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EVALUATION OF CLIMATE CHANGE IMPACTS AND ADAPTATION RESPONSES FOR MARINE ACTIVITIES

SUBDOCUMENT COASTAL FLOODING

CLIMAR – Evaluation of climate change impacts and adaptation responses for marine activities

Subdocument Coastal Flooding

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Abstract

Within the project CLIMAR an attempt is made to develop an evaluation framework for adaptation responses to climate change induced impacts within the North Sea environment. The identification and quantification of all the possible secondary impacts of climate change is handled on a sectoral level. The different case-studies investigated in the framework of the research are fishery, tourism, sand and gravel extraction, the port of Zeebrugge and flood risks. This document gives an overview of all the different types of land occupation and infrastructure within the coastal zone that might be subject to flood risks as a consequence of primary climate change impacts.

EVALUATION OF CLIMATE CHANGE IMPACTS AND ADAPTATION RESPONSES FOR MARINE ACTIVITIES

(CLIMAR)

INTERMEDIARY REPORT

SUBDOCUMENT COASTAL FLOODING

General study and evaluation of potential impacts of climate change on the Belgian Part of the North Sea

Date:	March 2008
Author:	Katrien Van der Biest (WL)

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1 COASTAL INFRASTRUCTURE

When identifying the secondary impacts of climate change on coastal flooding, the first 10 kilometres landwards from the coastline have to be taken into consideration. A breach which is formed in the sea defence, can potentially lead to flooding of the whole area of the coastal hinterland situated below the depth of the breach. Fig. 1 illustrates the vulnerability of the Belgian coastal zone: a large part of the hinterland area is located at approximately 2m below the level of an average yearly storm of 5,5m TAW (Verwaest et al., 2005). Therefore, the coastline itself together with the coastal areas below 5m TAW and within the strip of 10km landwards from the shoreline will be taken into account in the identification and quantification of the impacts of climate change.

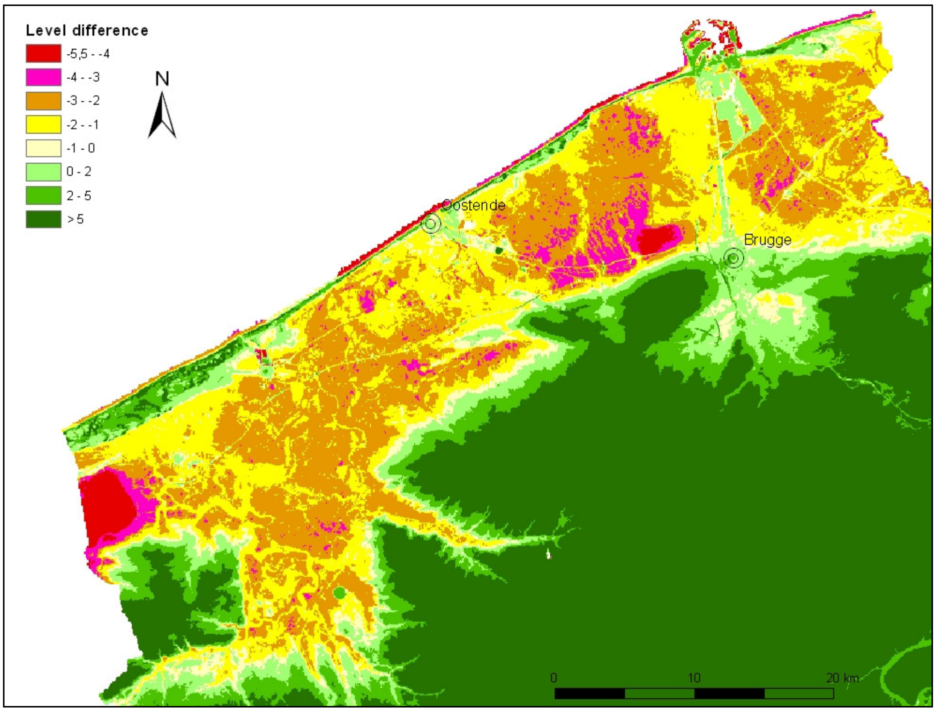

Fig. 1 - Level difference between land and North Sea during an average yearly storm of 5,5m TAW (edited from Verwaest et al., 2005)

Because statistical data are usually available on municipality level, the limit of the study area is fixed to the southern border of (sub) municipalities that lie to a large extent within the strip of 10km and below 5m TAW (Fig. 2). If the largest part of the amalgamated municipality lies within this strip, the whole municipality will be taken into account. If just a small part lies within the strip then only the formerly independent municipality lying within 10km will be considered (ex.: *Jabbeke* is not completely within the study-area, only the sub municipality *Stalhille* is considered).

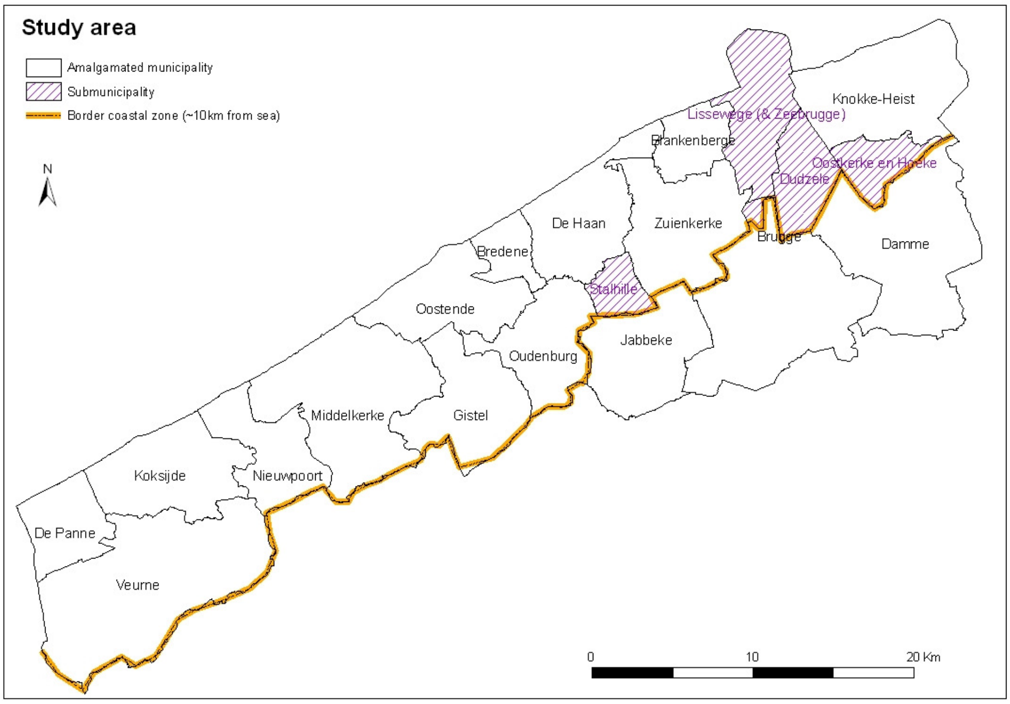

Fig. 2 - Study area for the case-study of coastal flooding risks

The main effects of climate change which will have an impact on coastal infrastructure are sea level rise and increase in storminess. Both of these elements will result in an increase in flooding risks and a higher erosion rate of the coastline. On its turn, these events will cause considerable secondary impacts on ecologic, economic and social structures related to coastal infrastructure.

More specifically, flooding risks are expected to increase due to a combination of different changing factors:

1) Effects of climate changes: higher sea level, increased erosion of the coastline, higher wave impact (significant wave height and storm surge). These changing physical parameters will increase the **probability** of occurrence of extreme storm events (return period).

2) Increasing human settlement and development along the coastline. These man-induced changes will lead to higher damages when an extreme weather event occurs (**impact** increases).

RISK = PROBABILITY x IMPACT

1.1 DEFENSE STRUCTURES

The Belgian shoreline is protected against erosion by a variety of artificial defence techniques (Fig. 3): hard structures such as dikes, dune foot reinforcements, jetties, quay walls, weirs, locks and groynes, as well as soft defence measures such as sand nourishments, marram grass, brushwood and managed retreat. More then half of the Belgian coastline is protected against erosion and flooding by reinforcement measures (Belpaeme & Konings, 2004).

