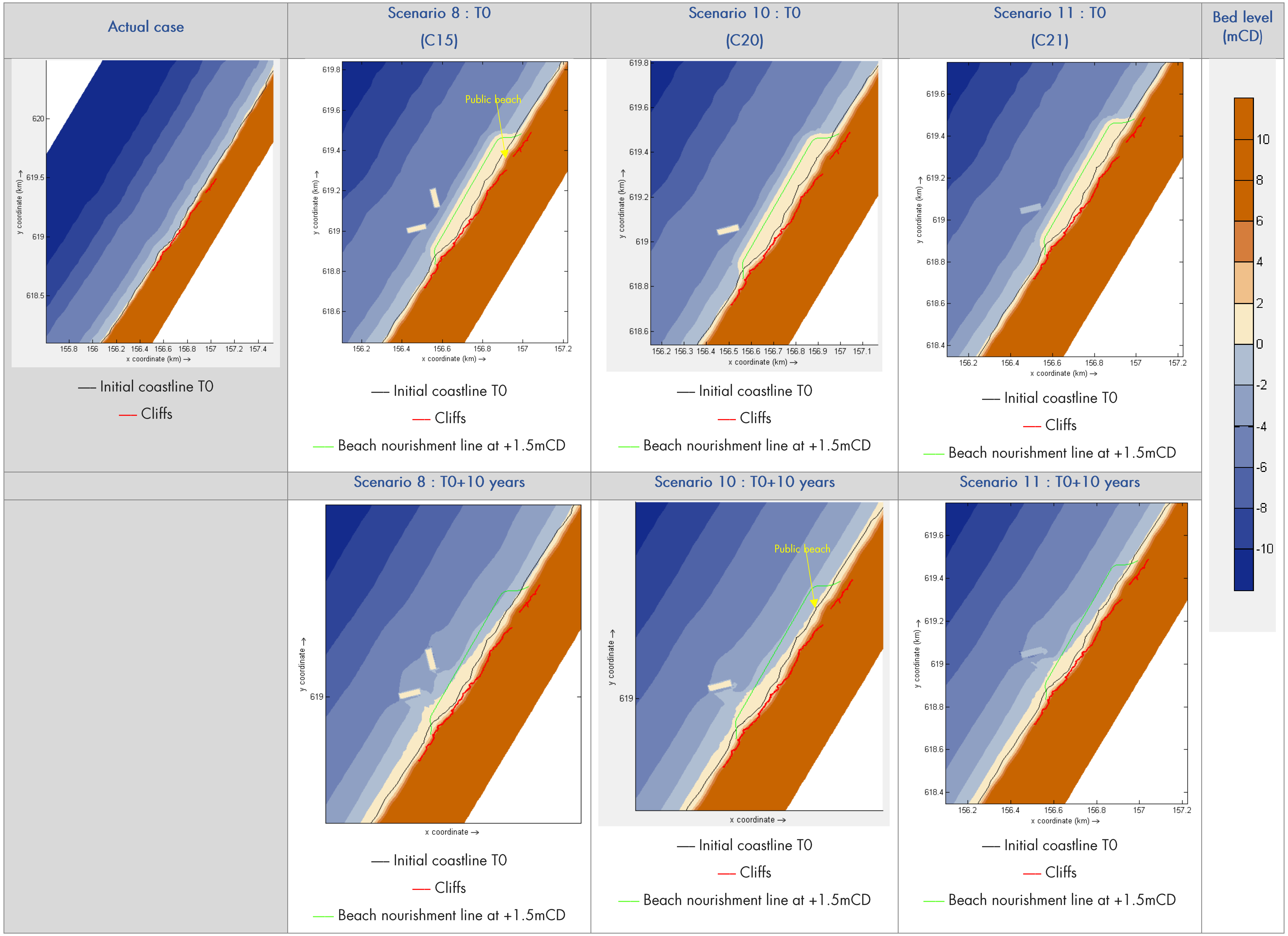


Figure 17. Simulations results: scenarios 8, 10 and 11

Observations :

At first, what is important to point out is that the nourishment of the beach was carried out on a linear of about 1100ml and a volume of about 206 000m^3.

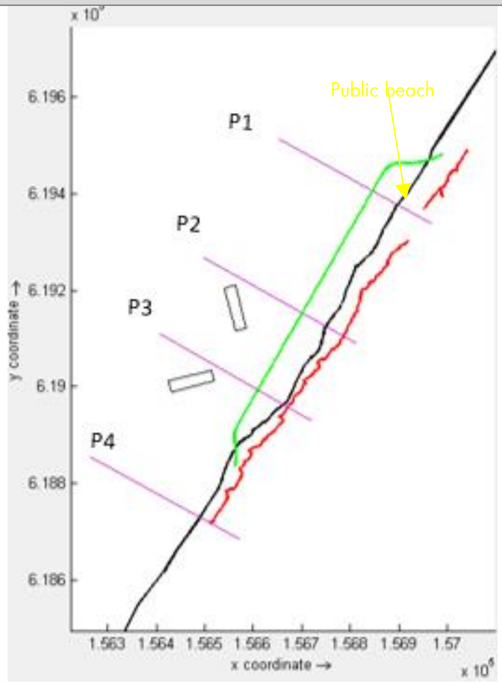
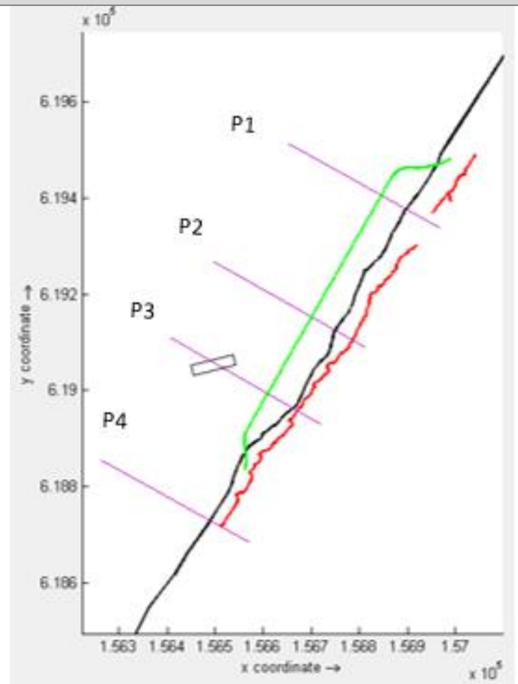
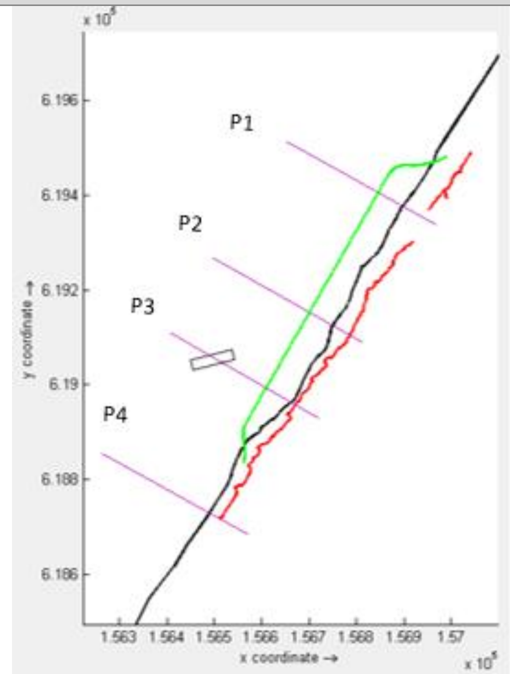
This choice of reloading was retained, because it allowed, as was seen in previous simulations, to maintain a minimum beach width of about 16 m at the level of the profile P1 (with a berm elevation than or equal to 0.0mCD)..

On scenarios 10 and 11, the installation of a breakwater in front of the wall at the foot of the cliff allows to effectively protect this area.

On the part of the recharged but unprotected beach, the recoil of the coastline is more important than on scenario 8 with the presence of two breakwaters and therefore a beach linear more protected.

The beach width values at the different profiles P1, P2, P3 and P4 are written 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.

Comparison of the evolution of beach profiles 8; 10 and 11		
Scenario 8 (C15)	Scenario 10 (C20)	Scenario 11 (C21)
 — 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

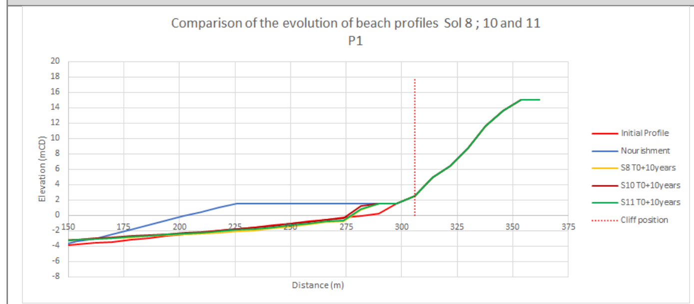
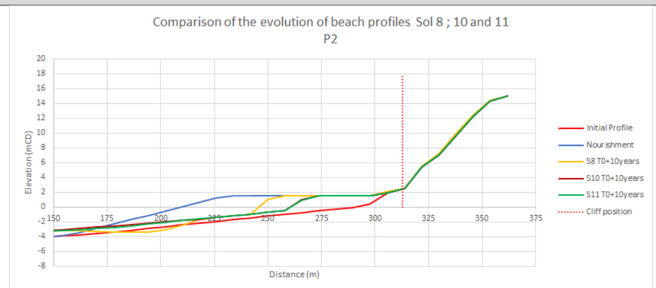
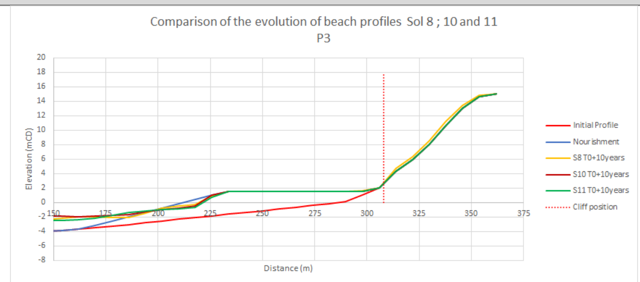
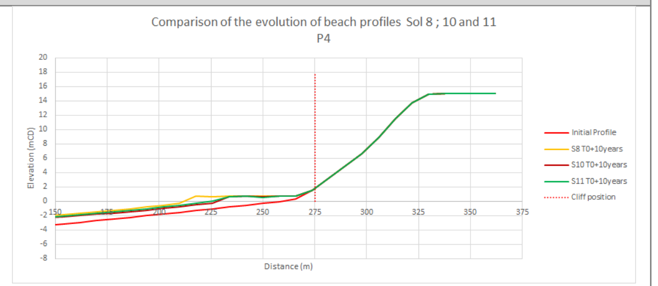
Profile P1	Profile P2	Profile P3	Profile P4
			

Figure 18. Simulation results: scenarios 8, 10 and 11 – comparison of the evolution of beach profiles (P1, P2, P3, P4)

Table 17: table of comparison between the scenarios 8, 10 and 11

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	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
	S10	Elevation of the beach: +1.5mCD (small nourishment) Beach slope: 4° Number of submerged reefs: 1 Elevation of berm structures: 0.0mCD Depth of implantation: -4.0mCD to -5.0mCD Length: 91m - Width: 23m 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	40m Elevation E≥+1.5mCD	74m Elevation E≥+1.5mCD	44m Elevation E≥ 0.0mCD
	S11	Elevation of the beach: +1.5mCD (small nourishment) Beach slope: 4° Number of submerged reefs: 1 Elevation of berm structures: -0.2mCD Depth of implantation: -4.0mCD to -5.0mCD Length: 91m - Width: 23m 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	40m Elevation E≥+1.5mCD	74m Elevation E≥+1.5mCD	44m Elevation E≥ 0.0mCD

Conclusion :

The installation of a single breakwater at zone 39 allows the area surrounding the profile P3 to be protected. Effectively at profile P3, the beach width goes from about 88m at time T0, to about 74m after 10 years (with a berm elevation than or equal to 1.5mCD).

At the level of the P2 profile, there is a decrease in the beach width after 10 years between scenarios 8 and 10-11. Indeed, the beach width after 10 years for scenario 8 is about 56m for 40m for scenarios 10 and 11 (with a berm elevation than or equal to 1.5mCD).

At the P1 profile, the beach width after 10 years is around 16m for all scenarios (with a berm elevation than or equal to 0.0mCD).

At the level of profile P4, there is a smaller widening of the beach on scenarios 10 and 11 than on scenario 8 (with a berm elevation than or equal to 0.0mCD).

At the linear beach, protected by the breakwater, the installation of a single breakwater brings the same efficiency as the installation of two breakwaters. The difference is observed on the unprotected part located further north with a greater reduction of the beach width at the level of the profile P2 with the installation of a single breakwater.

Finally, the modification of the elevation of the berm, between 0.0mCD and -0.2mCD, does not bring, in these configurations, of major modifications.

3.2.5 Beach nourishment without the installation of protective structures

In these scenarios, the objective was to realise a sensitivity study on the particular case of a nourishment of the beach with different nourishment volumes in order to evaluate the impact on maintaining the coastline.

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 (scenario 12 bis) and d50=0.1mm (scenario 12 bis_one).

