolution of beach profiles (P1, P2, P3, P4)

Table 15: table of comparison between the scenarios 3, 6 and 7

Aera	Case	Layout description	Nourishment volume (m³)	Initial beach berm width (m) from the cliff toe line				Beach berm width after 10 years (m) from the cliff toe line			
				P1	P2	P3	P4	P1	P2	P3	P4
39	S3	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 2 Elevation of berm structures: 0.0mCD Depth of implantation: -4.0mCD Breakwaters length (m): 96 and 110 Gap: 80m D50 0.25mm	310 000 m^3	140m Elevation E≥+1.5mCD	140m Elevation E≥+1.5mCD	128m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	0m Erosion up the cliff	64m Elevation E≥+1.5mCD	90m Elevation E≥+1.5mCD	64m Elevation E≥ 0.0mCD
	S6	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 2 Elevation of berm structures: 0.0mCD Reef parallel to the coast: Length: 96m - Width: 15m Depth of implantation: towards -4.0mCD - Gap : 80 Oblique reef: Length: 90m - Width: 23m Depth of implantation: from -4.0mCD to -5.0mCD - Gap : 80m D50 0.25mm	310 000 m^3	140m Elevation E≥+1.5mCD	140m Elevation E≥+1.5mCD	128m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	10m Elevation E≥+1.5mCD	56m Elevation E≥+1.5mCD	98m Elevation E≥+1.5mCD	70m Elevation E≥ 0.0mCD
	S7	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 2 Elevation of berm structures: 0.0mCD Depth of implantation: -4.0mCD to -5.0mCD Length: 91m - Width: 23m Gap : 96m D50 0.25mm	310 000 m^3	140m Elevation E≥+1.5mCD	140m Elevation E≥+1.5mCD	128m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	16m Elevation E≥+1.5mCD	56m Elevation E≥+1.5mCD	90m Elevation E≥+1.5mCD	70m Elevation E≥ 0.0mCD

<u>Conclusions about to the influence of the orientation of the breakwaters relative to the incident wave and the coastline</u>:

It can be seen with the profiling that the orientation of the breakwaters influences the maintenance of the coastline, in particular at the level of the profile P1. Indeed, on this profile, scenario 3 (breakwaters parallel to the coast), after 10 years, the beach no longer exists; orienting the breakwaters so as to create an angle of approximately 45 ° with respect to the shoreline, makes it possible to maintain at the level of the profile P1 a beach width between 10 and 16m on scenarios 6 and 7.