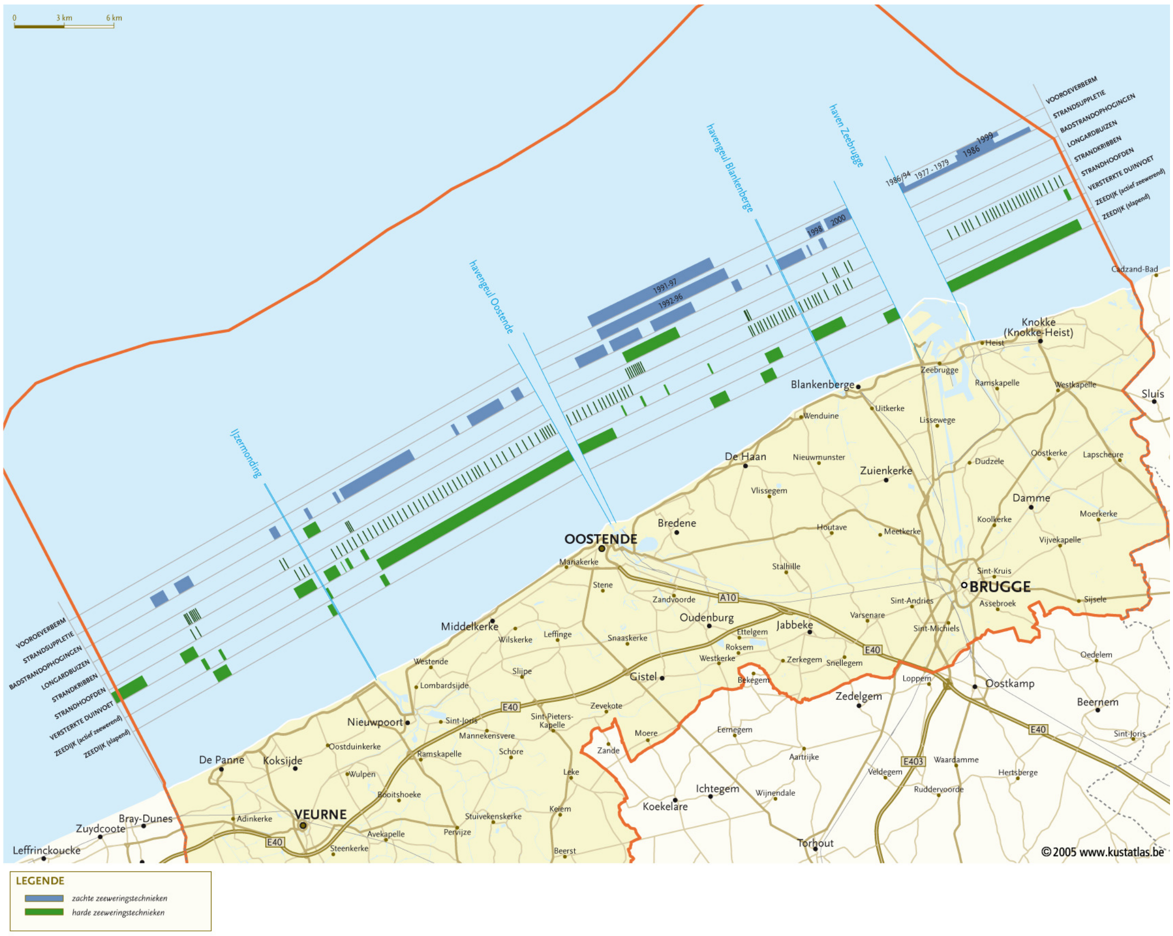

Fig. 3 - Overview of coastal defence techniques along the Belgian coastline (Belpaeme & Konings, 2004)

1.1.1 Intensity

1.1.1.1 Dikes

In Belgium, nearly 50% of the coastline is protected by hard dikes. The most common materials from which the constructions are made up are red bricks (Fig. 4) or concrete bricks (Fig. 6) with a concrete basis underneath. At some locations the top layer consists of rubbles (Fig. 4), Tournaisian limestone (Fig. 4 5) or concrete. As bottom layer other materials like bituminous sand and loam are also used sometimes. The total thickness of the seawalls ranges between 0,25m and 1,2m while the slope of the dike usually ranges between 8/4 to 12/4 (Fig. 8).

At the top of some dikes, the slope ends in a small vertical wall about 0,4m to 0,7m high (Fig. 7). It is constructed to reduce the wave overtopping discharges during storms.

In Table 1 an inventory of all the dikes along the Belgian coastline is given.

Fig. 4 - Dike made up of bricks (L), rubbles (R)

Fig. 5 - Dike made up of Tournaisian limestone

Fig. 6 - Dike made up of concrete stones *Fig. 7 - Small vertical wall at the top of the dike*

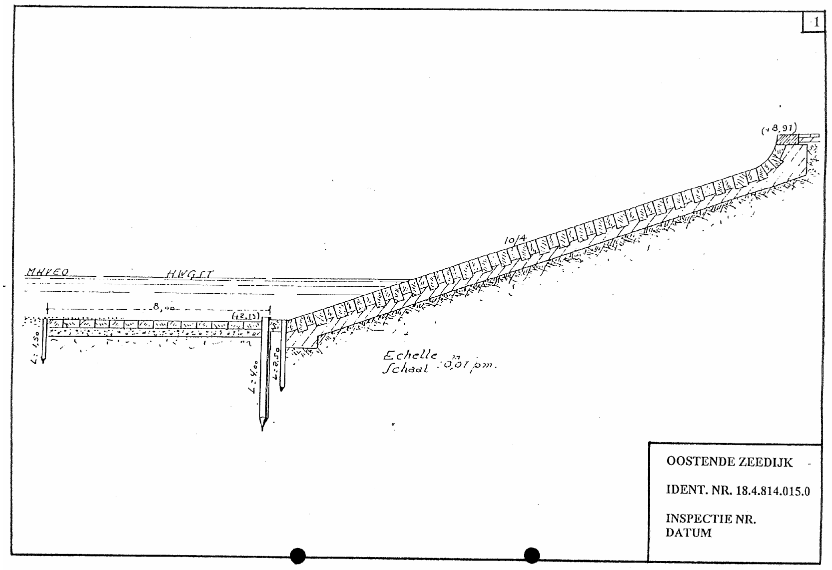

Fig. 8 - Example of dike construction (Afdeling Kust)

Nr. dike	Start coord. X	Start coord. Y	End coord. X	End coord. Y	Constr. year	Section nr.	Community
18.4.811.3.0	27444.02	201967.82	27804.00	202218.00	1953	26	Koksijde
18.4.811.4.0	27803.78	202217.75	27876.00	202266.00	1951	27	Koksijde
18.4.811.5.0	27875.73	202266.00	27975.00	202328.00	1953	27_28	Koksijde
18.4.811.6.0	27975.48	202327.84	28053.00	202375.00	1949	28	Koksijde
18.4.811.7.0	28052.74	202375.27	28143.00	202421.00	1957	29	Koksijde
18.4.811.8.0	28142.97	202420.67	28504.00	202621.00	1967	29_31	Koksijde
18.4.811.9.0	28504.09	202620.67	28543.00	202653.00	1953	32	Koksijde
18.4.812.1.0	33532.00	205103.00	33879.00	205326.00	1900	54_56	Nieuwpoort
18.4.812.2.0	33879.00	205326.00	34090.00	205469.00	1952	57	Nieuwpoort
18.4.812.3.0	34090.00	205469.00	34191.02	205535.92	1953	57	Nieuwpoort
18.4.812.4.0	34192.56	205536.43	34252.38	205578.87	1953	57	Nieuwpoort
18.4.812.5.0	34252.38	205578.87	34322.43	205636.13	1953	58	Nieuwpoort