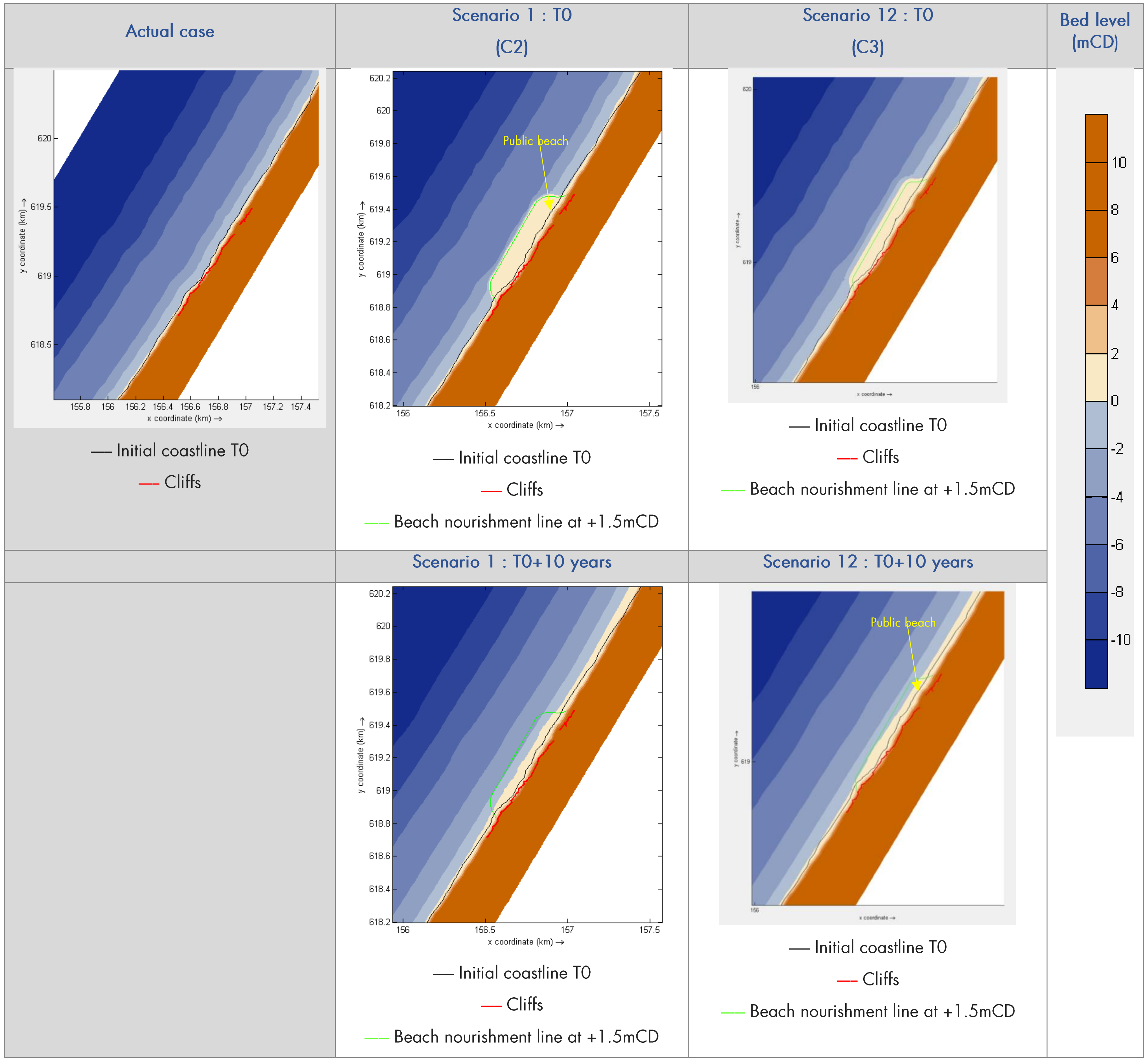


Figure 19. Simulations results: scenarios 1and 12

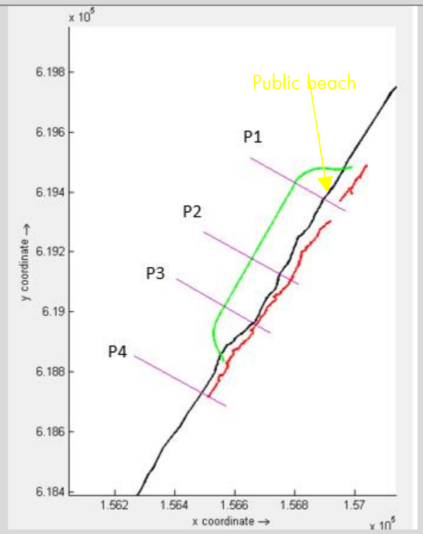
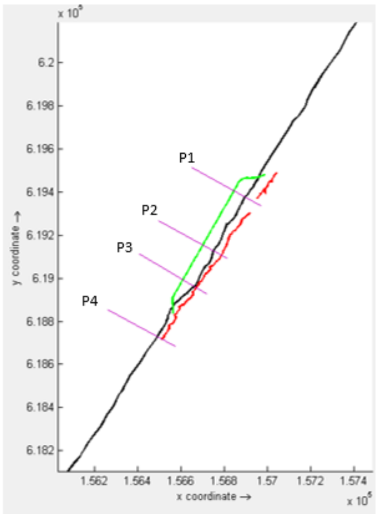
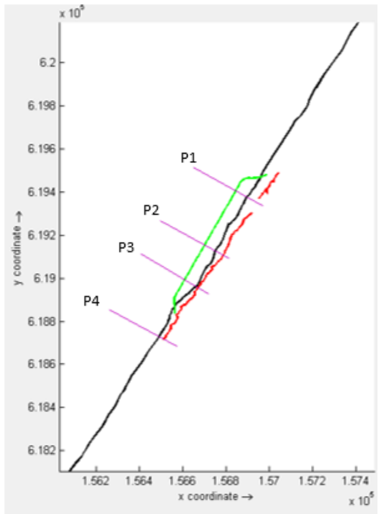
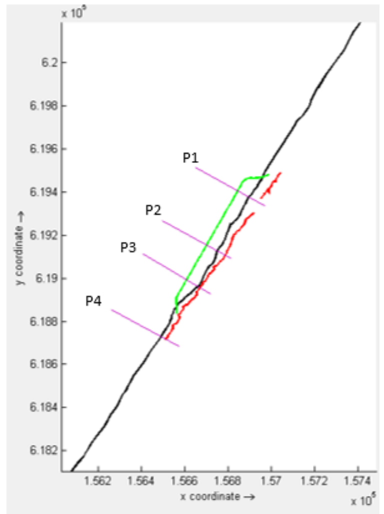
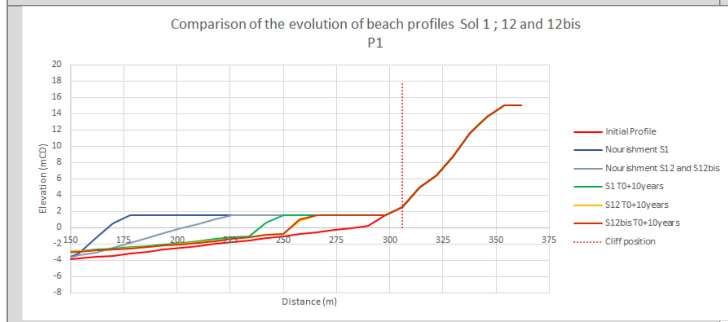
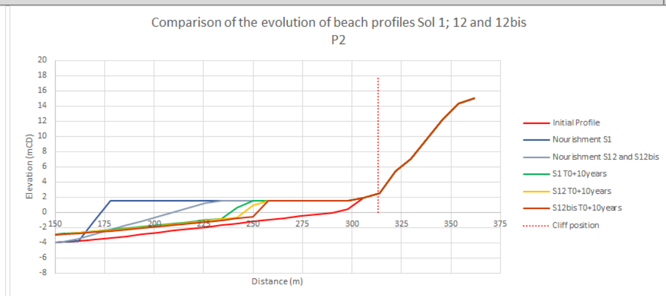
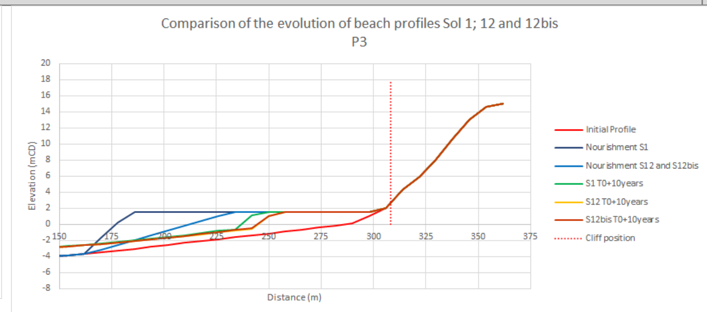
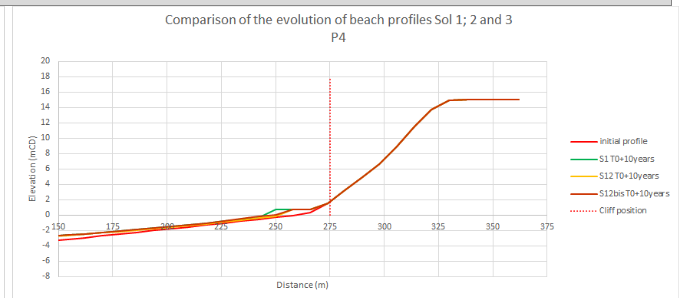
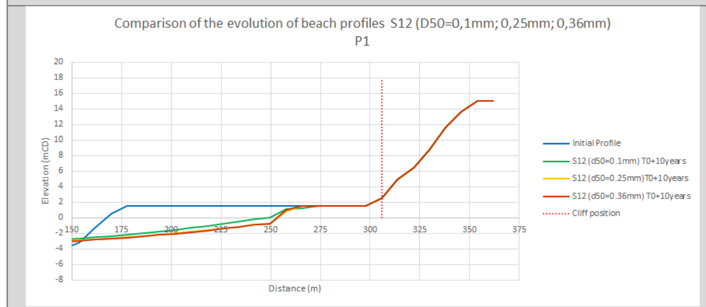
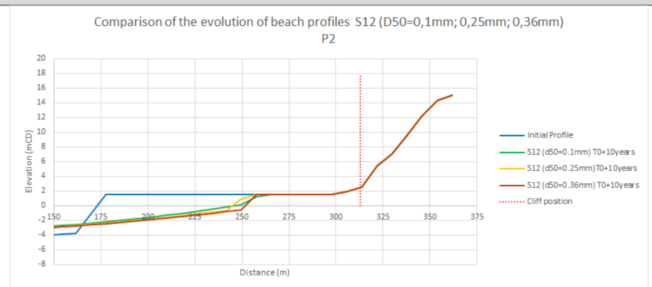
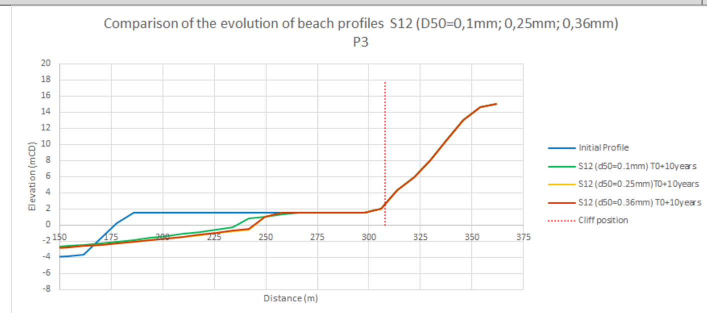
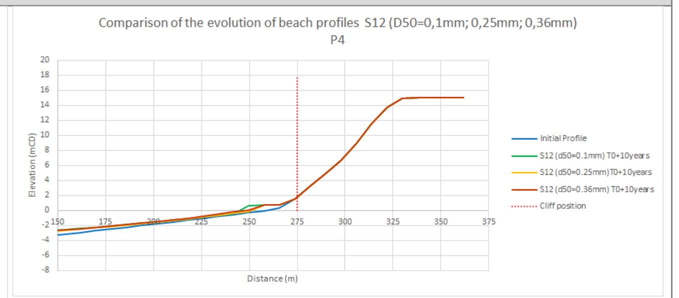
Observations :

On the outputs, there appears to be little difference between the width of the range after 10 years of simulation (at the recharge zone) for a nourishment of 310 00m^3 (S1) or 206 000m^3 (S12)

The profiles traced along the beach will help to quantify the differences between the two scenarios.

The profiles traced along the beach will help to quantify the differences between the two scenarios.

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 1; 12; 12 bis and 12 bis_one			
Scenario 1 (C2)	Scenario 12 (C3)	Scenario 12 bis (C3_036)	Scenario 12 bis_one (C3_010)
 — 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
Profile P1 (S1, 12 and 12 bis)	**Profile P2 (S1, 12 and 12 bis)**	**Profile P3 (S1, 12 and 12 bis)**	**Profile P4 (S1, 12 and 12 bis)**
			
Profile P1 (S12, S12_bis and S12_bis_one)	**Profile P2 (S12, S12_bis and S12_bis_one)**	**Profile P3 (S12, S12_bis and S12_bis_one)**	**Profile P4 (S12, S12_bis and S12_bis_one)**
			

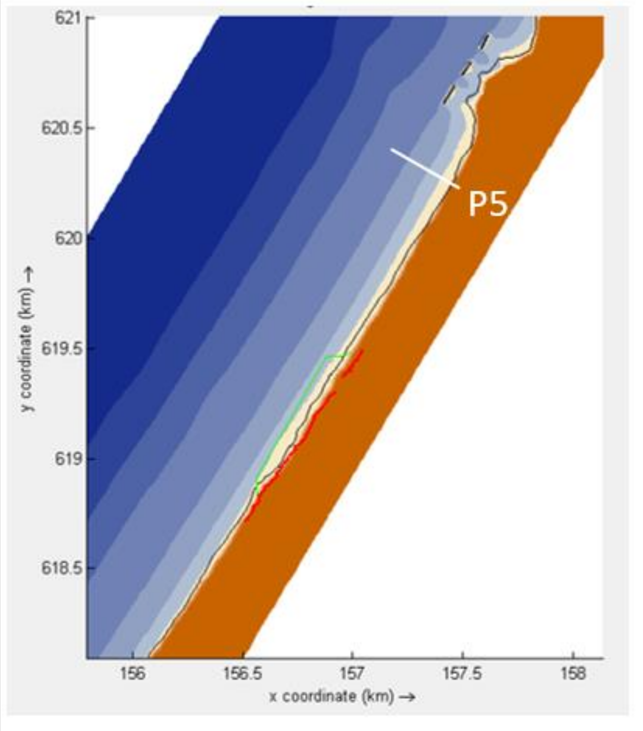
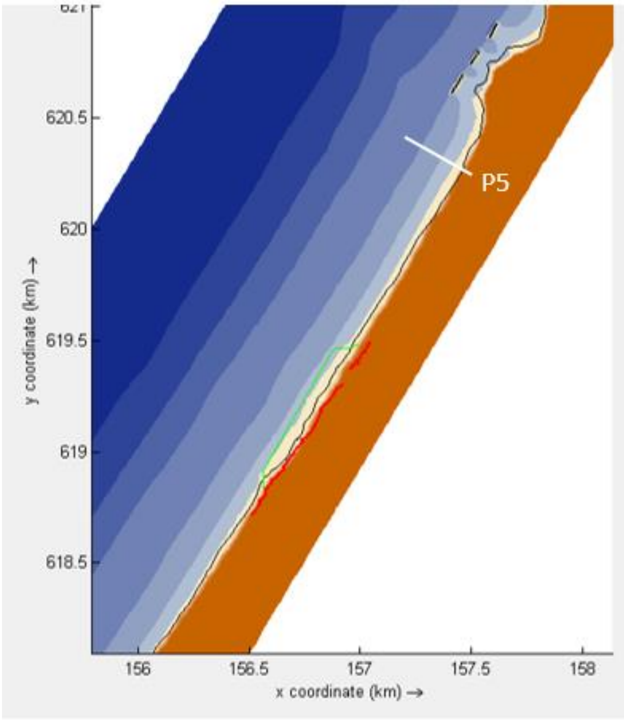
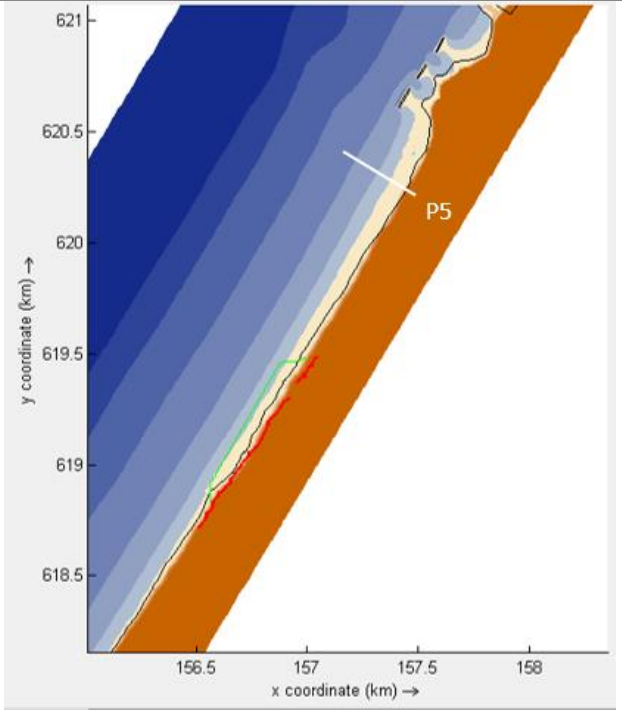
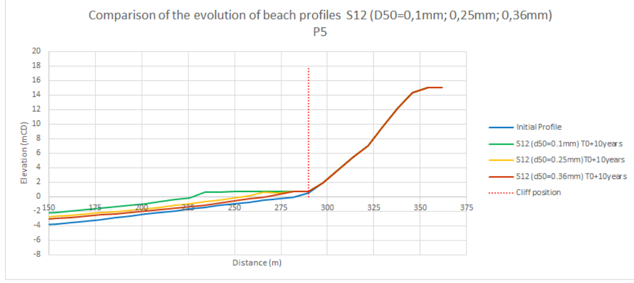
Scenario 12 : T0+10 years (d50=0.25mm)	Scenario 12bis : T0+10 years (d50=0.36mm)	Scenario 12bis_one : T0+10 years (D50=0.10mm)	Profile P5 (S12, S12_bis and S12_bis_one)
			

Figure 20. Simulation results: scenarios 1, 12, 12bis and 12bis_one– comparison of the evolution of beach profiles (P1, P2, P3, P4, P5)

Table 18: table of comparison between the scenarios 1 and 12

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	P5	P1	P2	P3	P4	P5
39	S1	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 0 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	/	56m Elevation E≥+1.5mCD	64m Elevation E≥+1.5mCD	56m Elevation E≥+1.5mCD	30m Elevation E≥ 0.0mCD	/
	S12	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 0 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≥ 0.0mCD	40m Elevation E≥+1.5mCD	56m Elevation E≥+1.5mCD	50m Elevation E≥+1.5mCD	24m Elevation E≥ 0.0mCD	32m Elevation E≥ 0.0mCD
	S12 bis	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 0 D50 0.36mm	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≥ 0.0mCD	40m Elevation E≥+1.5mCD	56m Elevation E≥+1.5mCD	50m Elevation E≥+1.5mCD	24m Elevation E≥ 0.0mCD	24m Elevation E≥ 0.0mCD
	S12 bis_one	Elevation of the beach: +1.5mCD (medium nourishment) Beach slope: 15° Number of submerged reefs: 0 D50 0.10mm	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≥ 0.0mCD	32m Elevation E≥+1.5mCD	48m Elevation E≥+1.5mCD	42m Elevation E≥+1.5mCD	28m Elevation E≥ 0.0mCD	64m Elevation E≥ 0.0mCD

Conclusion :

The results of the Xbeach simulations show that:

- For a beach nourishment of 310 000m^3 (without protection offshore), the beach width between 128m and 140m at T0 becomes between 56m and 64m after 10 years of simulations.
- For a beach nourishment of 206 000m^3 (without protection offshore), the beach width between 74m and 88m at T0 becomes between 40m and 56m after 10 years of simulations.
- On the nourishment zone (Z39), the modification of grain size, d50=0.25mm replaced by a size d50=0.36mm does not lead to a significant change in the maintenance of the coast line.
- For a grain size d50 = 0.10 mm, we observe:
  - ➢ On the nourishment zone the beach width smaller than those obtained for a d50 = 0.25mm or 0.36mm, if reference is made to an elevation E≥ + 1.5mCD (which is the initial elevation of reloading).
  - ➢ On a larger scale, there is a more significant variation in the width of the beach to the North of zone 39 (for an elevation E≥ 0.0mCD). After the 10 years of simulated modelling, it is observed that the smaller the grain, the more it tends to go up on the beach and fattening the beach (which is physically natural: the smaller grain are more easily suspended and the small waves transport these grain to the beach).