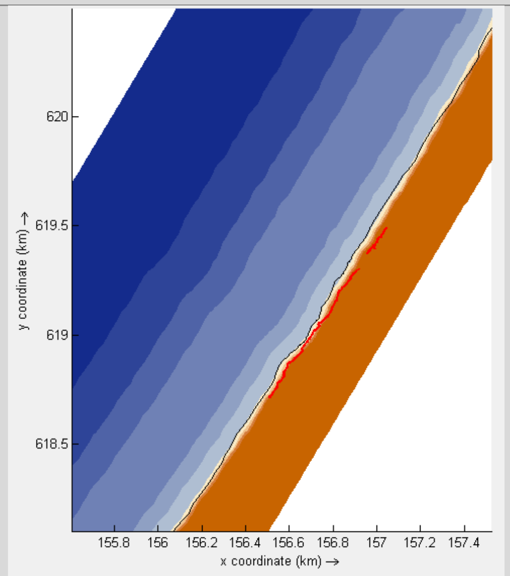
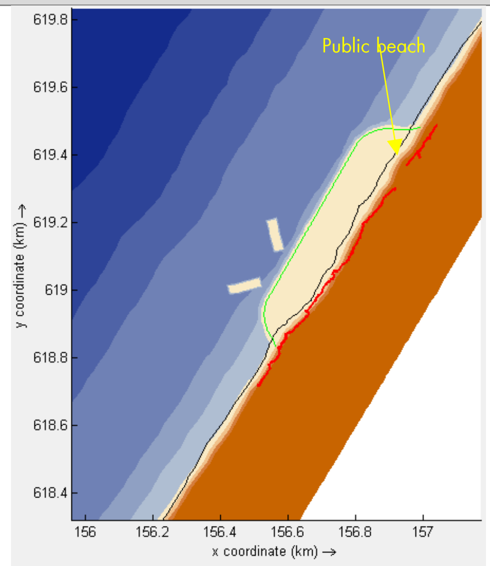
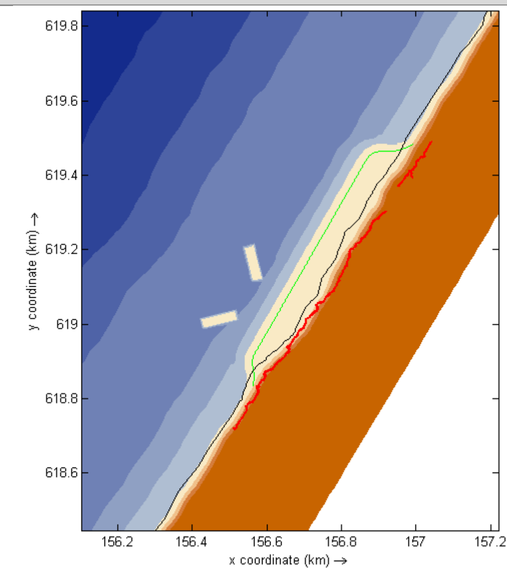
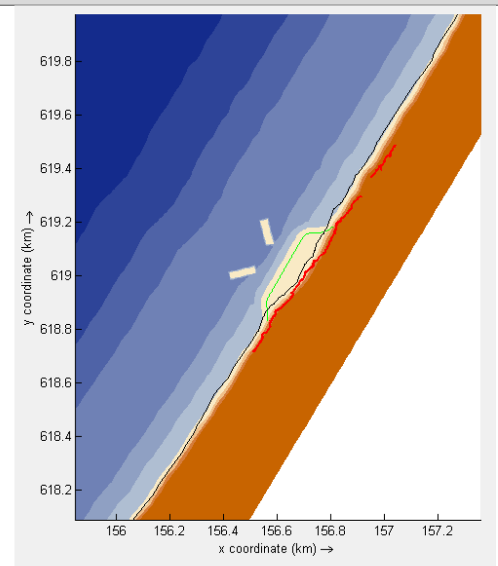
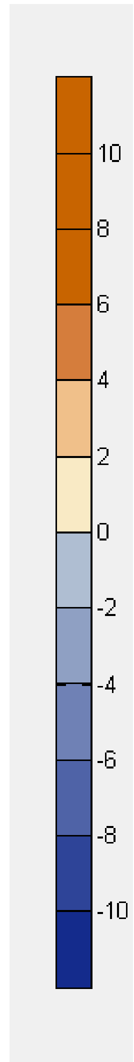
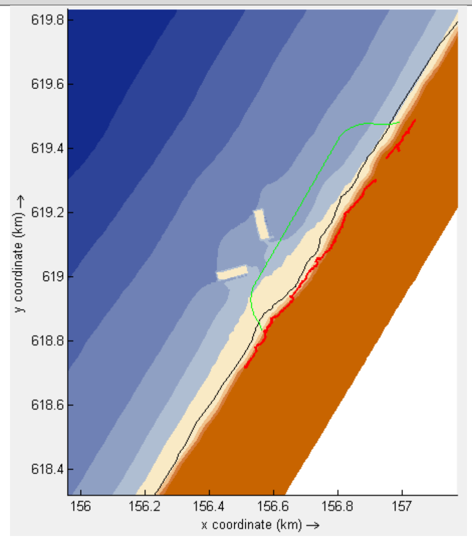
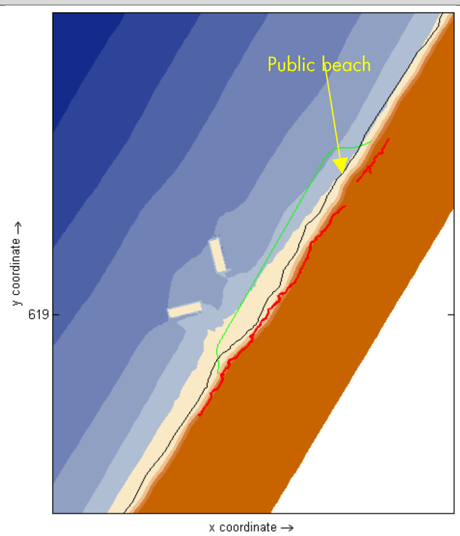
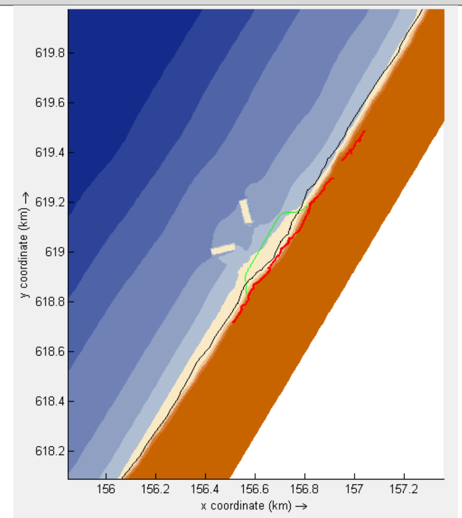
Actual case	Scenario 7 : T0 (C16)	Scenario 8 : T0 (C15)	Scenario 9 : T0 (C18)	Bed level (mCD)
 — Initial coastline T0 — Cliffs	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	
	Scenario 7 : T0+10 years	Scenario 8 : T0+10 years	Scenario 9 : T0+10 years	
	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	