18.4.812.6.0	34322.43	205636.13	34420.08	205703.63	1953	58	Nieuwpoort
18.4.812.7.0	34420.08	205703.63	34484.00	205749.13	1953	58	Nieuwpoort
18.4.812.8.0	34484.00	205749.13	34739.14	205928.09	1930	58	Nieuwpoort
18.4.812.9.0	34739.14	205928.09	34757.03	206029.84	1950	59	Nieuwpoort
18.4.812.10.0	34964.00	206107.30	35110.00	206198.00	1935	60	Nieuwpoort
18.4.813.1.0	37684.50	207438.69	37906.26	207564.71	?	73	Westende
18.4.813.2.0	37906.63	207565.84	37965.96	207670.90	?	74	Westende
18.4.813.3.0	37966.72	207671.66	38793.56	208148.56	?	74_76	Westende
18.4.813.4.0	38792.05	208170.86	39222.00	208453.00	1900	77_78	Middelkerke
18.4.813.5.0	39222.00	208453.00	39269.33	208463.35	1953	78	Middelkerke
18.4.813.6.0	39269.33	208463.35	39393.69	208543.17	1905 ?	79	Middelkerke
18.4.813.7.0	39393.69	208543.17	39406.00	208579.00	1953	79	Middelkerke
18.4.813.8.0	39405.59	208578.87	39560.00	208683.00		79	Middelkerke
18.4.813.10.0	39607.88	208669.73	39647.91	208698.94	1977	80	Middelkerke
18.4.813.11.0	39647.91	208698.94	39712.82	208742.21	1975	80	Middelkerke
18.4.813.12.0	39712.82	208742.21	39727.96	208750.87	1953	80	Middelkerke
18.4.813.13.0	39727.96	208750.87	39819.91	208816.85	1984	80	Middelkerke
18.4.813.9.0	39560.29	208682.72	39608.00	208670.00	1953	80	Middelkerke
18.4.813.14.0	39819.91	208816.85	39894.55	208868.78	1975	81	Middelkerke
18.4.813.15.0	39894.55	208868.78	39970.28	208920.70	1953	81	Middelkerke
18.4.813.16.0	39970.28	208920.70	40033.02	208966.14	1973	81	Middelkerke
18.4.813.17.0	40033.02	208966.14	40135.24	209031.04	1978	81	Middelkerke
18.4.813.18.0	40135.24	209031.04	40267.74	209123.92	1953	82	Middelkerke
18.4.813.19.0	40268.50	209124.67	40346.19	209180.33	1900	82	Middelkerke
18.4.813.20.0	40346.19	209180.33	41124.52	209692.27	1900	83_84	Middelkerke
18.4.813.21.0	41124.52	209692.27	41150.89	209705.13	1953	85	Middelkerke
18.4.813.22.0	41150.89	209705.13	41192.13	209736.90	1902	85	Middelkerke
18.4.813.23.0	41192.13	209736.90	41290.84	209859.95	1978	86	Middelkerke
18.4.813.24.0	41290.84	209859.95	41339.52	209820.73	1953	86	Middelkerke
18.4.813.25.0	41339.52	209820.73	41440.94	209885.64	1905	86	Middelkerke
18.4.813.26.0	41440.94	209885.64	41959.51	210216.93	1905	87	Middelkerke
18.4.813.27.0	41959.51	210216.93	42000.07	210242.62	1908	88	Middelkerke
18.4.813.28.0	42000.07	210242.62	42041.99	210269.67	1953	88	Middelkerke
18.4.813.29.0	42041.99	210269.67	42938.73	210877.74	1908	89_91	Middelkerke
18.4.813.30.0	42939.48	210877.37	43031.81	210937.32	2000	92	Middelkerke
18.4.813.31.0	43031.81	210937.32	43107.02	210982.96	1976	92	Middelkerke
18.4.813.32.0	43107.02	210982.96	43189.27	211038.73	2000	92	Middelkerke
18.4.814.1.0	43190.03	211038.73	43231.22	211063.67	1997	93	Raversijde
18.4.814.3.0	43190.78	211039.11	43308.31	211113.93	1900/1998	93	Raversijde
18.4.814.4.0	43309.07	211114.69	43348.00	211139.00	1998	93	Raversijde
18.4.814.5.0	43348.00	211139.00	43435.29	211198.96	1976	93	Raversijde
18.4.814.2.0	43231.98	211064.05	43308.69	211114.31	1996	93	Raversijde
18.4.814.6.0	43436.42	211199.34	43827.00	211452.00	1900	94_96	Raversijde
18.4.814.7.0	43827.00	211452.00	43865.00	211478.00	?	96	Raversijde
18.4.814.8.0	43865.00	211478.00	44210.00	211709.00	1900	96	Raversijde
18.4.814.9.0	44210.00	211709.00	45925.00	212922.00	1900	97_103	Rav./Mariak.
18.4.814.10.0	45925.00	212922.00	46071.00	213010.00	1900	104	Mariakerke
18.4.814.11.0	46071.00	213010.00	47379.54	213816.49	1900/2000	105_109	Mariak./Oost.
18.4.814.12.0	47379.54	213816.49	47420.00	213854.00	2000	110	Oostende
18.4.814.13.0	47420.00	213854.00	47889.00	214206.00	1900/1988	111	Oostende

18.4.814.14.0	47889.00	214206.00	48182.00	214439.00	1935	112	Oostende
18.4.814.15.0	48170.01	214562.77	48722.84	214949.87	1900	113_117	Oostende
18.4.814.16.0	48726.18	214948.75	48822.00	214906.00	1979	117	Oostende
18.4.814.17.0	48822.00	214906.00	49014.27	214870.89	1900	117	Oostende
18.4.815.1.0	49085.85	215137.09	49419.48	215158.61	1815	118	Oostende
18.4.815.2.0	49436.00	215147.00	49463.00	215195.00	1900	119	Oostende
18.4.815.3.0	49463.00	215195.00	49498.00	215224.00	1953	119	Oostende
18.4.815.4.0	49498.00	215224.00	49601.00	215300.00	1977	119	Oostende
18.4.815.10.0	49707.91	215339.76	49923.00	215459.00	1912	120	Oostende
18.4.815.5.0	49601.00	215300.00	49631.17	215318.67	1912	120	Oostende
18.4.815.6.0	49631.32	215318.49	49649.04	215320.95	1912	120	Oostende
18.4.815.7.0	49649.86	215320.95	49687.47	215332.12	1974	120	Oostende
18.4.815.8.0	49688.29	215331.85	49696.74	215334.85	1912	120	Oostende
18.4.815.9.0	49697.83	215335.12	49707.64	215339.76	1974	120	Oostende
18.4.815.11.0	49923.00	215459.00	49943.69	215470.59	1953	121	Oostende
18.4.815.12.0	49943.97	215471.14	50017.29	215513.11	1977	121	Oostende
18.4.815.13.0	50017.56	215512.84	50078.07	215554.54	1900	121	Oostende
18.4.815.14.0	50078.34	215554.54	50112.42	215573.08	1977	121	Oostende
18.4.815.15.0	50112.42	215573.35	50286.92	215682.41	1953	122	Oostende
18.4.815.16.0	50287.60	215682.75	50407.17	215754.28	1953	123	Oost./Bred.
18.4.815.17.0	50407.51	215754.62	50630.63	215888.16	1912	123	Bredene
18.4.815.18.0	50631.31	215888.84	50646.64	215898.72	1903	123	Bredene
18.4.815.19.0	50646.98	215898.72	51068.02	216151.47	1912	123_124	Bredene
18.4.815.20.0	51070.06	216152.16	51095.61	216165.78	?	124	Bredene
18.4.816.1.0	51617.29	216497.90	51662.99	216522.27		127	Bredene
18.4.816.2.0	52089.56	216776.69	52127.65	216808.68		129	Bredene
18.4.816.3.0	53121.00	217361.48	53168.30	217406.15		134	Bredene
18.4.817.3.0	59110.00	221330.00	59246.10	221428.59	1950	168	Wenduine
18.4.817.4.0	59246.10	221429.03	59277.00	221455.00	1905	168	Wenduine
18.4.817.5.0	59277.00	221455.00	59293.29	221469.66	1950	169	Wenduine
18.4.817.6.0	59293.29	221471.41	59333.04	221498.50	1950	169	Wenduine
18.4.817.7.0	59333.48	221499.81	59425.00	221570.00	1950	169	Wenduine
18.4.817.10.0	59475.00	221609.00	59480.00	221613.00	1904	170	Wenduine
18.4.817.11.0	59480.00	221613.00	59666.39	221810.87	1904	170	Wenduine
18.4.817.8.0	59425.00	221570.00	59468.00	221604.00	1950	170	Wenduine
18.4.817.9.0	59468.00	221604.00	59475.00	221609.00	1904	170	Wenduine
18.4.817.12.0	59666.39	221811.75	59715.32	221861.55	1900	171	Wenduine
18.4.817.13.0	59715.76	221861.99	59813.00	221960.00	1953	172	Wenduine
18.4.817.14.0	59813.00	221960.00	59820.00	221970.00	1936	172	Wenduine
18.4.817.15.0	59798.77	222010.97	59971.00	222065.00	1869	172	Wenduine
18.4.817.16.0	59971.00	222065.00	60507.90	222372.37	1882	173	Wenduine
18.4.818.1.0	62487.50	223274.30	63475.85	223665.56	1860	185	Blankenberge
18.4.818.2.0	63477.79	223665.56	63700.00	223740.00	1960	190	Blankenberge
18.4.818.3.0	63700.00	223740.00	64387.00	224007.00	1860	191	Blankenberge
18.4.819.1.0	66550.00	224834.00	66775.00	224926.00	1912	211_212	Zeebrugge
18.4.819.2.0	66775.00	224926.00	67360.00	225135.00	1895	213_216	Zeebrugge
18.4.819.3.0	67363.96	225125.38	67138.22	225566.47	1984	216	Zeebrugge
18.4.820.1.0	70468.04	226158.75	71346.00	226346.00	1870	217_221	Heist
18.4.820.2.0	71346.25	226346.53	71541.41	226385.56	1953	222	Heist
18.4.820.3.0	71541.41	226386.13	71779.00	226365.20	1903	222	Heist