However, those results on the sensitivity of sediment size have their validity limits.

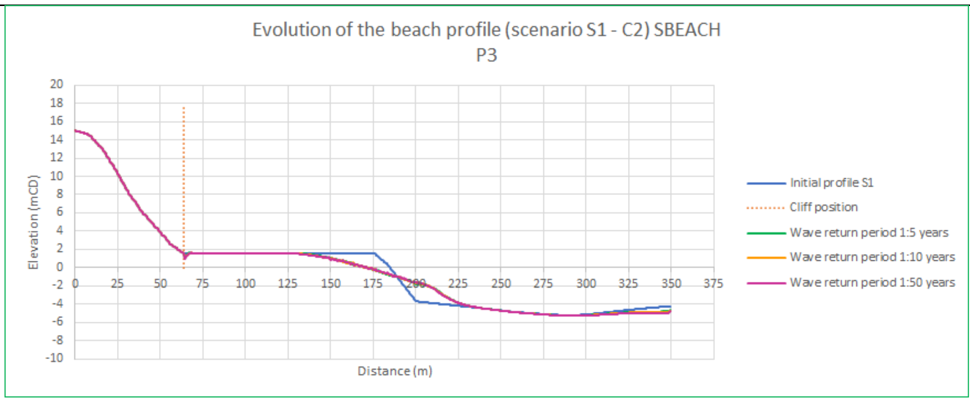
Indeed:

- ➢ The calibration of the model (wave, current …) was carried out on the basis of a sediment size of d50 = 0.25mm.
- ➢ On each simulation, the sediment size is the same on all the model and not only on the nourishment zone. So, we observe a global phenomenon and not only related to the nourishment. This refers, to the reflection on the calibration of the model realized.
- ➢ The size of the meshes being of the order of 8 m, the variation of the width of the range between each simulation can vary between 0 and 8 m maximum.

But the general feeling of the sand displacement is correct even if the sand volume might not be exact.

It should be noted that the Xbeach modeling does not take into account the reflection that occurs on the wall at the foot of the cliff at the level of the profile P3.

Below, simulations carried out with Sbeach (1DH), allow to take into account the reflection of this one.

	Scenario S1 (C2) – Profile P3
	

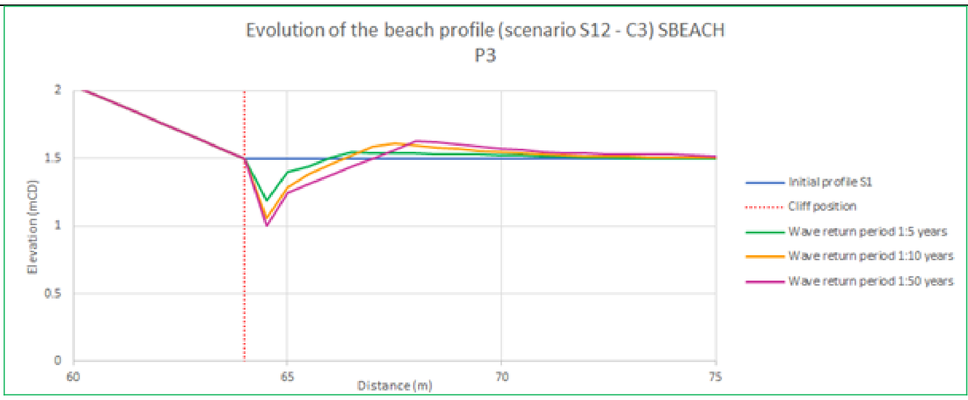
<table>
<tr>
<td>Zoom on the foot of the cliff</td>
<td>
</td>
</tr>
</table>

Figure 21. Sbeach (1DH) simulation results: scenario 1- comparison of the evolution of beach profiles (P3) for waves return period (1:5; 1:10; 1:50 years) , direction N306°, with water sea level (1.0; 1.2; 1.3mCD)

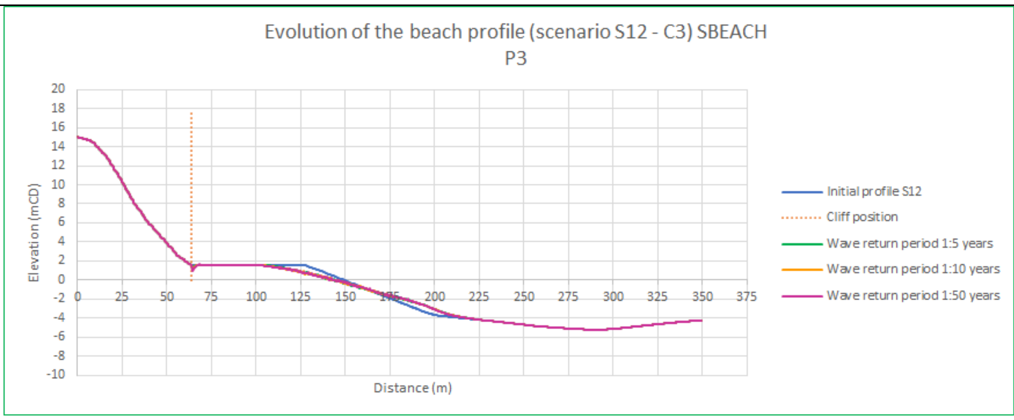
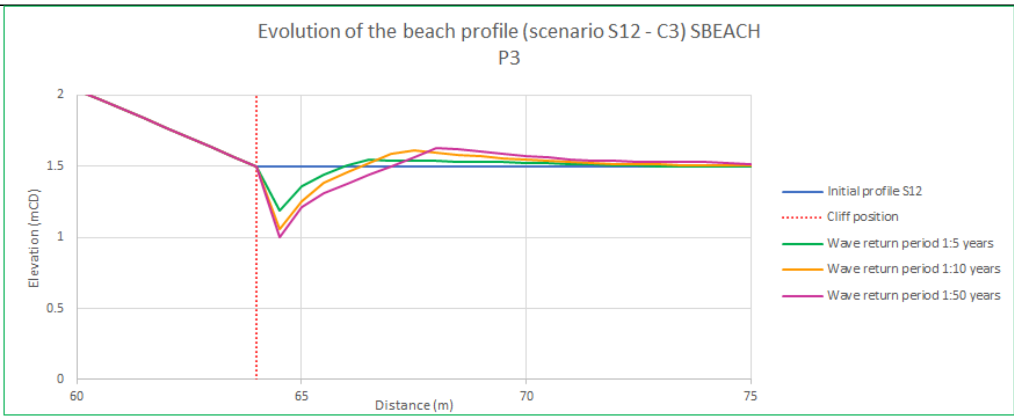
<table>
<tr><td></td><td>Scenario S12 (C3) – Profile P3</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Zoom on the foot of the cliff</td><td></td></tr>
</table>

Figure 22. Sbeach (1DH) simulation results: scenario 12- comparison of the evolution of beach profiles (P3) for waves return period (1:5; 1:10; 1:50 years), direction N306°, with water sea level (1.0; 1.2; 1.3mCD)

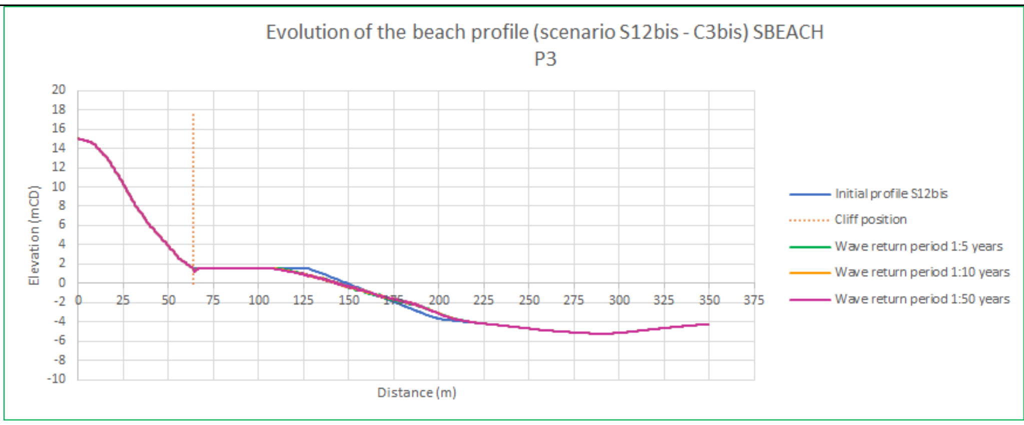
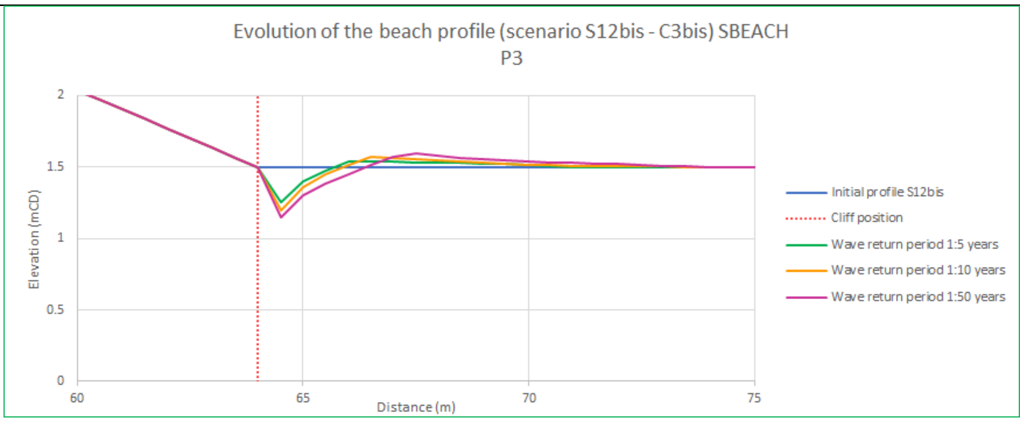
	Scenario S12bis (C3) – Profile P3 – d50=0.36mm
	
Zoom on the foot of the cliff	

Figure 23. Sbeach (1DH) simulation results: scenario 12bis- comparison of the evolution of beach profiles (P3) for waves return period (1:5; 1:10; 1:50 years), direction N306°, with water sea level (1.0; 1.2; 1.3mCD) - d50=0.36mm

The results of the Sbeach simulations at the level of the P3 profile, with the presence of a wall at the foot of the cliff, highlight a scouring phenomenon to be expected during extreme swell events (return period 1: 5 years and more). On this section to avoid loosening of the wall, it is desirable to provide protection as in scenarios 8, 10 or 11.

The placement of sediment of size d50 = 0.36mm instead of d50 = 0.25mm, makes it possible to slightly reduce the scouring phenomenon but in a non-significant way.

3.3 GENERAL CONCLUSION

Implantation of the breakwaters (geotubes): The installation of breakwaters over the entire coast linear of zone 39, leads to an erosion zone further north after this protection.

Depth of implantation: in the case of the installation of breakwaters parallel to the coastline, the installation in depths greater towards -5.0mCD (scenario S4) rather than -4.0mCD (scenario 3), brings an improvement on the maintenance of the Coastline. Nevertheless, one must pay attention to what is technically possible to achieve.

Orientation of breakwaters: the installation of breakwaters with an angle of approximately 45 ° with respect to the coast (scenario 7, 8) makes it possible to reduce the erosion phenomena on the part further north, not protected directly by the structures.

Nourishment volume of the beach: the volume and linear nourishment of the beach depends on the actual area to be protected. It is observed that a linear reloading that is too small (scenario 9) does not allow 10 years to obtain beach widths on the northern part of zone 39, sufficient (less than 8m wide).

If one considers area 39 and its neighbours, the installation of one or two breakwaters (scenario 8, 10 or 11) would provide better protection than the installation of a whole row of breakwaters. The choice of the number of breakwaters depends essentially on the minimum width beach to be maintained after 10 years, knowing that on the northernmost part of zone 39, the erosion of the beach will always be greater.

Scenario 8 with the installation of two breakwaters at 45 ° is safer because it is this scenario which allows after 10 years of simulation to obtain a width of beach (on the recharging zone) the largest.

The following table shows the evolution of the width beach over zone 39 over the 10 years of simulation (scenario 8 and 10).

Table 19: table of comparison between the scenarios 8 and 10

	Scenario 8								Scenario 10							
Nourishment volume (m3)	206 000 m³								206 000 m³							
	Beach berm width from the cliff toe line				% diff				Beach berm width from the cliff toe line				% diff			
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
Before nourishment	0.0m CD < Elevation								0.0m CD< Elevation							
	30m	30m	10m	16m					30m	30m	10m	16m				
Elevation of nourishment	+1.5mCD	+1.5mCD	+1.5mCD	/					+1.5mCD	+1.5mCD	+1.5mCD	/				
YEAR	E≥ +1.5m CD			0.0m CD <E					E≥ +1.5m CD			0.0m CD <E				
0	88	88	74	16					88	88	74	16				
1	48	88	74	20					56	72	74	20	-36.36	-18.18	0.00	25.00
2	40	88	74	32	-45.45	0.00	0.00	25.00	48	64	74	36	-14.29	-11.11	0.00	80.00
3	24	84	74	32	-16.67	0.00	0.00	60.00	32	56	74	38	-33.33	-12.50	0.00	5.56
4	24	84	74	40	-40.00	-4.55	0.00	0.00	32	48	74	40	0.00	-14.29	0.00	5.26
5	16	72	74	36	0.00	0.00	0.00	25.00	24	48	74	40	-25.00	0.00	0.00	0.00
6	16	72	74	44	-33.33	-14.29	0.00	-10.00	24	48	74	40	0.00	0.00	0.00	0.00
7	16	64	74	48	0.00	0.00	0.00	22.22	16	48	74	40	-33.33	0.00	0.00	0.00
8	16	64	74	52	0.00	-11.11	0.00	9.09	16	40	74	40	0.00	-16.67	0.00	0.00
9	16	64	74	60	0.00	0.00	0.00	8.33	16	40	74	44	0.00	0.00	0.00	10.00
10	16	56	74	60	0.00	0.00	0.00	15.38	16	40	74	44	0.00	0.00	0.00	0.00

Note:

In this table like all the tables in this report, beach width values are given to the mesh size near the model which is of the order of 8m to 10m.

Depending on the scenario chosen, the final positioning of the breakwaters may be slightly displaced so that it is positioned as in scenarios 10 and 11, facing the wall at profile P3.

Additional simulations were carried out with the Sbeach model, at the level of the P3 profile, at the level of which a wall at the foot of the cliff is positioned. These simulations showed that in absence of protection on this section (as scenario 1 and 12), a phenomenon of scouring at the foot of the wall is to be expected during extreme swells (return period 1: 5 years and more). Phenomenon not observed, with the XBeach model, which does not take into consideration the reflection effects.