Figure 15. Simulations results: scenarios 7, 8 and 9

Observations:

As a reminder, the volumes of nourishment are the following:

Scenario 7: 310 000m^3 with a beach berm at + 1.5mCM and a reload on 1100ml beach

Scenario 8: 206 000m^3 with a beach berm at + 1.5mCM and a reload on 1100ml beach

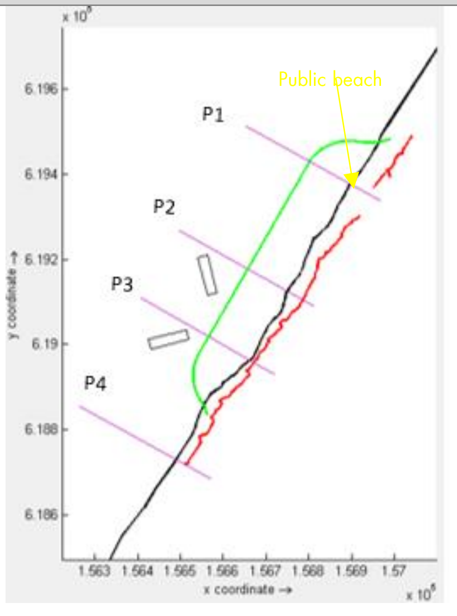
Scenario 9: 142 300m^3 with a beach berm at + 1.5mCM and a reload on 420ml beach

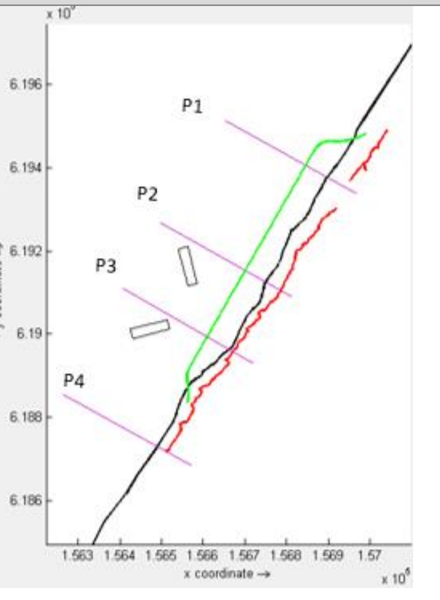
When comparing the results of the simulations after 10 years on scenarios 7 and 8, a similar decline in the beach berm was observed, suggesting that a stabilization equilibrium was achieved whatever the recharge volume (310 000m^3 or 206 000m^3) during the 10 years of simulations. Since the simulations have not been extended for more than 10 years, the future evolution of this coastline after 10 years can still evolve, in particular, by the action of an independent storm event that has not yet been the subject of at this stage of the simulations carried out.