18.4.820.4.0	71782.39	226364.07	72472.00	226632.00	1907	223_224	Heist
18.4.820.5.0	72472.00	226632.00	72849.00	226790.00	1901	225	Heist
18.4.820.6.0	72849.00	226790.00	72941.00	226831.00	1953	225	Heist
18.4.820.7.0	72941.00	226831.00	73116.50	226776.00	1922	226	Heist
18.4.820.8.0	73116.50	226776.00	74339.50	227320.00	1922	226_232	Heist/Knokke
18.4.820.10.0	74405.50	227448.00	74477.00	227508.00	1974	232	Knokke
18.4.820.9.0	74339.50	227320.00	74405.50	227448.00	1922	232	Knokke
18.4.820.11.0	74477.00	227508.00	74600.00	227580.00	1972	233	Knokke
18.4.820.12.0	74598.99	227582.85	74635.00	227595.00	1972	234	Knokke
18.4.820.13.0	74635.00	227595.00	74812.00	227654.00	1972	234	Knokke
18.4.820.14.0	74812.00	227654.00	75017.00	227717.00	1974	235	Knokke
18.4.820.15.0	75017.00	227717.00	75154.00	227760.00	1976	236	Knokke
18.4.820.16.0	75154.00	227760.00	75237.00	227785.00	1953	236	Knokke
18.4.820.17.0	75237.00	227785.00	75434.00	227816.00	1977	237	Knokke
18.4.820.18.0	75434.00	227816.00	75496.07	227832.98	?	237	Knokke
18.4.820.19.0	75496.07	227832.98	75602.00	227857.00	1977	238	Knokke
18.4.820.20.0	75602.00	227857.00	75923.00	227992.00	1908	239	Knokke
18.4.820.21.0	75923.00	227992.00	75980.00	228020.00	1953	239	Knokke
18.4.820.22.0	75980.00	228020.00	76015.00	228033.00	?	239	Knokke
18.4.820.23.0	76015.00	228033.00	76133.00	228077.00	1976	240	Knokke
18.4.820.24.0	76133.00	228077.00	76245.00	228119.00	1953	240	Knokke
18.4.820.25.0	76245.00	228119.00	76358.76	228163.05	1974	240	Knokke
18.4.820.26.0	76358.76	228163.05	76562.00	228236.00	1953	241	Knokke
18.4.820.27.0	76562.00	228236.00	76574.92	228241.90	1977	242	Knokke
18.4.820.28.0	76574.92	228241.90	76711.00	228275.00	1946	242	Knokke
18.4.820.29.0	76711.00	228275.00	76945.00	228293.00	1953	243	Knokke
18.4.820.30.0	76945.00	228293.00	77022.00	228305.00	1962	244	Knokke
18.4.820.31.0	77022.00	228305.00	77080.31	228319.14	1953	244	Knokke
18.4.820.32.0	77080.82	228318.63	77122.50	228325.00	1953	244	Knokke
18.4.820.33.0	77122.50	228325.00	77206.00	228346.00	?	244	Knokke
18.4.820.34.0	77206.00	228346.00	77244.51	228358.53	1962	245	Knokke
18.4.820.35.0	77244.66	228358.73	77248.44	228359.43	1951	245	Knokke
18.4.820.36.0	77248.72	228359.29	77322.16	228380.56	1962	245	Knokke
18.4.820.37.0	77322.16	228380.69	77441.58	228422.81	?	245	Knokke
18.4.820.38.0	77441.58	228422.81	77559.00	228465.00	1962	246	Knokke
18.4.820.39.0	77559.00	228465.00	77648.00	228499.00	1962	246	Knokke
18.4.820.40.0	77648.00	228499.00	77685.00	228509.00	1953	246	Knokke
18.4.820.41.0	77685.00	228509.00	77779.07	228521.98	1953	247	Knokke
18.4.820.42.0	77779.54	228522.46	78185.19	228659.06	1974	247	Knokke
18.4.820.43.0	78186.02	228658.23	78417.50	228742.50	1974	248	Knokke
18.4.820.44.0	78417.50	228742.50	78478.32	228767.43	1977	248	Knokke
18.4.820.45.0	78478.32	228767.84	78875.00	228840.00	1977	249_250	Knokke
4.4.820.1.0	78515.56	228661.33	80055.15	227987.93	1953	249_253	Zwin
4.4.820.1.1	80055.15	227987.93	80749.48	227974.68	1953	253_255	Zwin

Table 1 - Inventory of Belgian dikes (Trouw et al., 2005)

1.1.1.2 Dune foot strengthening

Beside dikes, dune foot strengthening is another type of hard sea defence. This defence construction is expected to fail during heavy storms but it prevents dunes from eroding when smaller storm events occur. It is situated on the seaward dune foot and makes the transition between beach and dune. In Belgium it is generally build up of rubble concrete and gabion baskets covered with a concrete layer about 0,15m thick.

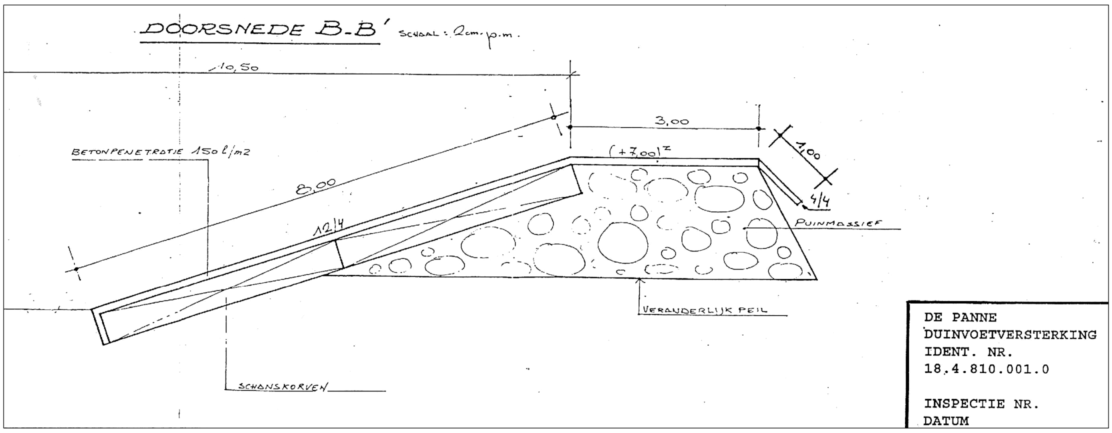

Fig. 9 - Construction design of dune foot strengthening off De Panne (Afdeling Kust)

Along the Belgian coastline, dune foot strengthening is currently used to protect dunes in *De Panne* (~2400 meters) and in *Lombardsijde* (~900 meters). Though in *Lombarsijde* (Fig. 10), the construction will be demolished by the end of 2008 in order to increase the natural value of the beach reserve in front of the military basis (De Wolf P., 2007).

Fig. 10 - Dune foot strengthening off Lombardsijde (Van der Biest K., 2007)

1.1.1.3 Jetties, quay walls, weirs and locks

Ports are protected against sea water and wave attack by jetties, quay walls, weirs and locks. Weirs and locks can fail during storm events due to intense wave load. They are constructed to resist a hydrostatic load with a still water level equal to the height of the top of the lock. The intense wave action during storms is expected to cause failure of weirs and locks (Verwaest et al., 2008).