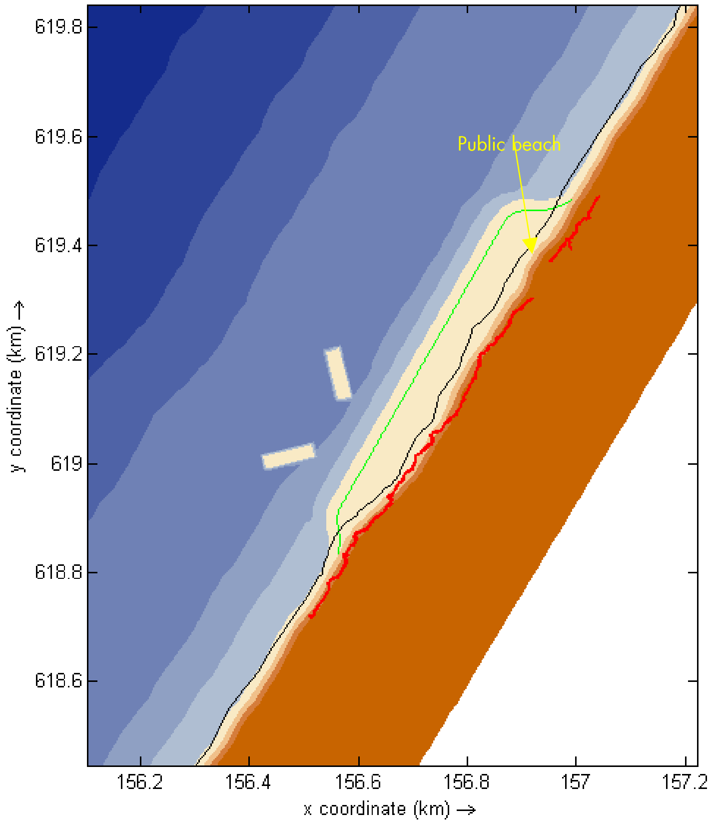
Furthermore in case of severe storm event, the scenarios with only pure nourishment will face severe retreat while protected scenarios will be less impacted.

Finally, a sensitivity study was realised on the size of sediments d50 = 0.25mm replaced by a size d50 = 0.36mm and a size d50 = 0.10mm on scenario 12. The results highlighted the following elements:

- On the nourishment zone (Z39), the modification of grain size, d50=0.25mm replaced by a size d50=0.36mm does not lead to a significant change in the maintenance of the coast line.
- For a grain size d50 = 0.10 mm, we observe:
  - On the nourishment zone the beach width smaller than those obtained for a d50 = 0.25mm or 0.36mm, if reference is made to an elevation E≥ + 1.5mCD (which is the initial elevation of reloading).
  - On a larger scale, there is a more significant variation in the width of the beach to the North of zone 39 (for an elevation E≥ 0.0mCD). After the 10 years of simulated modelling, it is observed that the smaller the grain, the more it tends to go up on the beach and fattening the beach (which is physically natural: the smaller grain are more easily suspended and the small waves transport these grain to the beach).

From this analysis, it appears that the most suitable scenarios could be the scenario 8.

Scenario 8 : T0
(C15)



— Initial coastline T0

— Cliffs

— Beach nourishment line at +1.5mCD

Nourishment (m³)	206 000	
Elevation of the beach nourishment (mCD)	+1.5	
Number of Breakwater	2	
Breakwater length (m)	South 90	North 90
Assumed breakwater crest width (m)	23	23
Gap length (m)	96	
Breakwater crest level (mCD)	0	
Seaward toe level of the breakwater (mCD)	-4 to -5	
Initial berm width (width of the dry beach)	74 to 88 From south to north	

4 EVOLUTION OF SCENARIOS 8

On the basis of scenarios 8, additional simulations were carried out to optimize the width of the geotubes and to study the sensitivity on the level of the berm of these geotubes.

In a first step, to avoid the scouring phenomena observed on scenarios S1 and S12, the geotubes were slightly displaced so as to protect the wall located at the foot of the cliff at the level of the profile P3.

In addition, the width of the geotubes was reduced from 23m to 17m.

Lastly, a sensitivity was realized on the level of elevation of the crest of the structures.

The characteristics of scenarios are presented in the table below:

Table 20: characteristics of initial studied scenarios (Scenario 8; 13 and 15)

- Evaluation of the influence of the breakwater crest width and displacement of structures towards the North (comparison scenario 8 (C15), scenario 13 (C22), scenario 14 (C28) and scenario 15 (C25))

	Scenario 8 (C15)		Scenario 13 (C22)		Scenario 14 (C28)		Scenario 15 (C52)	
Nourishment (m^3)	206 000		206 000		206 000		206 000	
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 90	North 90	South 90	North 90	South 90	North 90	South 90	North 90
Assumed breakwater crest width (m)	23	23	17	17	17	17	17	17
Gap length (m)	96		96		96		96	
Breakwater crest level (mCD)	0		0		-0.2		-0.5	
Seaward toe level of the breakwater (mCD)	-4 to -5		-4 to -5		-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		74 to 88 From south to north		74 to 88 From south to north	

The results of these simulations are presented below:

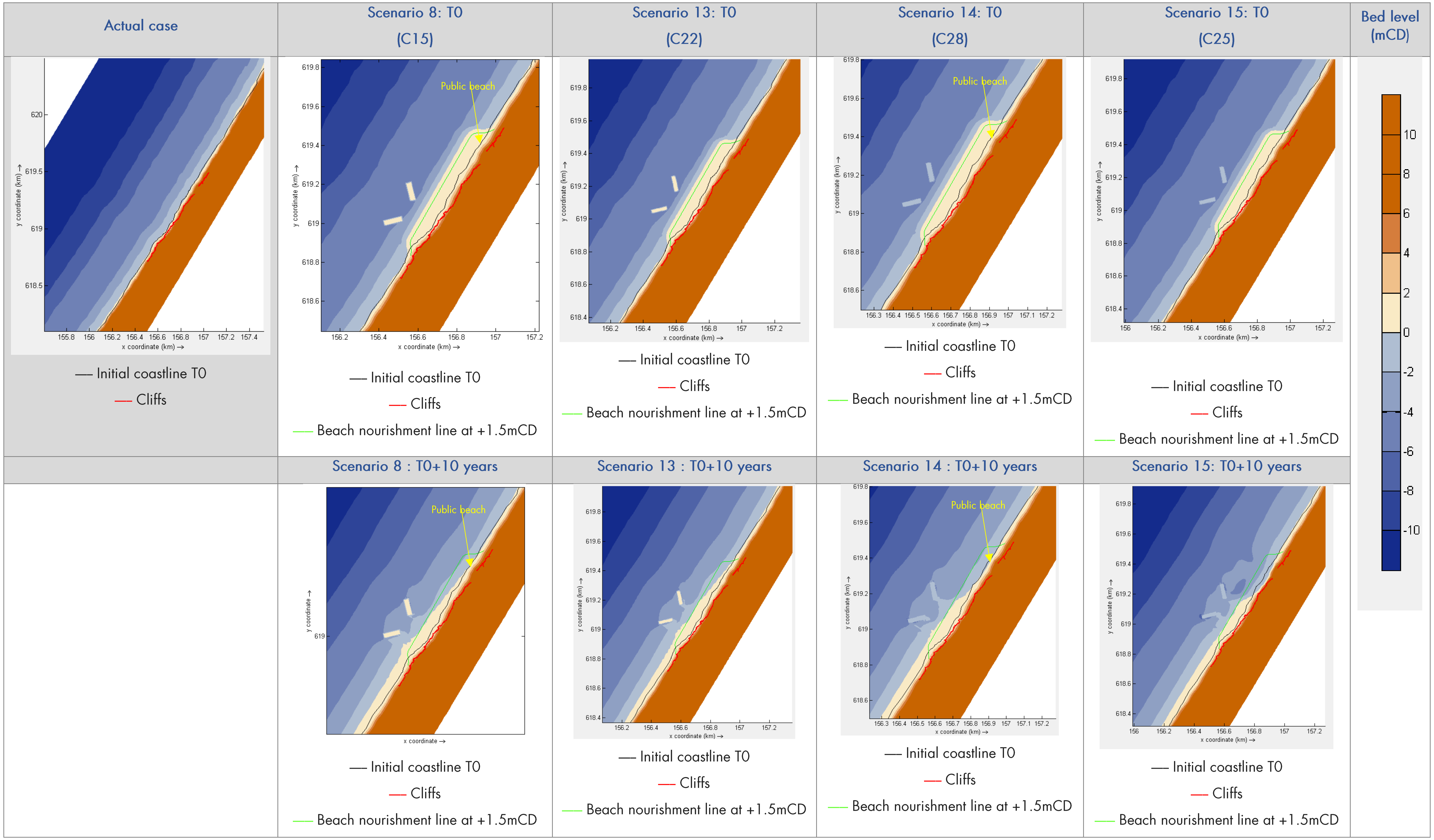


Figure 24. Simulations results: scenarios 8, 13, 14 and 15

Observations:

There is only little evolution between scenarios S8 and S13 after 10 years of simulation when the width of the submerged structures (geotubes) is reduced from 23m to 17m.

Moreover, shifting the geotubes in front of the wall located at the foot of the cliff in P3, makes it possible to protect more effectively the northern part of the recharged zone.

A significant retreat of the coastline is observed after 10 years of simulation when the level of the geotube head decreases from 0.0mCD to -0.5m CD in particular on the northern zone of the recharged beach. The plots of the profiles P1, P2, P3 and P4 as well as the table of comparison of the beach widths at these profiles make it possible to quantify the beach evolution over the entire recharged zone.

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.

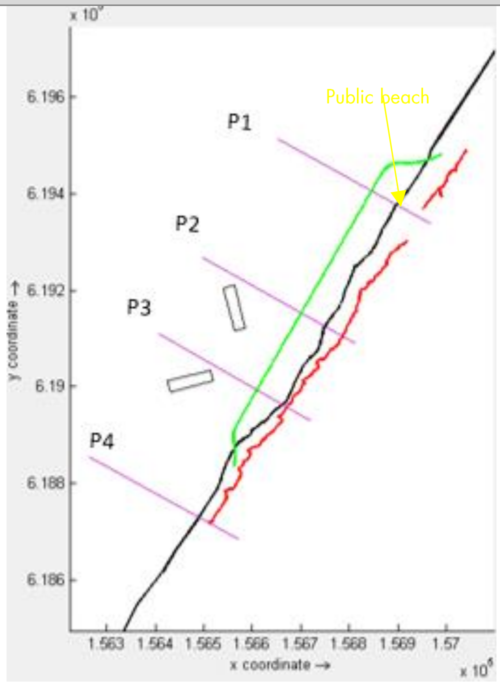
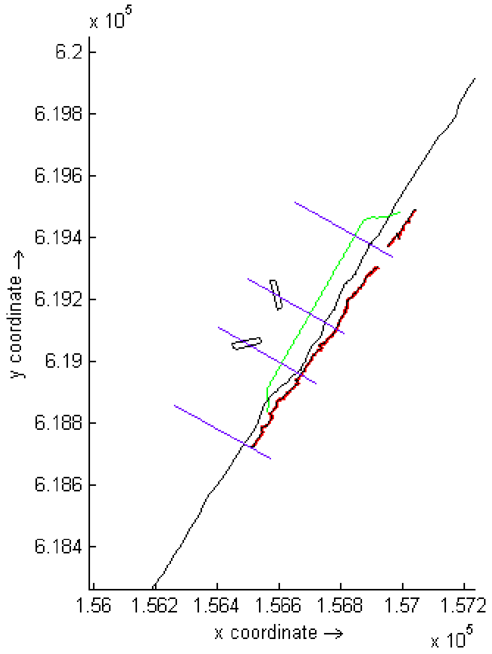
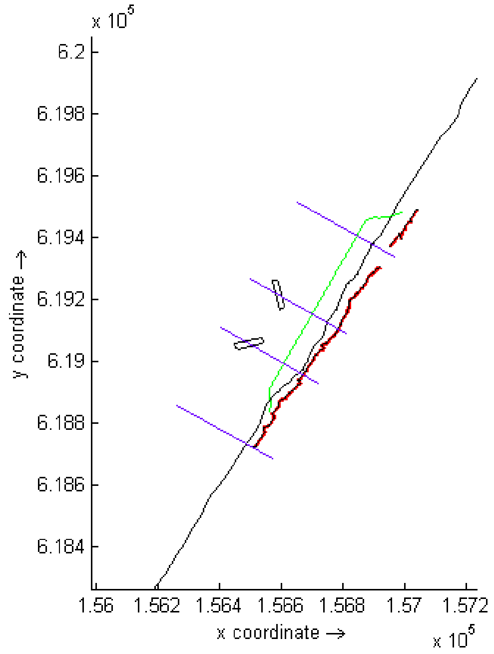
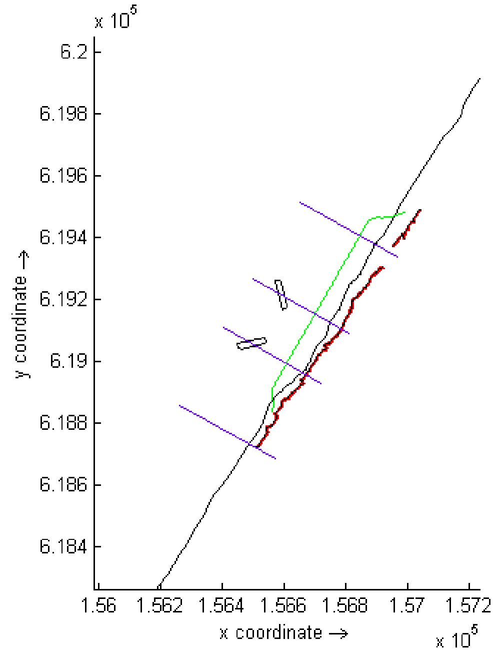
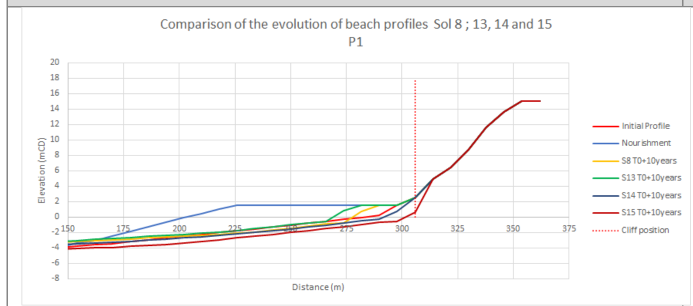
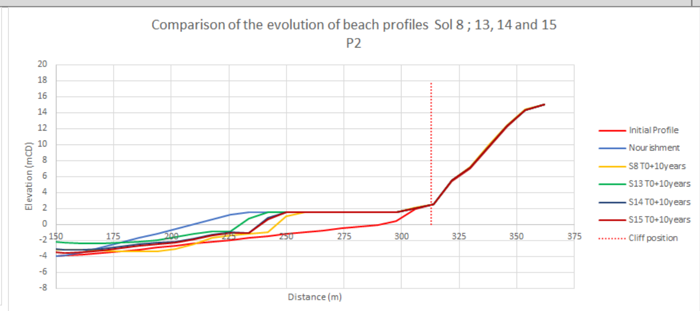
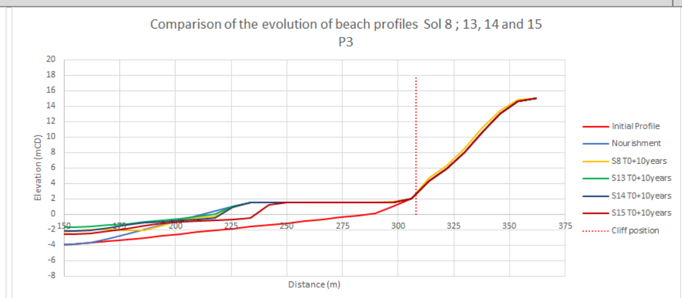
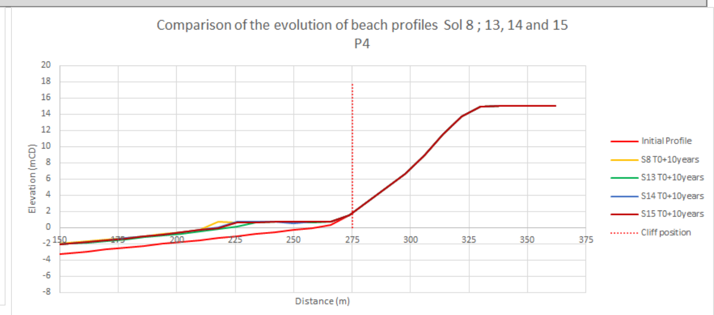
Comparison of the evolution of beach profiles 8; 13; 14 and 15			
Scenario 8 (C15)	Scenario 13 (C22)	Scenario 14 (C28)	Scenario 15 (C25)
 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD
Profile P1	**Profile P2**	**Profile P3**	**Profile P4**
			

Figure 25. Simulation results: scenarios 8, 13, 14 and 15 – comparison of the evolution of beach profiles (P1, P2, P3, P4)

Table 21: table of comparison between the scenarios 8, 13, 14 and 15

Aera	Case	Layout description	Nourishment volume	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	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 m³	**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
	S13	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: **17m** Gap : 110m D50 0.25mm	206 000 m³	**88m** Elevation E≥+1.5mCD	**88m** Elevation E≥+1.5mCD	**74m** Elevation E≥+1.5mCD	**16m** Elevation E≥ 0.0mCD	**30m** Elevation E≥+1.5mCD	**72m** Elevation E≥+1.5mCD	**74m** Elevation E≥+1.5mCD	**48m** Elevation E≥ 0.0mCD
	S14	Elevation of the beach: +1.5mCD (small nourishment) Beach slope: 4° Number of submerged reefs: 2 Elevation of berm structures: **-0.2mCD** Depth of implantation: -4.0mCD to -5.0mCD Length: 91m - Width: **17m** Gap : 110m D50 0.25mm	206 000 m³	**88m** Elevation E≥+1.5mCD	**88m** Elevation E≥+1.5mCD	**74m** Elevation E≥+1.5mCD	**16m** Elevation E≥ 0.0mCD	**0m** Elevation E≥+1.5mCD **<14m** Elevation E≥ 0mCD	**60m** Elevation E≥+1.5mCD	**74m** Elevation E≥+1.5mCD	**56m** Elevation E≥ 0.0mCD
	S15	Elevation of the beach: +1.5mCD (small nourishment) Beach slope: 4° Number of submerged reefs: 2 Elevation of berm structures: **-0.5mCD** Depth of implantation: -4.0mCD to -5.0mCD Length: 91m - Width: **17m** Gap : 110m D50 0.25mm	206 000 m³	**88m** Elevation E≥+1.5mCD	**88m** Elevation E≥+1.5mCD	**74m** Elevation E≥+1.5mCD	**16m** Elevation E≥ 0.0mCD	**0m** Erosion up the cliff	**60m** Elevation E≥+1.5mCD	**66m** Elevation E≥+1.5mCD	**56m** Elevation E≥ 0.0mCD

Conclusion:

To avoid scouring phenomena at the foot of a wall located at the level of profile P3, scenario S13 allows protection of the latter.