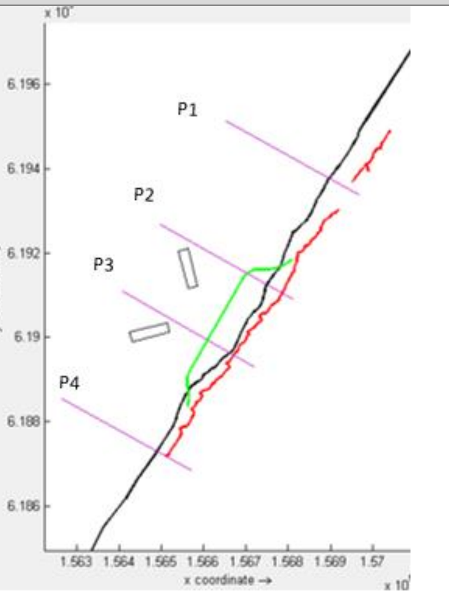
In Scenario 9, after 10 years of simulation, the presence of a relatively wide beach (the beach width values at the different profiles P1, P2, P3 and P4 are written in the following table) to the back of the area protected by the breakwaters. Farther north, the coast line is slightly receded. At the level of profile P1, the beach is reduced to the cliff.

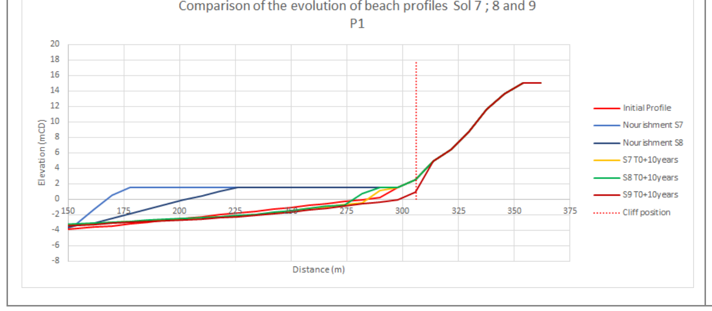
The quantification of the range widths at the profiles P1, P2, P3 and P4 are show in the following table.

Four profiles were drawn along the recharge zone on each scenario, in order to be aware of the evolution of the coastline. The values obtained are also reported in the table below.

<table>
<tr><th colspan="12">Comparison of the evolution of beach profiles 7; 8 and 9</th></tr>
<tr><th colspan="4">Scenario 7
(C16)</th><th colspan="4">Scenario 8
(C15)</th><th colspan="4">Scenario 9
(C18)</th></tr>
<tr><td colspan="4">

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
<td colspan="4">

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td>
<td colspan="4">

— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD</td></tr>
<tr><th colspan="3">Profile P1</th><th colspan="3">Profile P2</th><th colspan="3">Profile P3</th><th colspan="3">Profile P4</th></tr>
<tr><td colspan="3">
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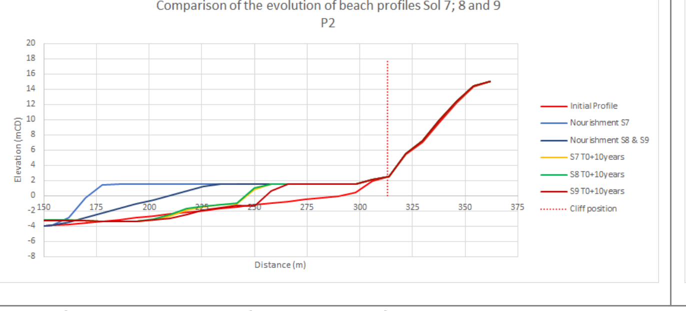
<td colspan="3">
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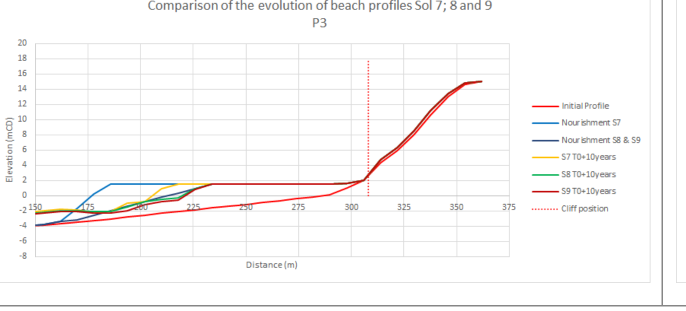
<td colspan="3">
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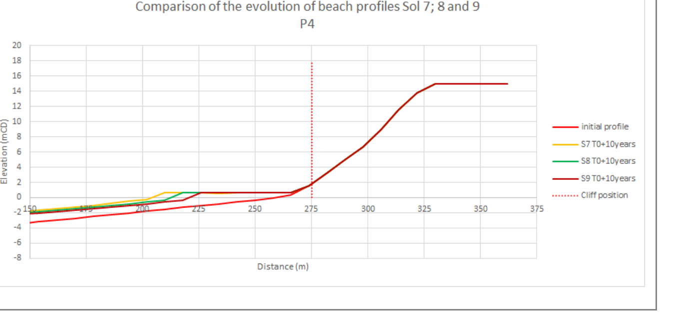
<td colspan="3">
</td></tr>
</table>