Quay walls at the other hand are not supposed to fail during storms. However, they will not prevent flooding when the total water level, as a sum of sea level plus wave surge, exceeds the top height of the construction.

1.1.1.4 Groynes

In Belgium, groynes are constructed in order to prevent erosion of the sandy beaches by dominant tidal currents flowing in north-eastern direction. They are constructed perpendicularly on the coastline so that strong currents don't reach the coast and breakers are interrupted. Sediment displacement parallel with the coastline *(littoral drift)* will be reduced (VLIZ, 2001).

Belgian groynes are built up of debris covered by a top layer of bricks, concrete blocks or limestone surfaced with cement or covered with asphalt. Sides and head are protected with osier covered by stone blocks. Along the Belgian coastline 127 regular and 33 smaller groynes were constructed at an average distance of 350m between each other. The only places where no groynes were constructed are *De Panne, Oostduinkerke, De Haan* and in front of the *Zwin*. The eldest stone groynes were built in 1912, as the most recent date from the early nineties. Nowadays groynes are not used anymore as defence measure. Their construction costs are high and alternative soft defence measures like beach nourishments are more often given preference to. Though, damages after storms are generally repaired, and in some cases the groynes are extended (VLIZ, 2001).

1.1.1.5 Sand nourishments

One of the most common present-day sea defence measures used along the Belgian coastline are beach and foreshore nourishments. Sand with a coarse diameter (~300µm) is extracted from the North Sea bottom (seawards from the -20m depth contour) and spouted out (supply of sand and water mixture with pipe) or levelled up (supply of sand with trucks) on the beach in front of the dike. This technique is used to compensate the erosion of beaches due to tidal currents and wave impact. Less frequently in Belgium, sand nourishments also take place on foreshore (underwater). Foreshore nourishments are longer lasting and cheaper then beach nourishments though the latter have quicker results: as soon as the sand is deposited, beaches are larger and broader.

Table 2 gives an overview of all the effectuated sand nourishments along the Belgian coastline since the first supply in 1983.

Plaats	Ligging in figuur	Aard van de werken	Periode	Benaderende hoeveelheid (m³) (per jaar)	Volume (m³) aangebracht in het voorjaar van 2004
Sint-Idesbald	A	aanvoer zeezand	sinds 1983	9000	9400
Koksijde-Bad	B	aanvoer zeezand	sinds 1983	5000	6000
	B	opvoer strandzand	sinds 1983	6000	2500
	B	veiligheidsophoging zeezand	nov-dec 2006	10600	
Nieuwpoort-Bad	C	aanvoer zeezand	sinds 1994	5000	5100
Mil. Domein Lombardsijde	D	aanvoer zeezand	sinds 1999	4000	5100
Westende-Sint-Laureins	E	aanvoer zeezand	sinds 1988	3000	3600
Middelkerke-Krokodil	F	aanvoer zeezand	sinds 1988	11000	11700
	F	opvoer strandzand	sinds 1988	4000	4000
	F	veiligheidsophoging zeezand	nov-dec 2006	**34700**	
Middelkerke-Bad	G	aanvoer zeezand	sinds 1983	20000	23700
Raversijde	H	aanvoer zeezand	sinds 1983	3000	2500
	H	veiligheidsophoging zeezand	nov-dec 2006	**34900**	
Mariakerke - Oostende West	I	aanvoer zeezand	sinds 1983	23000	25600
	I	veiligheidsophoging zeezand	winter 05-06	**118200**	
	I	veiligheidsophoging zeezand	nov-dec 2006	**56700**	
Oostende Groot Strand	J	aanvoer zeezand	sinds 1999	6000	5000
Oostende-Centrum	K	strandsuppletie noodstrand	apr-jun 2004	**718300**	
	K	voedingsberm noodstrand	apr 2004	**144500**	
	K	strandsuppletie onderhoud	jun 2005	**159000**	
Bredene-West en Astrid	L, M	aanvoer zeezand	sinds 1990	15000	15000
	L, M	opvoer strandzand	1990-2003	10000	
Hippodroom - Wenduine	N	strandsuppleties	1992-1996	**3200000**	
	N	vooroeversuppleties	1991-1998	**1500000**	
	N	vooroever, bijstortingen	1998-2000	**197000**	
De Haan-Centrum	N	strandsuppletie, onderhoud	mei-jun 2000	**260500**	
Wenduine - zeedijk	O	aanvoer zeezand	sinds 1983	6000	6700
	O	opvoer strandzand	sinds 1983	10000	8000
	O	veiligheidsophoging zeezand	nov. 2005	**42900**	
	O	veiligheidsophoging zeezand	nov-dec 2006	17700	
paviljoen Harendijke	P	opvoer strandzand	sinds 1997	6000	5400
Blankenberge	Q	opvoer strandzand	sinds 1985	8000	9600
Duinse Polders	R	strandsuppletie	1998-1999	**486300**	
Heist	S	strandsuppletie	1993	**72000**	
	S	strandsuppletie	1994	**124000**	
Duinbergen	T	opvoer strandzand	1997-2003	13000	
	T	aanvoer zeezand	sinds 2004	17000	13100
Knokke-Zoute	U	strandsuppletie	1986	**1000000**	
	U	strandsuppletie	mrt-mei 1999	**490000**	
	U	strandsuppletie	jun 2004	**390000**	
	U	veiligheidsoph. zeezand Lekkerbek	mei-jun 2006	**62500**	
Heist - Zwin	V	strandsuppletie	1978-1980	**8500000**	

Table 2 - Overview of effectuated sand nourishments along the Belgian coastline. Yearly averages rounded off to thousands, most recent data rounded off to hundreds. In bold data about large-scale nourishments (De Ronde et al., 2007)

1.1.1.6 Marram grass and brush wood

Marram grass is typical pioneer vegetation growing in dunes. The roots of the plant are very long and help to stabilise dunes. Along the Belgian coastline, marram grass is planted on dunes to fixate the sand and reduce eolic erosion in order to create new or enlarge existing dunes. Brush wood is installed at the seaward foot of the dune to fixate the sand and so stabilise the dune foot.

Fig. 11 - Marram grass plantation (www.vliz.be)

Fig. 12 - Brush wood (www.vliz.be)

1.1.1.7 Managed retreat

Managed retreat is an alternative solution for defence structures as protection against flooding and coastal erosion. In the context of the policy shift from 'hard' to 'soft' defence, it became internationally a more and more applied measure against sea level rise and coastal erosion. Artificial 'hard' coastal defences are replaced with natural 'soft' coastal landforms (Pethick, 2002), as soft measures create a more natural transition between sea and dunes and the costs to build protection become too high.

Managed retreat allows a particular area that was not previously exposed to flooding to become susceptible to flooding by removing or by not maintaining existing coastal protection. These controlled flooding areas are usually former intertidal zones that have been claimed from the sea in the past. Managed retreat allows the natural coastal ecosystem to restore itself as it becomes again subject to tidal flooding. This leads to an increase in habitat diversity and biodiversity. In Belgium, examples of managed retreat can be found in the east coast (*Zwin*) and in the west coast (*Westhoek*).

Zwin

The Zwin is an international natural reserve situated on the boarder between Belgium (160ha) and the Netherlands (23ha). Behind the beach and dunes, the reserve consists of tidal flats and salt marshes which are inundated by the sea every high tide, spring tide or storm tide. The result of that is a unique habitat (*slikke en schorre*) which harbours a very specific fauna and flora adapted to regular flooding and salty conditions. By the end of 2008, the Flemish government will start works to enlarge the area of the reserve (Fig. 13). The plan is to demolish the existing international dike and rebuild a new dike more landwards, to level the most silted up parts, to deepen and extend the main channel and to deepen the side gullies (Berteloot, 2007). In the context of coastal protection, these works will permit to enlarge the tidal basin storage capacity so that it acts as a buffer for flood water.