Moreover, moving the geotubes a few meters to the north, to provide this protection of the wall, further protects the northern part of the recharged beach.

As long as the head of the geotubes is at 0.0m CD, the width of the range after 10 years of simulation on the recharged zone is between 30 and 74m. (+ E≥ 1.5mCD)

When the level of the head of the geotubes is lowered to -0.2m CD, an acceptable decrease in the beach width is observed at the level of the profile P1. This width is after 10 years of simulation of the order of fifteen meters (E≥0.0m CD). On the rest of the recharged zone (between P2 and P4), the beach width after 10 years of simulation is between 40 and 74m (E≥ + 1.5mCD).

When the level of the head of the geotubes is lowered to -0.5m CD, the simulations show a zero-beach width, with probable erosion of the cliff at the level of the profile P1. On the rest of the recharged area (between P2 and P4), the beach width after 10 years of simulation is between 40 and 66m (E≥ + 1.5mCD).

5 COMPLEMENTARY SIMULATIONS

During the last discussions with the Client on 06 July 2017, it appears that an aerial photography showing the appearance of rocky areas within the project boundary was available. Superimposing the layout to the aerial photography shows that some of the geotubes reef were supposed to be on rocks formation.

The Client wished the geotubes to be moved and positioned on a sandy area.

5.1 STAY WITH THE DISTANCE TO THE SHORE

The shift of the geotubes was therefore carried out from aerial photography. In situ surveys must be carried out to ensure of the positioning of rocky areas.

On the images below are represented:

- the geotubes of the solution initially retained but positioned on rocky areas (scenario n ° 14),

- the shift of these geotubes over non-rocky areas (scenario 16),

- a complementary simulation with the rotation of the geotubes (and positioned in a non-rocky zone), in order to evaluate the influence of the positioning angle on the maintenance of the coastline (scenario 17).

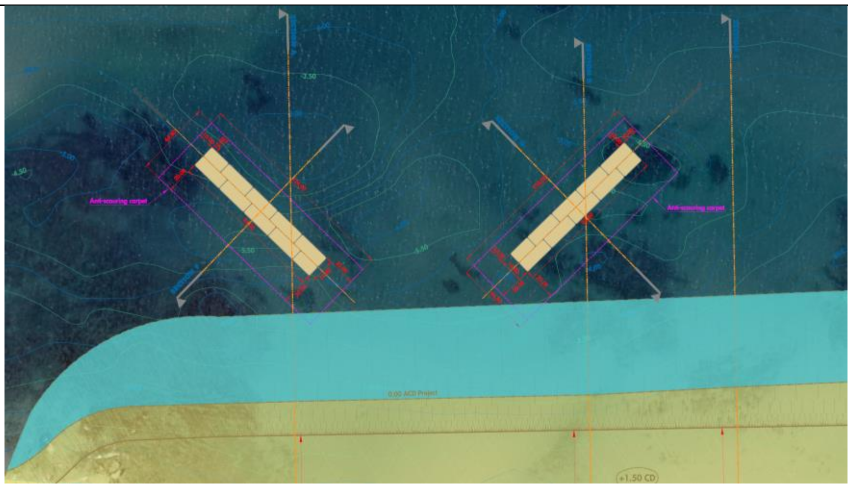
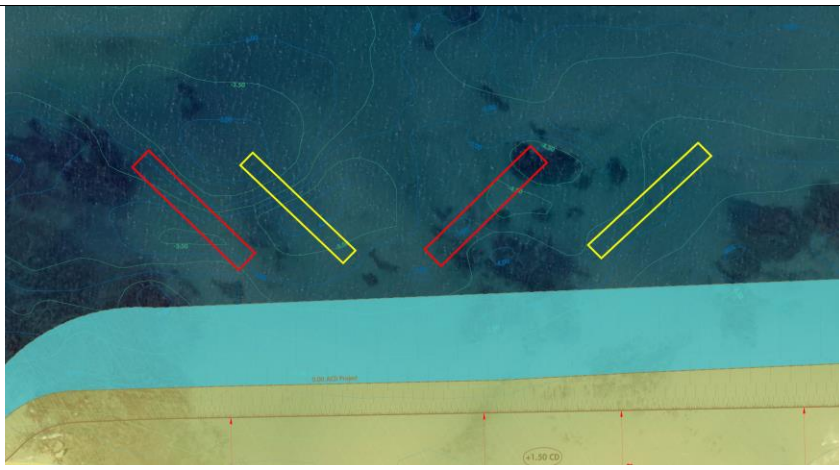
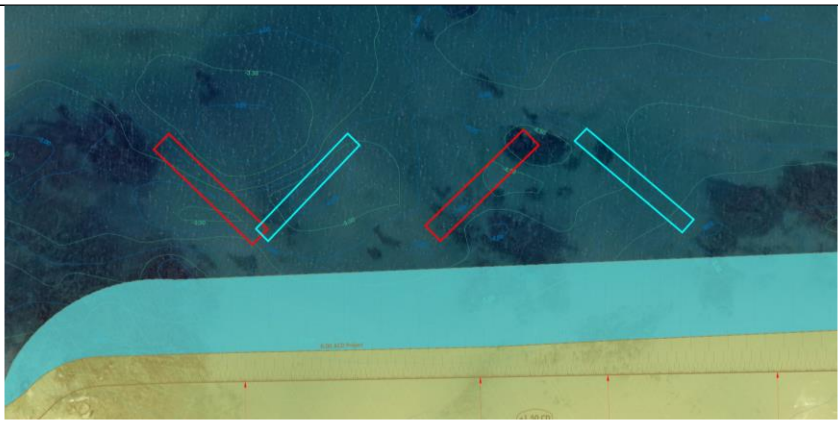
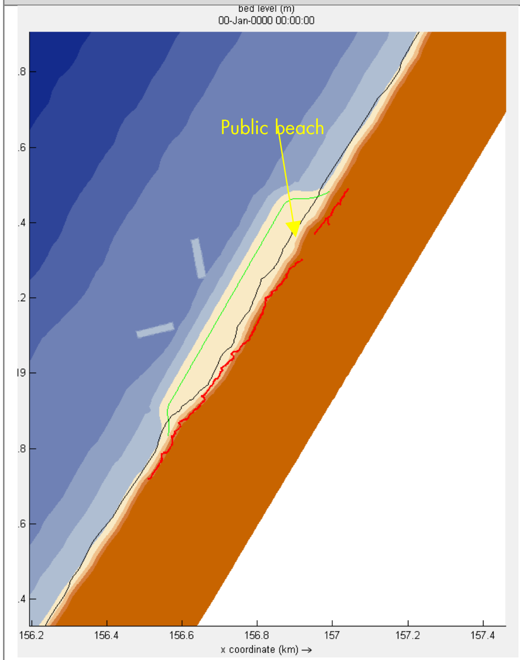
Scenario 14	
Scenario 16	 — scenario 14 — scénario 16
Scenario 17	 — scenario 14 — scenario 17

Figure 26. superimposition of scenarios 14, 16 and 17 on the aerial image

The results of these simulations are presented below:

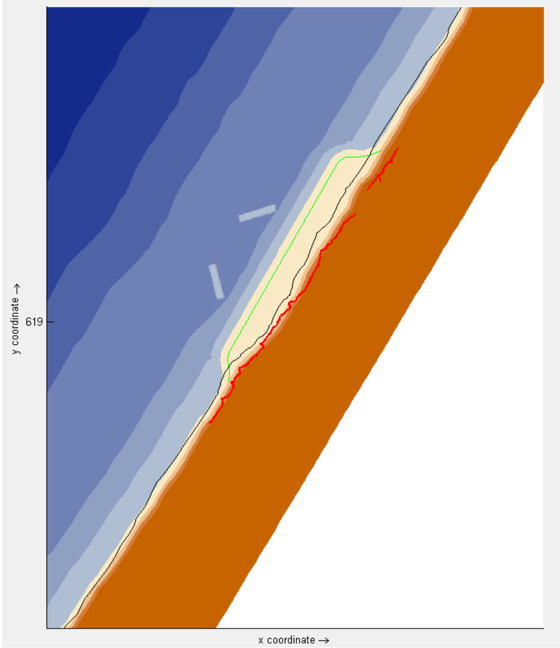
	Scenario 16 (C34)		Scenario 17 (C35)	
Nourishment (m^3)	206 000		206 000	
Elevation of the beach nourishment (mCD)	+1.5		+1.5	
Number of Breakwater	2		2	
Breakwater length (m)	South 90	North 95	South 90	North 96
Assumed breakwater crest width (m)	12	12	12	12
Gap length (m)	147		147	
Breakwater crest level (mCD)	-0.2		-0.2	
Seaward toe level of the breakwater (mCD)	-4.0 to -5.5		-4.0 to -5.5	
Initial berm width (width of the dry beach)	74 to 88 From south to north		74 to 88 From south to north	

Scenario 16: T0 (C34)



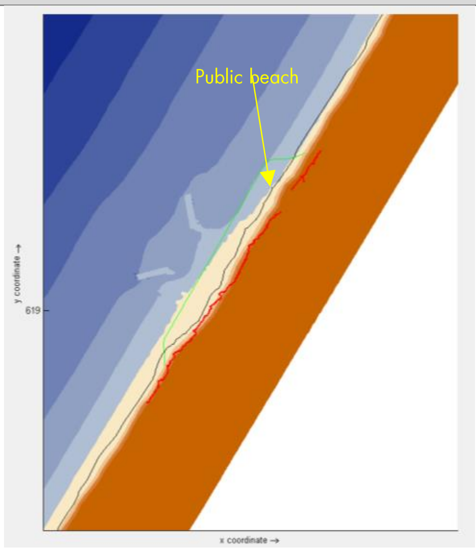
— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD

Scenario 17: T0 (C35)



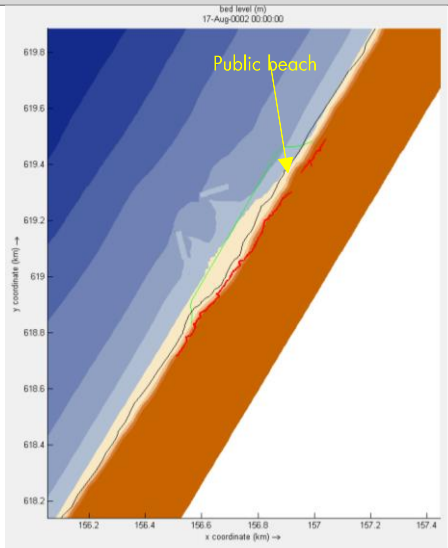
— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD

Scenario 16 : T0+10 years



— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD

Scenario 17 : T0+10 years

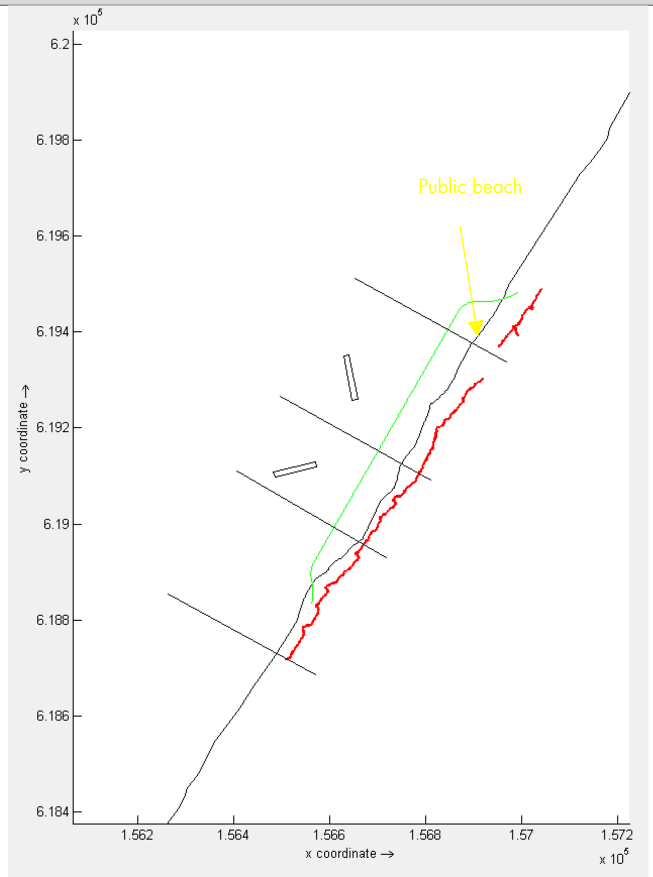
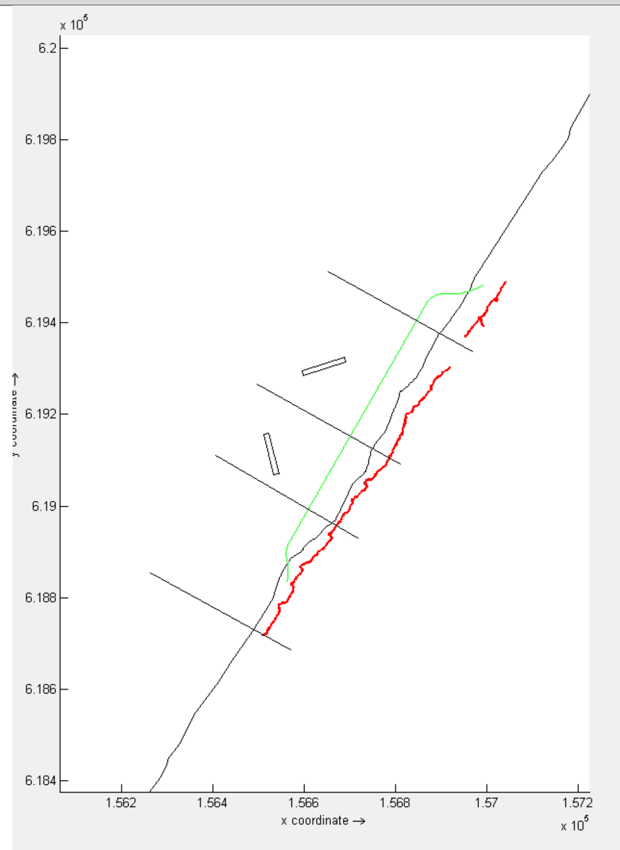