Figure 16. Simulation results: scenarios 7, 8 and 9 – comparison of the evolution of beach profiles (P1, P2, P3, P4)

Table 16: table of comparison between the scenarios 7, 8 and 9

Aera	Case	Layout description	Nourishment volume (m^3)	Initial beach berm width (m) from the cliff toe line				Beach berm width after 10 years (m) from the cliff toe line			
				P1	P2	P3	P4	P1	P2	P3	P4
39	S7	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 2 Elevation of berm structures: 0.0mCD Depth of implantation: -4.0mCD to -5.0mCD Length: 91m - Width: 23m Gap : 96m D50 0.25mm	310 000 m^3	140m Elevation E≥+1.5mCD	140m Elevation E≥+1.5mCD	128m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	16m Elevation E≥+1.5mCD	56m Elevation E≥+1.5mCD	90m Elevation E≥+1.5mCD	70m Elevation E≥ 0.0mCD
	S8	Elevation of the beach: +1.5mCD (small nourishment) Beach slope: 4° Number of submerged reefs: 2 Elevation of berm structures: 0.0mCD Depth of implantation: -4.0mCD to -5.0mCD Length: 91m - Width: 23m Gap : 96m D50 0.25mm	206 000 m^3	88m Elevation E≥+1.5mCD	88m Elevation E≥+1.5mCD	74m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	16m Elevation E≥+1.5mCD	56m Elevation E≥+1.5mCD	74m Elevation E≥+1.5mCD	60m Elevation E≥ 0.0mCD
	S9	Elevation of the beach: +1.5mCD (small nourishment) Beach slope: 4° Number of submerged reefs: 2 Elevation of berm structures: 0.0mCD Depth of implantation: -4.0mCD to -5.0mCD Length: 91m - Width: 23m Gap : 96m D50 0.25mm	142 300 m^3	30m Elevation E≥ 0.0mCD	88m Elevation E≥+1.5mCD	74m Elevation E≥+1.5mCD	16m Elevation E≥ 0.0mCD	<8m Elevation E≥+1.5mCD	48m Elevation E≥+1.5mCD	74m Elevation E≥+1.5mCD	52m Elevation E≥ 0.0mCD

<u>Conclusion about to the influence of the nourishment volume beach on the maintenance of the shoreline</u>:

When the beach widths are compared (with the profiles P1, P2 and P3) in scenarios 7, 8 and 9, it can be seen that:

- At the level of profiles P2 and P3 (those concerned by breakwater protections), the beach width is of the same order on the three scenarios, between 48 and 56m: profile P2 and between 74 and 90m: profile P3 (with a berm elevation than or equal to 1.5mCD).
- At the level of profile P1, located farther north, beach nourishment in this zone makes it possible to maintain a beach width after 10 years (with a crest at + 1.5mCD) of the order of 16m (scenarios 7 and 8) Whereas for the scenario not affected by this nourishment (scenario 9), the beach width significantly reduces and becomes less than 8m compared with 30m in the initial state (with a berm elevation than or equal to 1.5mCD).
- At the level of the P4 profile, on the three solutions one observes an enlargement of the beach width passing from about 30m to 52m-70m depending on the scenario (with a berm elevation than or equal to 1.5mCD).

The linear of nourishment to be provided, will have to take into account the total linear of cliff to be protected in zone 39.

3.2.4 Installation of a single breakwater and influence of the crest level

In these scenarios, the objective was to position a single breakwater immersed before the wall positioned at the foot of the cliff, at the level of profile P3.

Indeed, as mentioned before, the Xbeach model and the modelling put in place, does not take into account the reflection that is done on this wall. In fact, it is difficult to appreciate the scouring phenomena that could scour in this area.

Finally, an evaluation was carried out on the level of the crest of the breakwater in order to evaluate the influence on the stability of the beach.