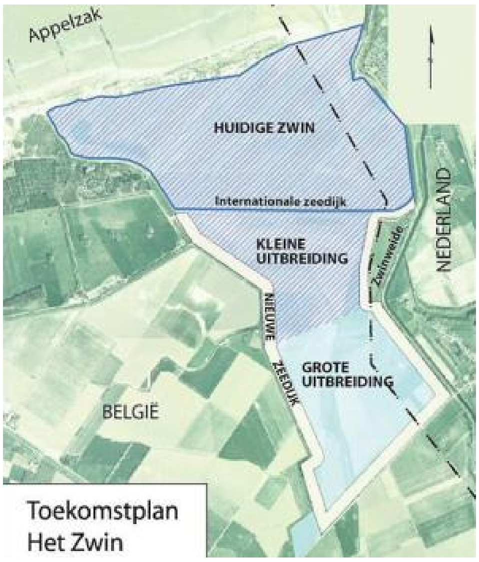

Fig. 13 - Future plan of Zwin (www.bndestem.nl, 2006)

Westhoek

Since the construction of a concrete dune foot strengthening to protect the coastal hinterland from flooding, the natural dune system in the reserve Westhoek has been cut off from tidal influence. In 2004, the Flemish government made an artificial breach in the construction at two different places (*slufters*). These sea inlets allow the sea to enter the dune system during spring tide in combination with a strong west wind. In the context of coastal protection, the low-lying valleys between the dunes can act as buffers to flood water. Beside, the flood water flowing back to the sea leaves new sediment behind and permits the dunes to expand. The hinterland continues to be protected against flooding due to the very broad natural dune system.

Fig. 14 - Two sea inlets (slufters) at reserve Westhoek

1.1.2 Economical importance

Damage and maintenance costs

(eerst iets over damage costs aan zeedijken)

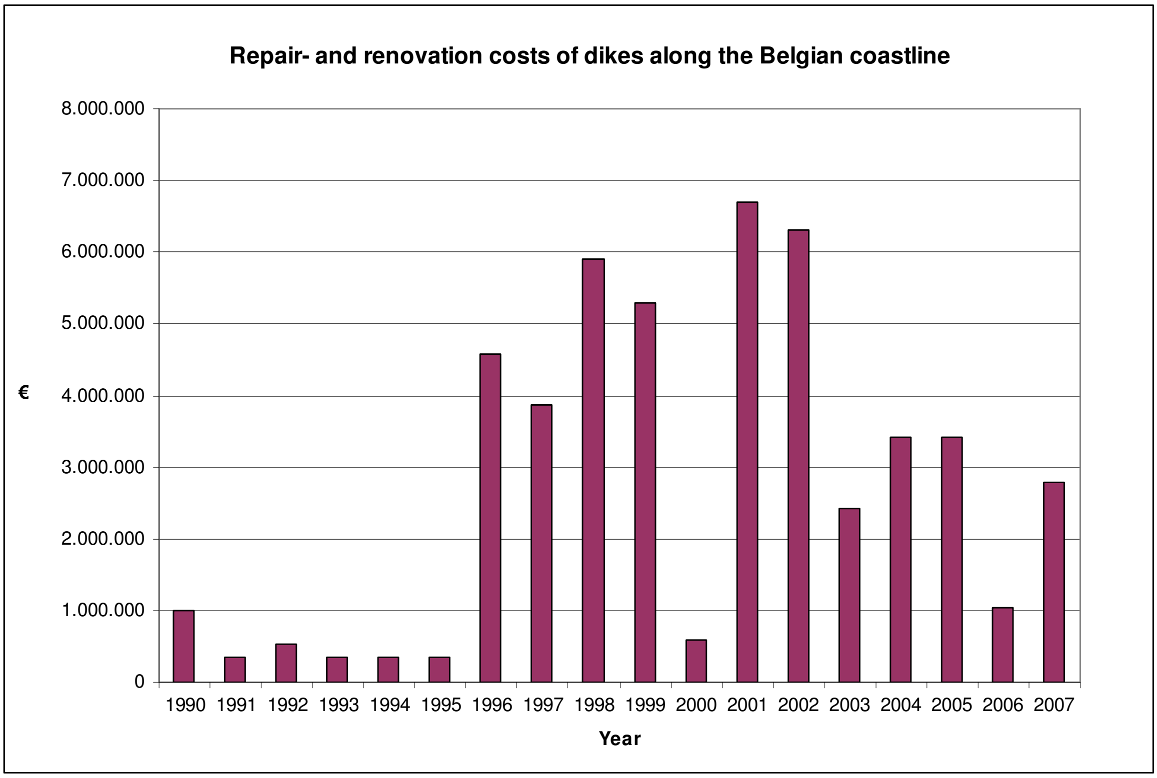

Fig. 15 - Repair- and renovation costs of dikes along the Belgian coastline (Afdeling Kust, 2008)

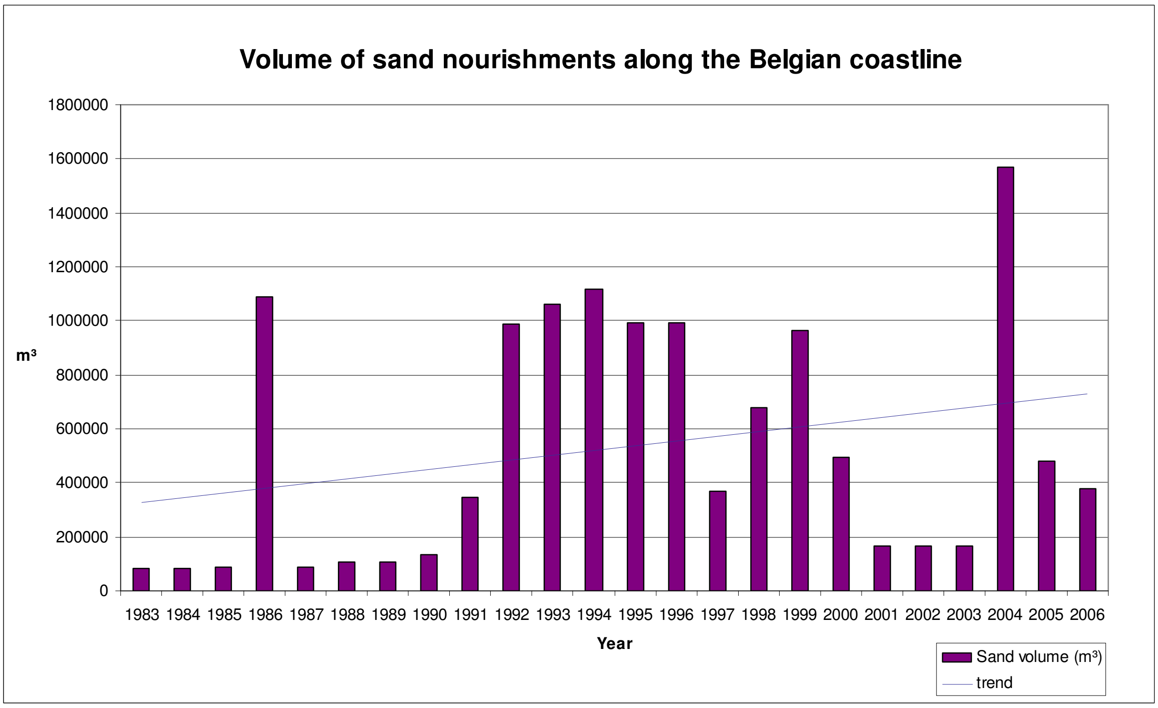

Fig. 16 - Effectuated sand nourishments along the Belgian coastline (De Ronde et al., 2007). Large-scale nourishments equally spread over the whole period (cfr. Table 2)

The methodology developed by WL and Ugent to estimate the total amount of damage costs caused by flooding makes a distinction between different types of land cover. For each of the following land cover types an estimation of the maximal monetary assessable damage is made (Vanneuville et al., 2006): houses; industry; infrastructure and airports; recreational areas; arable and pasture land; vehicles; water, nature and forests; roads; railways; water supply zones, purification plants and reservoirs; churches, convents, abbeys, mills, hospitals, town halls, schools and castles; power stations, transmitting installations and wind turbines; underground parking garages and subway stations; gas stations, shopping malls and rest homes; train stations; fire stations, police stations, prisons and museums; amusement parks and zoos.

In the table below the estimated monetary value for each land cover or object at risk of flooding is given.