— Initial coastline T0
— Cliffs
— Beach nourishment line at +1.5mCD

Figure 27. Simulations results: scenarios 16 and 17

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 16 and 17

Scenario 16 (C34)	Scenario 17 (C35)
 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD	 — Initial coastline T0 — Cliffs — Beach nourishment line at +1.5mCD

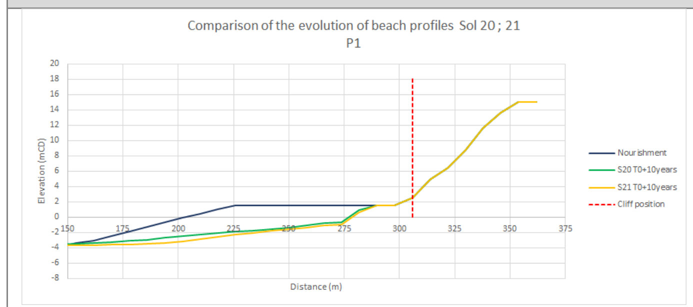
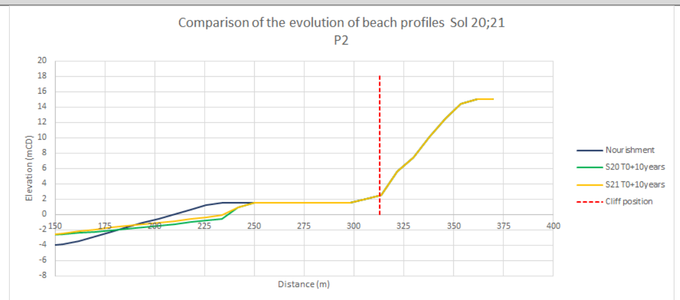
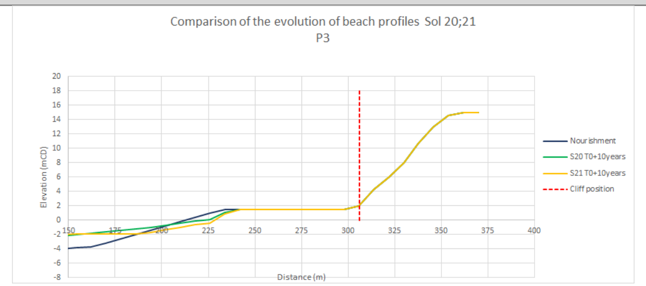
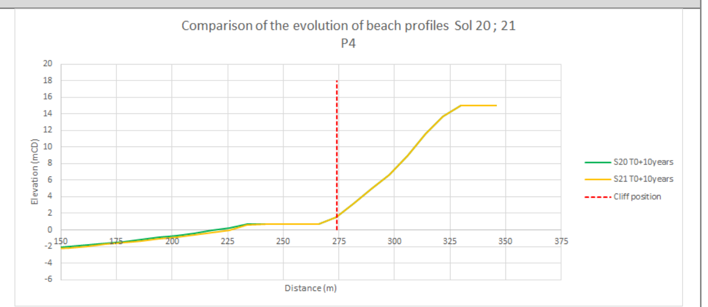
Profile P1	Profile P2	Profile P3	Profile P4
			

Figure 28. Simulation results: scenarios16 and 17 – comparison of the evolution of beach profiles (P1, P2, P3, P4)

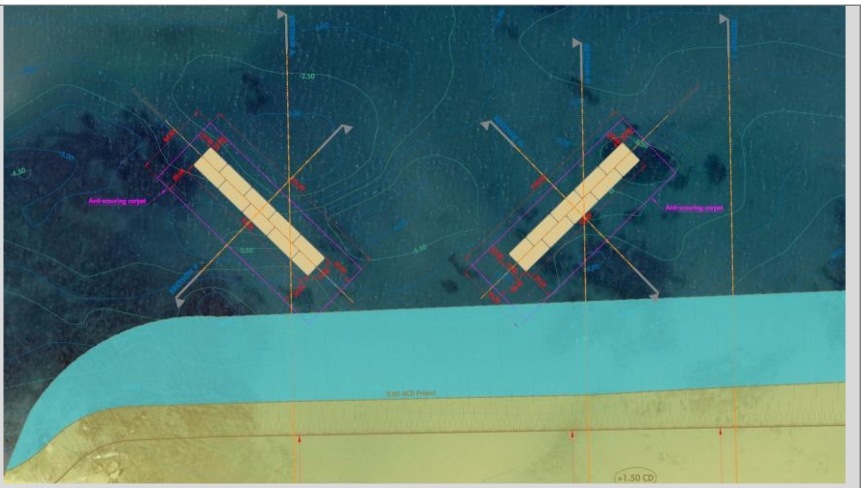
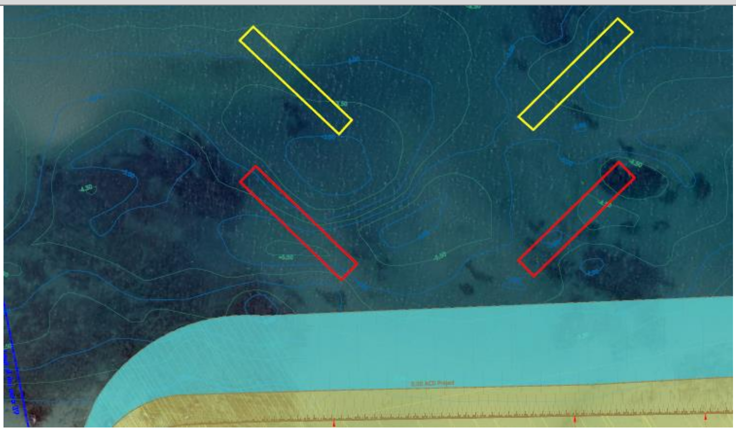
Table 22: table of comparison between the scenarios 16 and 17

Area	Case	Layout description	Nourishment volume	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	S16	Elevation of the beach: +1.5mCD (small nourishment) Beach slope: 4° Number of submerged reefs: 2 Elevation of berm structures: **-0.2mCD** Depth of implantation: -4.0to-5.5mCD Length: 90-95m - Width: **12m** Gap : 147m 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	**64m** Elevation E≥+1.5mCD	**66m** Elevation E≥+1.5mCD	**48m** Elevation E≥ 0.0mCD
	S17	Elevation of the beach: +1.5mCD (small nourishment) Beach slope: 4° Number of submerged reefs: 2 Elevation of berm structures: **-0.2mCD** Depth of implantation: -4.0to-5.5mCD Length: 90-97m - Width: **12m** Gap : 147m 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	**64m** Elevation E≥+1.5mCD	**66m** Elevation E≥+1.5mCD	**48m** Elevation E≥ 0.0mCD

5.2 MOVE THE GEOTUBES REEF OFFSHORE

We also try to simulate the impact a submerged structure litlle bit offshore to see the impact of such a reefs on the beach stability.

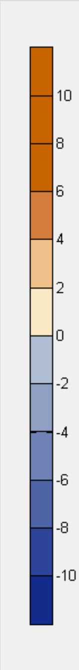
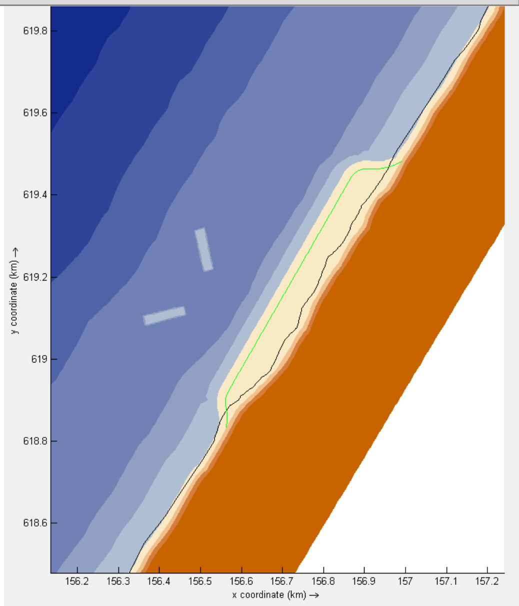
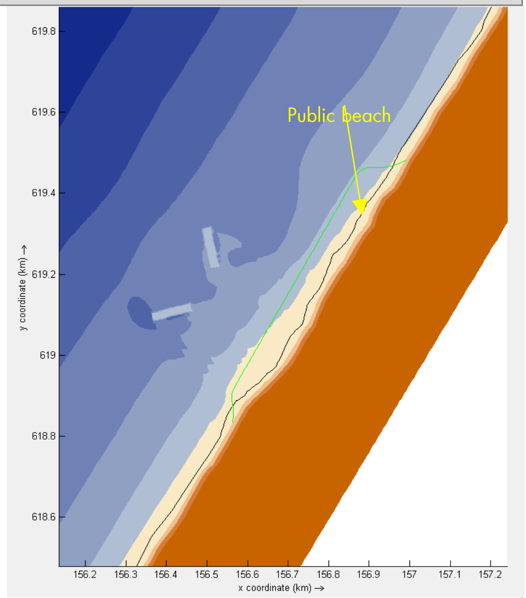
Therefore we perform a test based on scenario 14 but with the installation of the reefs nearly 100 m to the East.

Scenario 14	
Scenario 18	 — scenario 14 — scénario 18

	Scenario 18 (C31)	
Nourishment (m^3)	206 000	
Elevation of the beach nourishment (mCD)	+1.5	
Number of Breakwater	2	
Breakwater length (m)	South 90	North 90
Assumed breakwater crest width (m)	13	
Gap length (m)	110	
Breakwater crest level (mCD)	-0.2mCD	
Seaward toe level of the breakwater (mCD)	-4.5	–6
Initial berm width (width of the dry beach)	74 to 88 From south to north	

NOTA : the water depth is not really different from previous modelling even if the reefs are set further offshore.

The following pictures et cross section give an idea of the long term evolution of the beach shoreline.

Bed level (mCD)	Scenario 18 : T0	Scenario 18 : T 10years
	 —— Initial coastline T0 —— Cliffs —— Beach nourishment line at +1.5mCD	 —— Initial coastline T0 —— Cliffs —— Beach nourishment line at +1.5mCD

Area	Case	Layout description	Nourishment volume	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	S18	Elevation of the beach: +1.5mCD (small nourishment) Beach slope: 4° Number of submerged reefs: 2 Elevation of berm structures: **-0.2mCD** Depth of implantation: -4.5mCD to -6.0mCD Length: 90m - Width: **13m** Gap : 110m 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	**24m** Elevation E≥+1.5mCD	**56m** Elevation E≥+1.5mCD	**74m** Elevation E≥+1.5mCD	**48m** Elevation E≥ 0.0mCD

In this scenario 18, we have more or less the same result as per the previous modelling of the §5 but in this case, the reefs will be much more complicated to install.

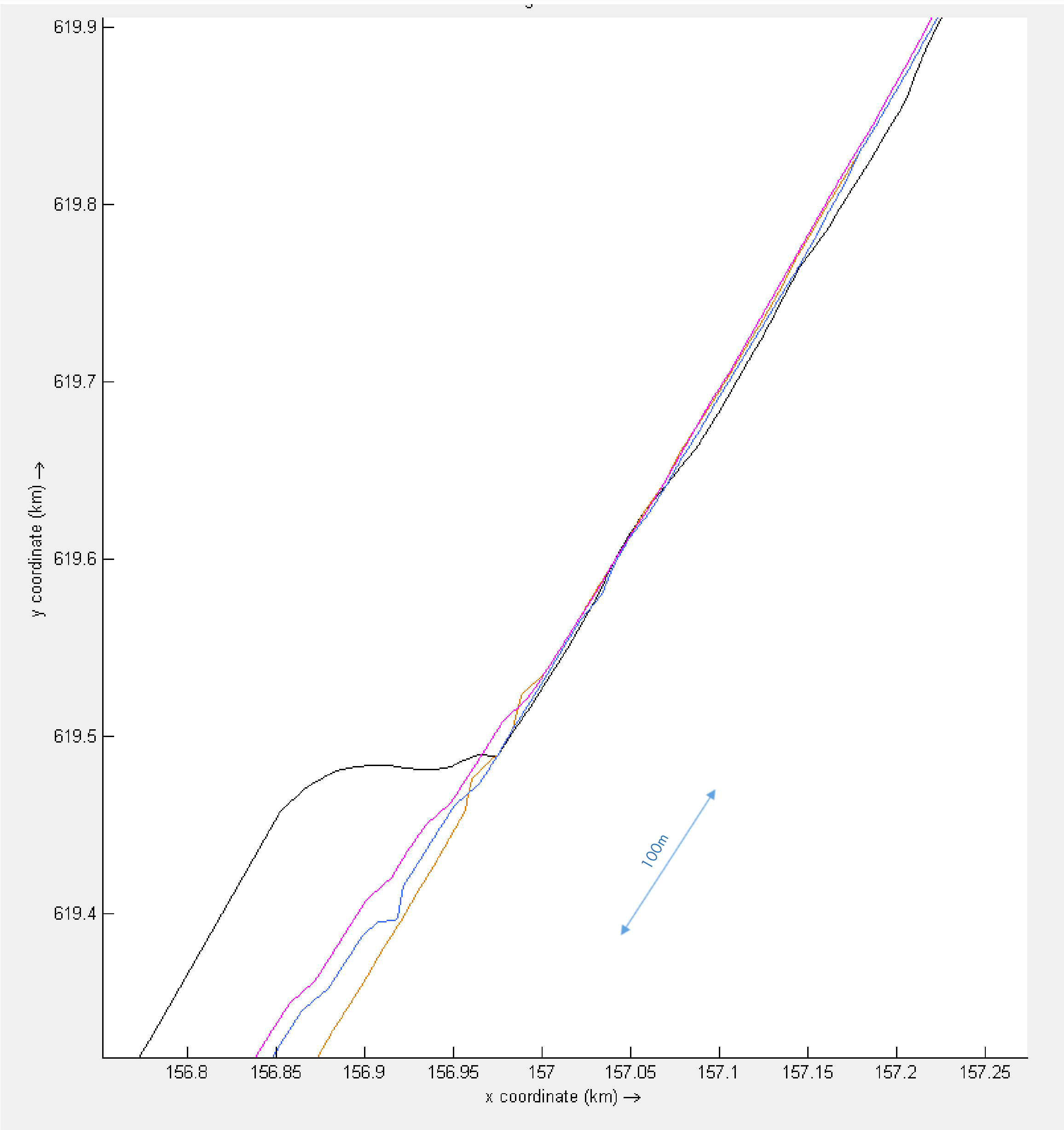
5.3 SUMMARY TABLE SHOWING AMOUNT OF SAND REMAINING EACH YEAR AFTER NOURISHMENT FOR THE RELEVANT SCENARIOS :S12, S14, S16 AND S18

	Scenario 12 (C3)								Scenario 14 (C28)									
Nourishment volume (m3)	206 000 m^3								206 000 m^3									
	Beach berm width from the cliff toe line				% diff				Beach berm width from the cliff toe line					% diff				
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P1	P4	P1	P2	P3	P1	P4
Before nourishment	0.0m CD< Elevation								0.0m CD< Elevation									
	30m	30m	10m	16m					30m	30m	10m	30m	16m					
Elevation of nourishment	+1.5mCD	+1.5mCD	+1.5mCD	/					+1.5mCD	+1.5mCD	+1.5mCD	+1.5mCD	/					
YEAR	E≥ +1.5m CD			0.0m CD <E					E≥ +1.5m CD			0.0m CD <E		E≥ +1.5m CD			0.0m CD <E	
0	88	88	74	16					88	88	74	104	16					
1	64	72	68	20	-27.27	-18.18	-8.11	25.00	56	88	74	68	20	-36.36	0.00	0.00	-34.62	25.00
2	56	72	58	24	-12.50	0.00	-14.71	20.00	40	80	74	52	36	-28.57	-9.09	0.00	-23.53	80.00
3	48	72	58	24	-14.29	0.00	0.00	0.00	24	80	74	36	36	-40.00	0.00	0.00	-30.77	0.00
4	48	64	58	24	0.00	-11.11	0.00	0.00	24	70	74	35	44	0.00	-12.50	0.00	-2.78	22.22
5	40	56	58	24	-16.67	-12.50	0.00	0.00	8	63	74	21	44	-66.67	-10.00	0.00	-40.00	0.00
6	40	56	50	24	0.00	0.00	-13.79	0.00	8	63	74	20	48	0.00	0.00	0.00	-4.76	9.09
7	40	56	50	24	0.00	0.00	0.00	0.00	4	60	74	14	52	-50.00	-4.76	0.00	-30.00	8.33
8	40	56	50	24	0.00	0.00	0.00	0.00	4	60	74	13	56	0.00	0.00	0.00	-7.14	7.69
9	40	56	50	24	0.00	0.00	0.00	0.00	0	60	74	13	56	-100.00	0.00	0.00	0.00	0.00
10	40	56	50	24	0.00	0.00	0.00	0.00	0	60	74	13	56	0.00	0.00	0.00	0.00	0.00