Land cover or object	Damage
Houses	Maximal damage in function of building density; direct damage in function of average sales value per region + indirect damage as cleaning up costs: 15% of direct damage when initially limited damage, 1% when total loss of house and moveables
Moveables	Maximal damage 50% of the maximal damage to house; also indirect damage (see ‘Houses’)
Industry	Two damage assessment methods: - based on surface: € 100/m²; indirect damage due to production loss and cleaning up costs 35% of direct damage when total loss and 45% when initially limited damage - based on number of employees: maximal damage in function of density of employees in industrial area (per town); €180.000 per employee; indirect damage due to production loss and cleaning up costs 35% of direct damage when total loss and 45% when initially limited damage
Infrastructure	€ 100/m² (buildings and installations not included in other categories, e.g. sheds, railway stations, platforms, buildings at recreational areas, cemeteries …)
Airports	Airport of Oostende considered separately; smaller airports: € 100/m² for airport I (buildings, runway), € 0/m² for airport II (area without buildings or infrastructure)
Recreational area	€ 0,03/m² (cleaning and repair costs: benches, information signs, … ; not included buildings)
Arable land	Value in function of crops and dependent on agricultural area and watershed; Flemish average ± € 0,50/m²; indirect damage: loss soil fertility and cleaning up costs 10% of direct damage
Pasture land	€ 0,08/m², indirect damage (cattle can’t use land during and right after flooding, hay land covered with mud) 10% of direct damage
Vehicles	€ 4.500 per vehicle
Water, nature, forests	€ 0/m²
Roads	Value depends on type of road; varying between € 300/m and € 7.500/m
Railways	Value depends on type of railway; varying

	between € 500/m and € 7.500/m
Water supply infrastructure	Value depends on expert opinion. Confidential
Amusement parks and zoos	Value depends on expert opinion. Confidential
Convents, abbeys, hospitals, town halls and schools	€ 1.150/m²
Churches	€ 1.150/m², fixed area of 400m²
Fire stations, police stations and prisons	€ 1.600/m²
Museums	€ 1.600/m², fixed area of 1.800m²; exclusive collection value
Historical mills	€ 687.500 per piece
Castles	€ 10.000.000 per piece
Rest homes	€ 12.500.000 per piece
Train stations	Differentiation between: - Large stations: value depends on expert opinion. Confidential - Medium-sized stations: € 295.000 per station - Small stations: € 30.000 per station
Power stations	€ 4.500.000.000 per station
Wind turbines	€ 712.000 per turbine
Transmitting installations	€ 60.000 per installation
Underground parking garages	€ 7.500.000 per garage
Subway stations	€ 5.000.000 per station
Gas stations	€ 900.000 per station
Shopping malls	€ 50.000.000 per mall

Table 3 - Maximal damage values per land cover type or object (translated and adapted from Vanneuville et al., 2006)

The actual damage caused by flooding depends on the water depth. At places where the flood water level is rather low there will not be full damage of the infrastructure. Therefore, damage is a function of the water depth and can be described as follows (Vanneuville et al., 2006):

$$S_w = \sum(\alpha \times n_i \times S_{max})$$

- S_w = damage as a consequence of a certain event
- α = damage factor (between 0 en 1, depending on land cover as discussed further)
- n_i = number of units (number, length in m, area in m²,…)
- S_{max} = maximal damage per length (m) or area (m²) as sum of all the different types of land cover

For each land cover type or object the evolution of the damage in function of water depth will be differently (Fig. 17). The monetary damage will be calculated using this function with different parameter values depending on the land cover type.

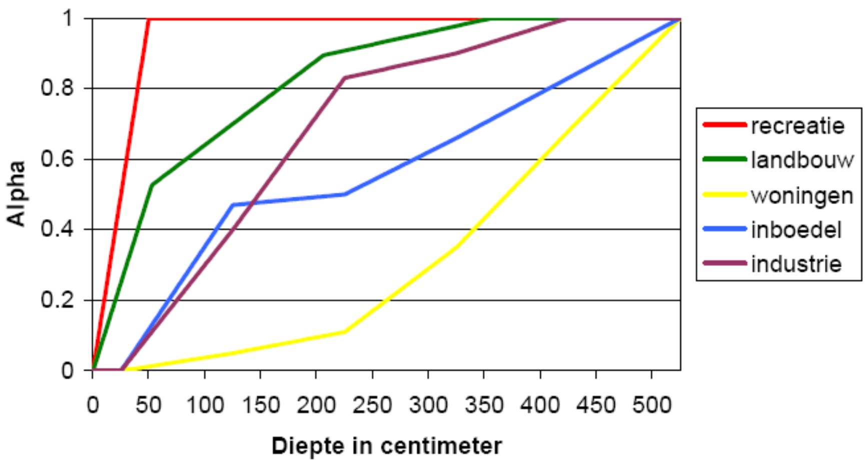

Fig. 17 - Flooding damage factors in function of water depth (Vanneuville et al., 2006)

1.1.3 Social importance

<u>Casualties</u>

Failure and/or erosion of the sea defence will potentially lead to casualties on the shoreline and in the low-lying areas susceptible to flooding. WL and UGent are together developing a methodology to assess damages and casualties caused by flooding. The total number of casualties that may occur depends on different factors (Jonkman and Cappendijk, 2006):

- Characteristics of the flooding event (water depth, rising velocity)
- Number of persons present in the flooded area (depending on evacuation)
- Number of victims among the persons present

The maximal number of affected people equals the number of people living in the low-lying coastal zone minus the number of people living in apartments (Table 4). The latter are expected to be able to escape to higher floors (Vanneuville et al., 2006). Although it could make a difference in number of casualties, the methodology does not make a distinction between summer and winter nor between day and night due to the complexity of the calculations.

Town	Population (01/01/2007)	Estimated # people living in apartments*
Blankenberge	18 329	6 783
Bredene	15 343	2 070
De Haan	12 177	2 673
De Panne	10 153	3 212
Dudzele (Brugge)	*2 453*	*33*
Gistel	11 170	750
Knokke-Heist	34 132	12 529
Koksijde	21 419	5 697
Lissewege & Zeebrugge (Brugge)	*10 949**	*1 334*
Middelkerke	18 080	4 261
Nieuwpoort	10 940	2 763
Oostende	69 115	29 140
Oostkerke & Hoeke (Damme)	*806**	*12*
Oudenburg	8 947	357
Stalhille (Jabbeke)	*650*	*11*
Veurne	11 832	656
Zuienkerke	2 743	99

*Table 4 - Population of Belgian towns located within study area (NIS, 2007). * based on assumption that average # of people living in apartments is 1,76 (O&S, 2008) (Italic: Wikipedia, 2008. * Population by 01/01/2004)*

Safety + attractiveness

As discussed above, ‘soft’ defence measures are gaining popularity vis-à-vis ‘hard’ defence structures. One of the main reasons for this policy shift is the aim of conservation and re-establishment of natural elements along the coastline. This increases the natural value of the coastal zone and makes it more attractive for tourists.

Employment

Flooding of industrial sites and business properties will cause temporarily and/or permanent loss of jobs in the afflicted area. The maximal number of people who could be at risk of loosing their job due to flooding is summarised in the table below.

Town	# working people (2005)
Blankenberge	6 966
Bredene	6 460
De Haan	4 698
De Panne	3 569
Dudzele (Brugge)	*1 059*
Gistel	4 797
Knokke-Heist	12 835
Koksijde	7 876
Lissewege & Zeebrugge (Brugge)	*4 725*
Middelkerke	6 663
Nieuwpoort	4 080
Oostende	25 340
Oostkerke & Hoeke (Damme)	*361*
Oudenburg	3 834
Stalhille (Jabbeke)	*299*
Veurne	5 118
Zuienkerke	1 337

Table 5 - Total number of people working within the study area (SWSE, 2005) (Italic: estimation based on value amalgamated municipality)

Besides direct loss of jobs in flooded areas, there will also be indirect loss of jobs in companies which depend on the stricken companies. However, due to the complexity of this indirect effect it will not be taken into account in the flooding damage calculations within the scope of this project.

1.2 NATURE

1.2.1 Intensity

Fig. 18 shows the different natural areas that can be found in the study-area. Protected reserves as well as non protected natural areas are taken into consideration.