	Scenario 16	Scenario 18

Nourishment volume (m3)	206 000 m³								206 000 m³							
	Beach berm width from the cliff toe line				% diff				Beach berm width from the cliff toe line				% diff			
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
Before nourishment	0.0m CD < Elevation								0.0m CD< Elevation							
	30m	30m	10m	16m					30m	30m	10m	16m				
Elevation of nourishment	+1.5mCD	+1.5mCD	+1.5mCD	/					+1.5mCD	+1.5mCD	+1.5mCD	/				
YEAR	E≥ +1.5m CD			0.0m CD <E					E≥ +1.5m CD			0.0m CD <E				
0	88	88	74	16					88	88	74	16				
1	48	72	74	20	-45.45	-18.18	0.00	25.00	56	80	74	20	-36.36	-9.09	0.00	25.00
2	40	72	74	32	-16.67	0.00	0.00	60.00	40	80	74	22	-28.57	0.00	0.00	10.00
3	32	72	74	36	-20.00	0.00	0.00	12.50	24	80	74	24	-40.00	0.00	0.00	9.09
4	24	72	66	40	-25.00	0.00	-10.81	11.11	24	72	74	36	0.00	-10.00	0.00	50.00
5	16	72	66	44	-33.33	0.00	0.00	10.00	24	72	74	38	0.00	0.00	0.00	5.56
6	16	72	66	48	0.00	0.00	0.00	9.09	24	64	74	40	0.00	-11.11	0.00	5.26
7	16	72	66	48	0.00	0.00	0.00	0.00	24	64	74	40	0.00	0.00	0.00	0.00
8	16	72	66	48	0.00	0.00	0.00	0.00	24	56	74	40	0.00	-12.50	0.00	0.00
9	16	64	66	48	0.00	-11.11	0.00	0.00	24	56	74	44	0.00	0.00	0.00	10.00
10	16	64	66	48	0.00	0.00	0.00	0.00	24	56	74	48	0.00	0.00	0.00	9.09

On the graph below, we observe: the linear impacted upstream of the zone recharged in the case of the installation of a structure:



Line at 0.0 CD - Initial time T0	
Line at 0.0 CD - T0+10: S14	
Line at 0.0 CD - T0+10: S16	
Line at 0.0 CD - T0+10: S18	

Upstream of the recharging zone (further north), the impact on the coastline is not significant. Nota The depth of implementation of Scenario 18 is greater and further from the shore.

5.4 COMPARISON BETWEEN PURE NOURISHMENT SCENARIO 12 AND SCENARIO 16.

Following thye 27th July meeting, we were asked to compare the beach evolution on the 1D model between scenario 12 and scenario 16. It is important to note that 1D simulation can not predict global shoreline as 2D impact are not taken into account. The most relevant information in 1D models the beach slope.

In detailed design, further modelling will have to be performed on storm condition retreat.

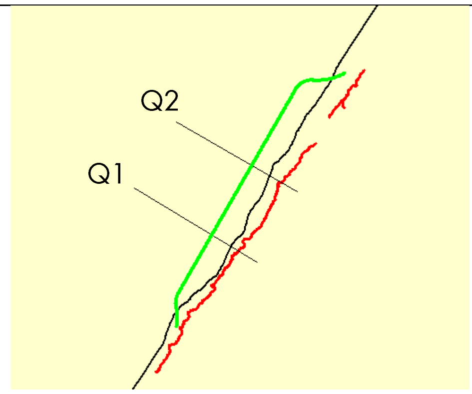
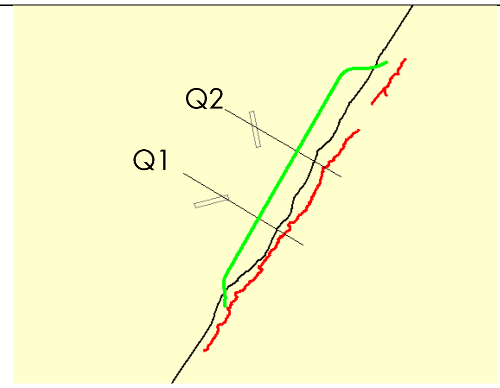
Numerical simulations of beach erosion due to a storm on scenarios 12 and 16 were performed using the SBEACH model (1DH).

The SBEACH model (Storm-induced BEAch Change model) is a numerical model of beach erosion due to a storm. The modeling is carried out on a profile perpendicular to the coast. The height of the swell and the water level are taken into account. The model is used as part of beach reloading, or other study of changing the beach profile.

It is a sediment transport model based **on the balance of the profile**. It takes into account the surge of the swell for regular waves or for a random swell. The run-up is calculated, as well as the water level due to the waves and the submersion of the beach. Non-erodible funds are taken into account.

The calibration of the model (wave, current ...) was carried out on the basis of a sediment size of d50 = 0.25mm.

On each simulation, the sediment size is the same on all the model and not only on the nourishment zone.

Scenario 12	Scenario 16
	

The results obtained are given in the following tables and make it possible to make a comparison of the evolution of the coastline without and with the placement of the submerged reefs.

Scenario 12 – Profile Q1						
Return Period (Year)	WL (m CD)	Hs (m) shallow	Erosion at +0m CD (m)	Erosion at +0.5m CD (m)	Erosion at +1.0m CD (m)	Erosion at +1.5m CD (m)
1	0.6	4.7	18.2	24.7	29.9	33.8
5	0.6	6.1	16.9	23.4	29.9	33.8
10	0.6	6.7	16.9	23.4	29.9	35.1
20	0.6	7.3	16.9	23.4	29.9	35.1
50	0.6	8	16.9	23.4	31.2	36.4
100	0.6	8.4	16.9	23.4	31.2	36.4

Scenario 16 – Profile Q1						
Return Period (Year)	WL (m CD)	Hs (m) shallow	Erosion at +0m CD (m)	Erosion at +0.5m CD (m)	Erosion at +1.0m CD (m)	Erosion at +1.5m CD (m)
1	0.6	4.7	1.3	10.4	20.8	27.3
5	0.6	6.1	2.6	11.7	22.1	27.3
10	0.6	6.7	5.2	13.6	22.1	28.6
20	0.6	7.3	5.2	14.3	24.7	29.9
50	0.6	8	5.2	15.6	24.7	31.2
100	0.6	8.4	5.2	16.2	26	31.2

Scenario 12 – Profile Q2						
Return Period (Year)	WL (m CD)	Hs (m) shallow	Erosion at +0m CD (m)	Erosion at +0.5m CD (m)	Erosion at +1.0m CD (m)	Erosion at +1.5m CD (m)
1	0.6	4.7	18.2	24.7	28.6	36.4
5	0.6	6.1	16.9	23.4	28.6	37.7
10	0.6	6.7	16.9	23.4	29.9	37.7
20	0.6	7.3	16.9	23.4	29.9	40.3
50	0.6	8	15.6	22.1	29.9	40.3
100	0.6	8.4	15.6	22.1	31.2	40.3

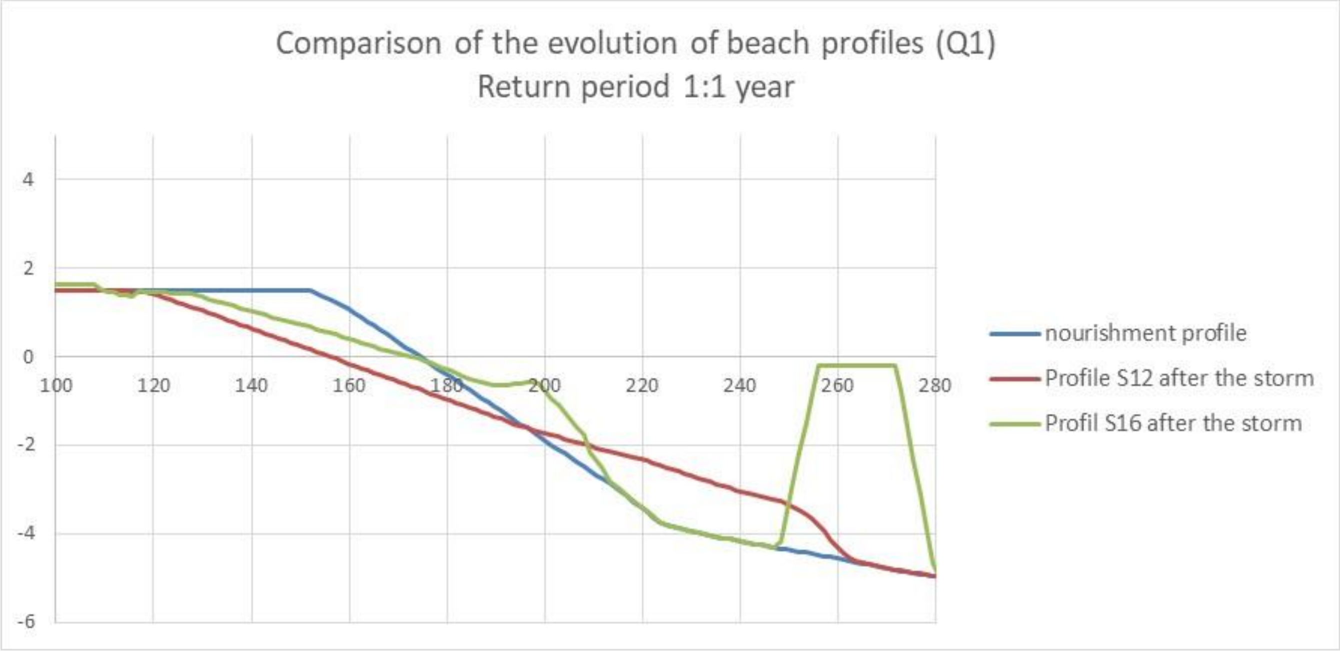
Scenario 16 – Profile Q2						
Return Period (Year)	WL (m CD)	Hs (m) shallow	Erosion at +0m CD (m)	Erosion at +0.5m CD (m)	Erosion at +1.0m CD (m)	Erosion at +1.5m CD (m)
1	0.6	4.7	2.6	11.7	20.8	32.5
5	0.6	6.1	3.9	11.7	22.1	31.2
10	0.6	6.7	3.9	13	23.4	32.5
20	0.6	7.3	5.2	14.3	24.7	33.8
50	0.6	8	5.2	15.6	24.7	35.1
100	0.6	8.4	6.5	15.6	26	36.4

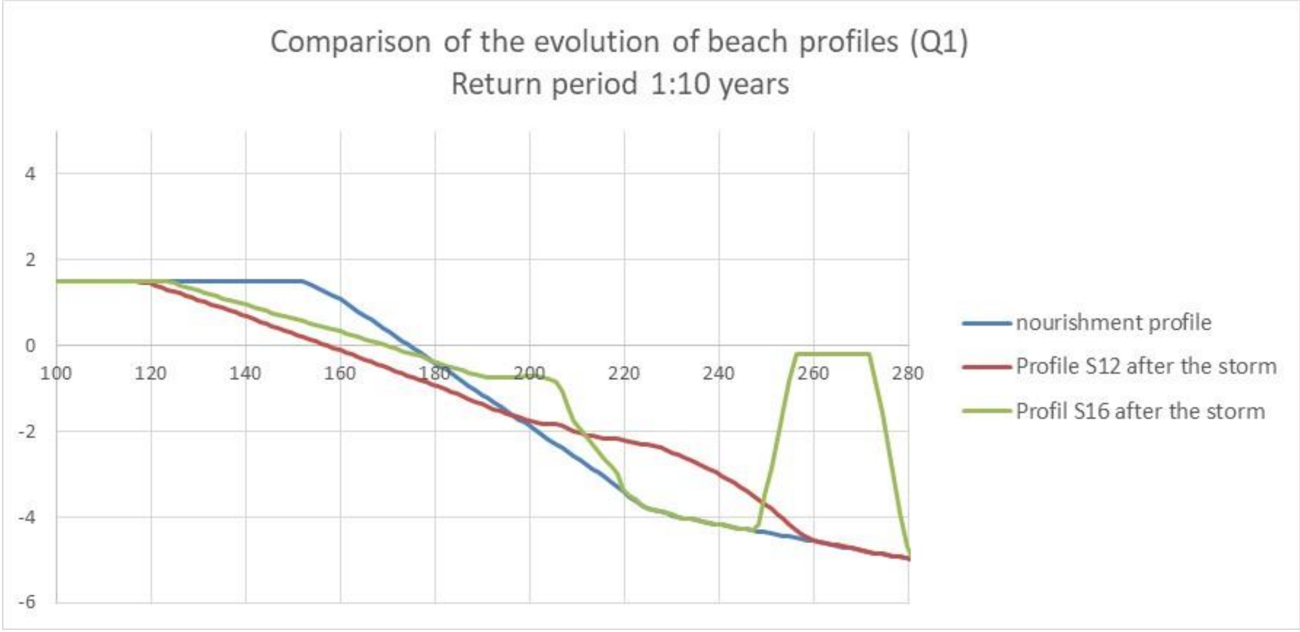
In conclusion, it is important to note that 1D model are not really relevant for a V shape reef as the V shape induce 2D event 3D effects that Sbeach cannot simulate. But for pure nourishment with a swell perpendicular to the shore the precision of the information are relevant.

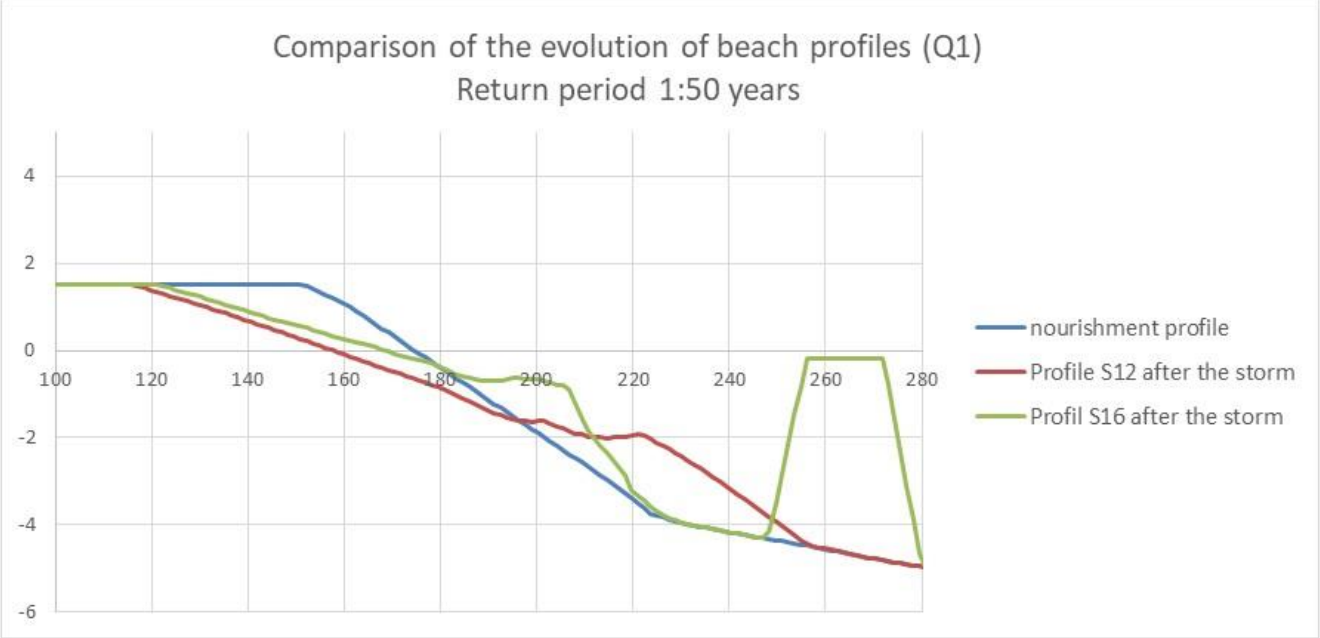
In addition, the rocky part of the seabed are not taken into consideration.

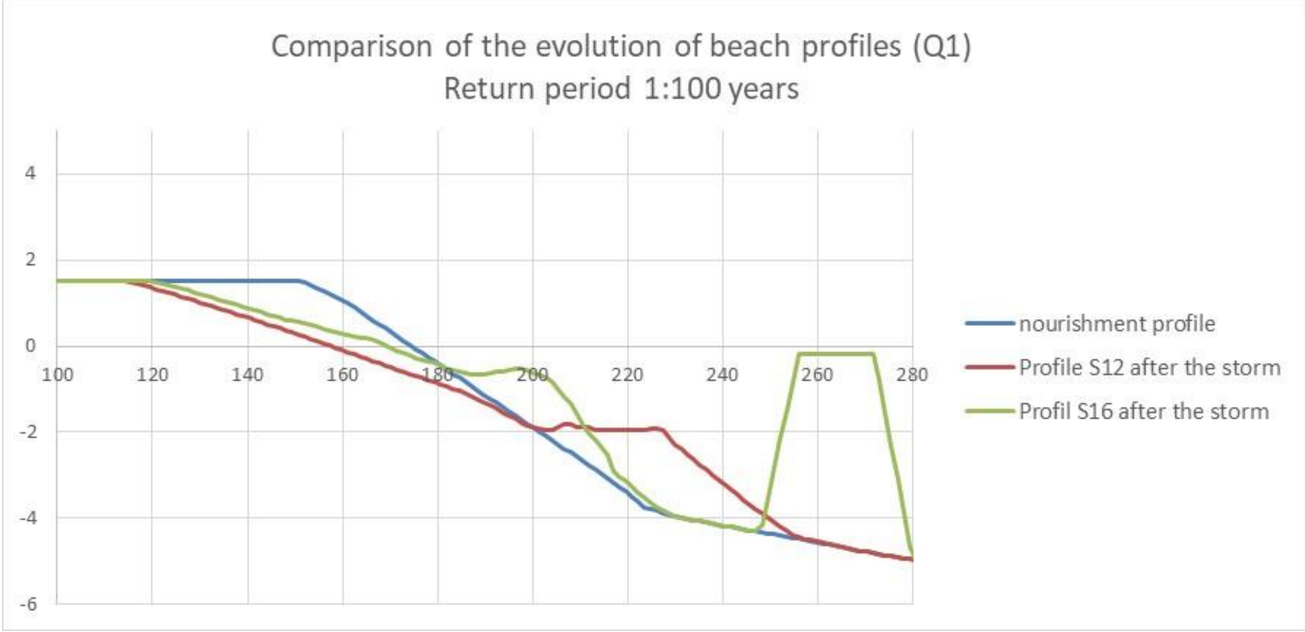
What we can see is that scenario 16 shows less erosion than scenario 12 especially at low level (0 and 0.5 CD). Man can see that the slope of the beach is much steeper and retreat with pure nourishment scenario.

Comparison of the evolution of the beach profiles Q1

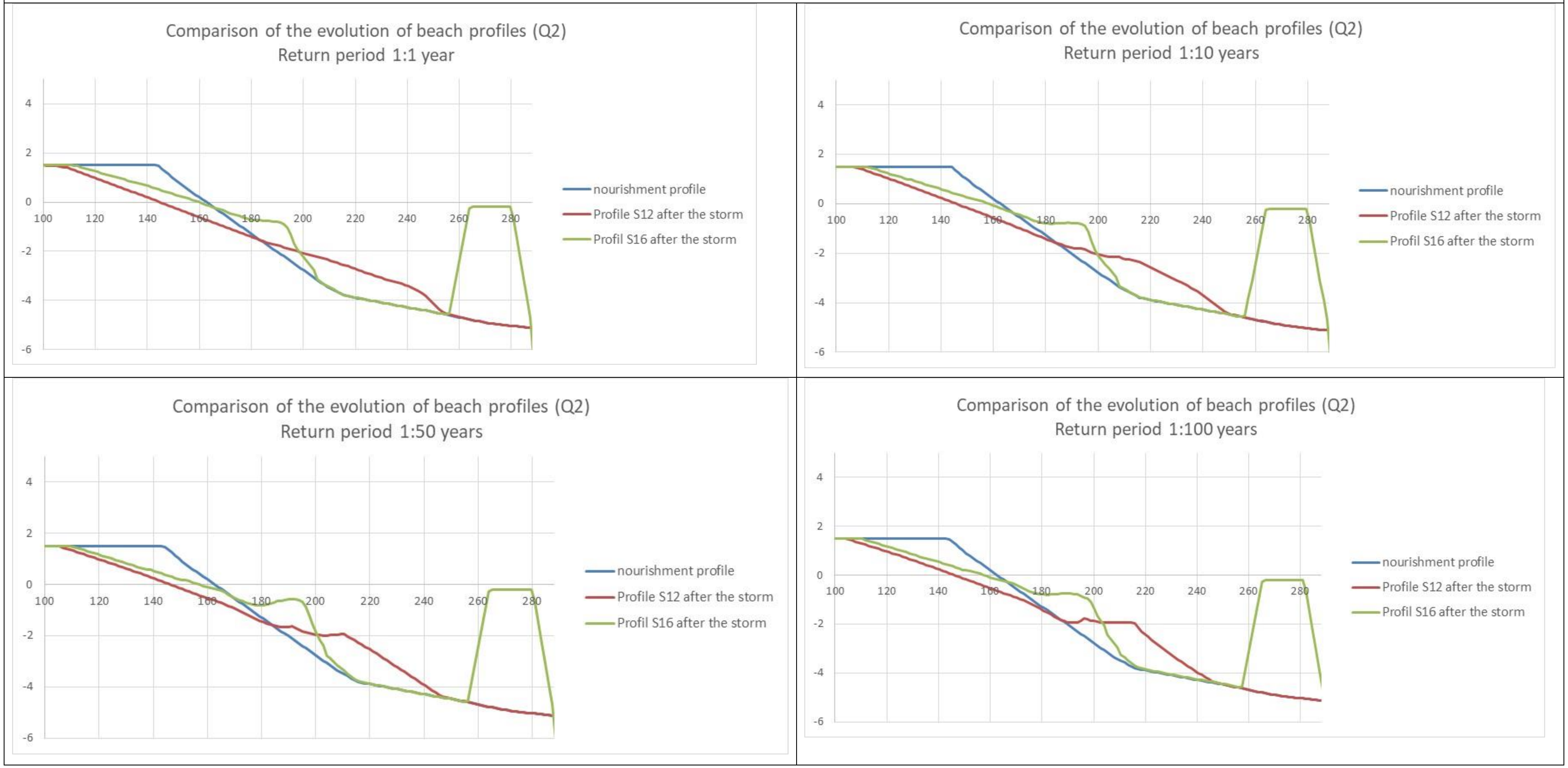








Comparison of the evolution of the beach profiles Q2



Those simulation give confirmation that pure nourishment may result in severe retreat during big storm event.

In the following table are reported sand volumes remaining annually on 10 years of simulation after initial nourishment of 206 000m³. XBeach results.

	Evolution of nourishment volume sand each year	
	S16	S12
T0	205 955.7 m³	205 982.0 m³
1 year	157 587.9 m³	151 211.5 m³
2 years	139 384.6 m³	134 258.2 m³
3 years	136 633.4 m³	124 740.5 m³
4 years	117 909.8 m³	117 857.6 m³
5 years	123 124.1 m³	115 506.2 m³
6 years	110 199.7 m³	113 221.2 m³
7 years	121 591.5 m³	114 833.5 m³
8 years	109 714.9 m³	113 653.7 m³
9 years	119 681.6 m³	116 501.1 m³
10 years	108 102.9 m³	116 252.8 m³

5.5 SWIMMER SAFETY

One can imagine that geotubes might change the condition for swimmers.

So we have to assess the currents in the maximum swimming conditions and compare them to conditions around the existing breakwaters.

First thing to know is that the geotubes should never be allowed to cross by anyone either swimmers or motor boat, sailing boats or any device.

To do so, warning buoys should be install all around the structure to show their location and prevent any accidental trespassing.

This is really important also according to the current because on top of the submerged structure, as it's a shallow water area current might be quite strong as it will be shown on the picture below.

Knowing that the geotubes will not allowed to anyone, we can compare the modeling of the existing situation and the future situation on the current point of view.

To do so, we run the model for the existing situation and the future situation with 1,5 m waves offshore which might be the limit for the swimmers to practice.

This situation is not exceed more than 10 % of time during a year.

The pictures below present the two situations in terms of currents.

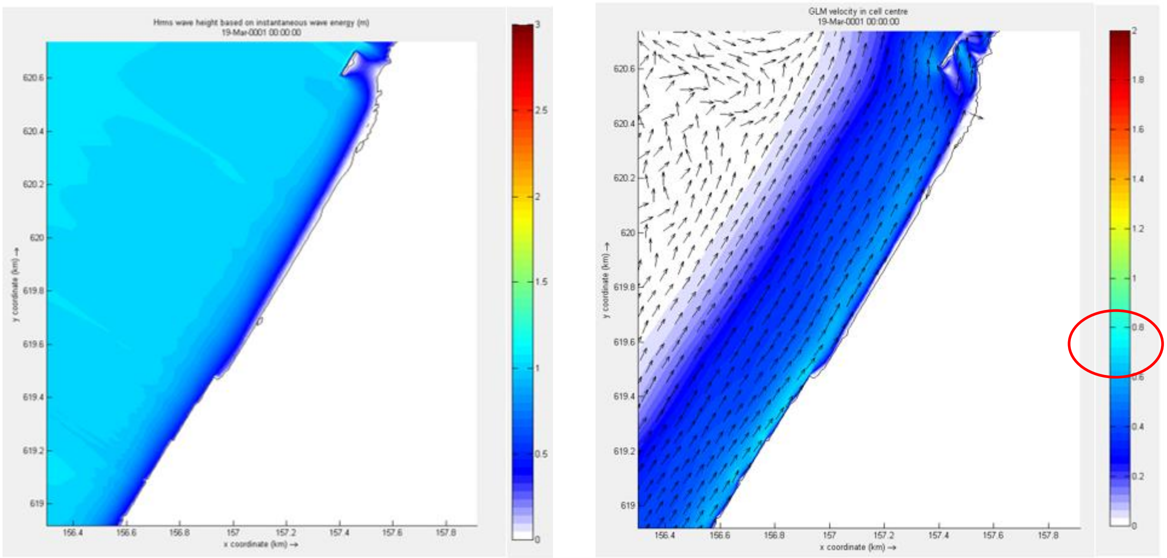


Figure 29 : Existing situation for current analysis

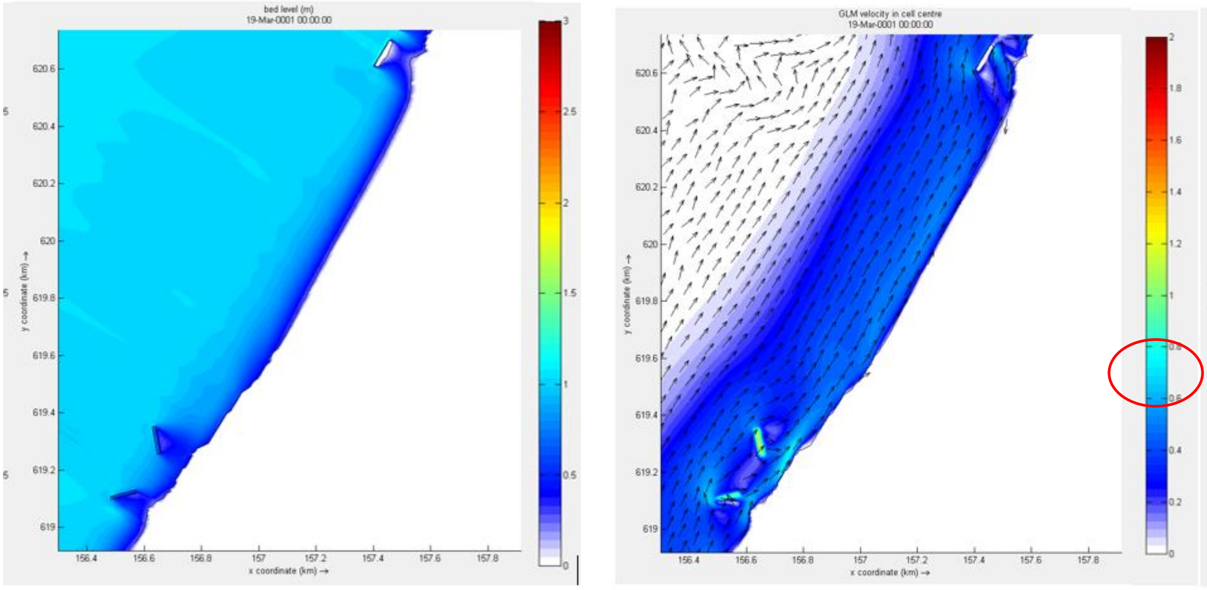


Figure 30 : Future situation for currents analysis (S16)

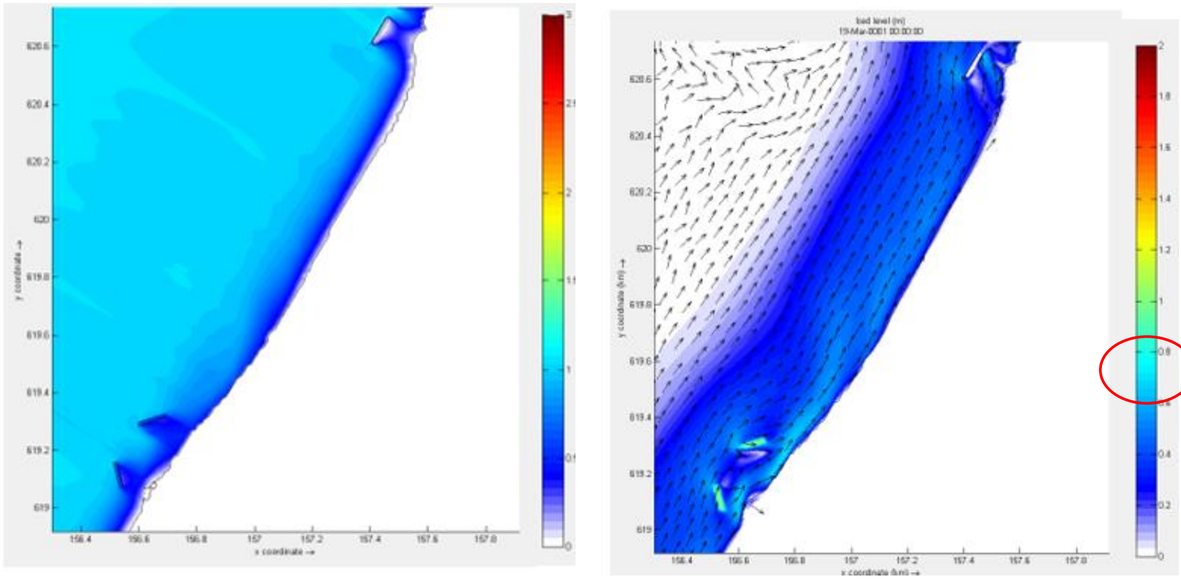


Figure 31 : Future situation for currents analysis (S17)

The pictures shows that the current in the existing situation is more than 0,9 m/s while in the future situation the current will be less than 0,9 m/s except on top of the submerged breakwaters.

Furthermore, we can see that the gap between the geotubes are wide enough to limit the current to reasonable value.

We can then conclude that the current will be of the same amount in the future situation than in actual situation except on top of the geotubes but buoys will prevent any crossing.

5.6 CONCLUSION OF COMPLEMENTARY SIMULATIONS DU TO ROCKY SEABED

By shifting the geotubes slightly to the north, so as to position them in a sand zone, it is possible to improve the results obtained in profile No. 1, compared with scenario 14. After 10 years of simulation, the width of the recharged beach is between 16 and 66m from North to South.

The simulations carried out also show that the orientation of the geotubes leads to similar results (scenarios 17 and 18).

For the project, either solutions (16,17) can be retained.

It should be noted that, compared to the modeling phase, in the design / realization phase, the length of the reefs may slightly change (elongation) in order to adapt to the standard length of the geotubes.

However, it will be necessary to check the quality of the bottom (positioning of the rocky areas by an in-situ survey) and to check the thicknesses of sand in order to integrate them in the simulations to control the behaviour of the coastline taking into account these parameters also.

With this information, we will be able to proceed to the detailed design stage.

6 REFERENCES

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[3] SERGIU DOV ROSEN in Coastal Engineering 2012: Assessing present and future Mediterranean Sea level rise impact on Isreal's coast and mitigation ways against beach and cliff erosion

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