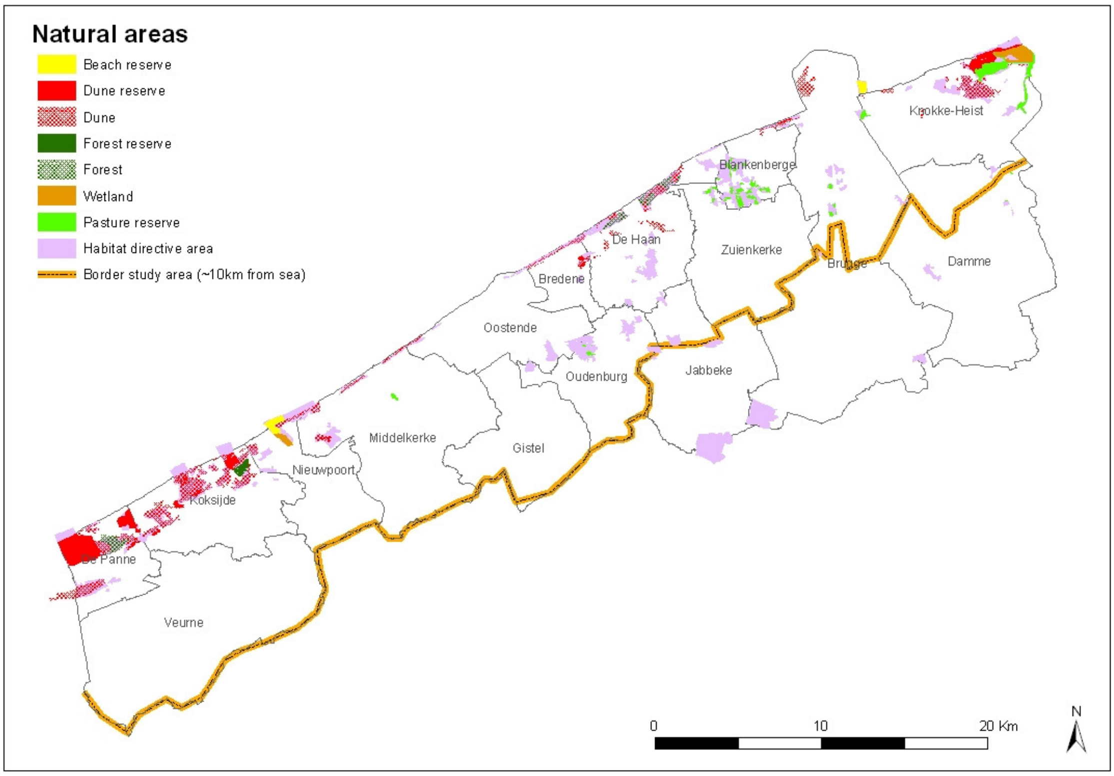

Fig. 18 - Natural areas along the Belgian coastline
(based on Corine land cover 1996 and Mercator Database: Duinendecreet 1997, Natuurreservaten 1997, Habitatrichtlijngebieden 2001)

1.2.1.1 Beach

Along the Belgian coastline only two protected beach reserves can be found, *Baai van Heist* and *Ijzermonding* (Fig. 18).

Baai van Heist, at *Knokke-Heist*, is a 54ha big beach plain located in the lee of the breakwater of the port of *Zeebrugge* (Belpaeme & Konings, 2004). The plain is built up of sand and silt deposits from the prevailing flood current in north-eastern direction. The breakwater intersects the easterly longshore flow and causes sedimentation in the calmer water behind the construction. The sedimentation continues at a rate of averagely 3 to 5 cm/year (Verwaest, 2007). The reserve, protected since 1997, harbours embryonic dunes, mud flats and salt marshes. It also constitutes an important nesting place for birds (Herrier JL., 2002).

One other beach reserve is located at *Lombardsijde*, at the estuary of the river *IJzer.* In 2008, the reserve of 98ha (Herrier JL., 2002) will be modified in order to create more natural value. The dune foot strengthening and groynes will be removed and the beach will be enlarged and given a gentler slope. These interventions will increase the amount of nesting sites available for birds. The beach will be protected against sand-drift by rows of piles (De Wolf P., 2007).

1.2.1.2 Dunes

The Belgian coastline consists of 800ha dunes. The largest system is found at *De Panne* in the western part of the country. Since 1957 the area is protected by the government as natural reserve *Westhoek* (340ha). At its broadest, the dune strip reaches up to 2200m. The reserve harbours almost all the different phases of dune formation: walking dunes, blowholes, dune slacks, blond, grey and black dunes. The highest dune along the Belgian coastline is *Hoge Blekker* at *Koksijde* (35m TAW). The oldest dunes can be found at the reserve *Cabourduinen* at *De Panne* (55ha on Belgian territory). They originated about 5000 years ago. Due to their distance from the sea, the dune formation processes came to an end. Other important protected dune reserves are *Oosthoekduinen* and *Houtsaegerduinen* at *De Panne; Doornpanne, Schipgatduinen* and *Ter Yde* at *Koksijde; Schuddebeurze* at *Middelkerke; d'Heye* at *Bredene* and *Fonteintjes* at *Blankenberge*. The latter being partly an artificial reserve made up of wet dune slacks, reed-lands and dune scrub (Natuurpunt, 2008). Besides the protected dune reserves there are also several smaller dune strips along the Belgian coastline (Fig. 18).

1.2.1.3 Wetland

The total area of wetlands along the Belgian coastline reaches up to about 180ha.

The *IJzermonding* wetland (38ha) at the estuary of the *Ijzer* makes part of the 100ha reserve consisting of salt marshes, mudflats, beach, dunes and grassland. The reserve constitutes an important nesting site for birds.

The *Zwin* reserve consists of salt marshes and mudflats (152ha) separated from the sea by a dune strip. At the Belgian-Dutch border a wide breach in the dunes allows the sea to penetrate the reserve during flood tide. The water flows through the main channel that branches off in smaller gullies and creeks. The ebbing water is then prevented from flowing back by 3 one-way valves. This avoids the lakes to dry out during periods with low water level. The reserve also constitutes an important nesting site for birds.

1.2.1.4 Forest

The most important coastal forests along the Belgian coastline are *Calmeynbos* at *De Panne* (60ha), *Hannecartbos* at *Koksijde* (47ha) and the dune forests at *De Haan* (152ha). They can be found between the dunes and at the transition between dune and polder. The initial aim of planting the forests was to protect the agricultural lands in the hinterland from wind and drifting sand. They also have the advantage of fixating migrating dunes. Nowadays, the forests are being planted to enhance the touristy value of the coastline. New forests have recently been planted near *Oostende (Keignaertbos), Blankenberge (Zeebos), Nieuwpoort* and *Knokke* (Belpaeme & Konings, 2004).

1.2.2 Economical importance

In most of the Belgian coastal towns the shoreline is intensely built-up. The original natural sea defences, the dunes, are levelled in favour of the construction of buildings and roads. They are directly adjacent to the beaches and artificially protected against the sea by hard defence structures such as groynes and dikes. The oldest existing dikes where constructed at the beginning of the 19^{th} century (Table 1). Since a few decades, beach (re)nourishments are more and more frequently used as protection measure against coastal erosion and flooding. Only a few coastal settlements are situated behind dune areas and so are naturally protected against the sea. It concerns the built-up area between *Bredene* and *De Haan*, *Lombardsijde,* some holiday villages west of *Westende* and the area west of *De Panne* (apartment buildings, *Vissersdorp*).

In terms of economical significance, the most important roles of the natural elements along the coastline are:

- Protection against damages to houses, roads, industry, infrastructure, … due to sea level rise and coastal erosion (see 1.1.2)
- Tourist activities such as walking, nature exploration, sports, … (see Subdocument Tourism for information on importance of nature as tourist attraction)

The absolute economical value of damages to nature is assumed to be €0,00/m². Small facilities in the nature reserves such as information panels and benches are attributed a maximal damage value of €0,03/m². Natural and sentimental values are not taken into account. However, degradation of natural reserves due to flooding will (temporarily) decrease the amount of tourists in the area. Damage to nature can thus indirectly lead to a decrease in the overall income of the tourist sector (Vanneuville et al., 2006).

1.2.3 Social importance

As discussed in the Subdocument Tourism and pointed out in chapter 1.2.1, the natural elements on the Belgian shoreline have an important attraction value for coastal tourism.

Besides their recreational value and the protection against flooding, dunes are also significant sources for freshwater provision. Precipitation water infiltrates into the sand and forms a freshwater lens inside of the dune. Under natural circumstances the freshwater drains off to the sea and the polders, preventing the more dense salty water to flow into the dunes. In Belgium, drinking-water is pumped up from coastal dunes in *De Panne,* reserve *Westhoek* 94ha; *Koksijde, Sint-André* 124ha; *Knokke-Heist*, golfcourse (Fig. 19) and *Bredene* (Fig. 20).

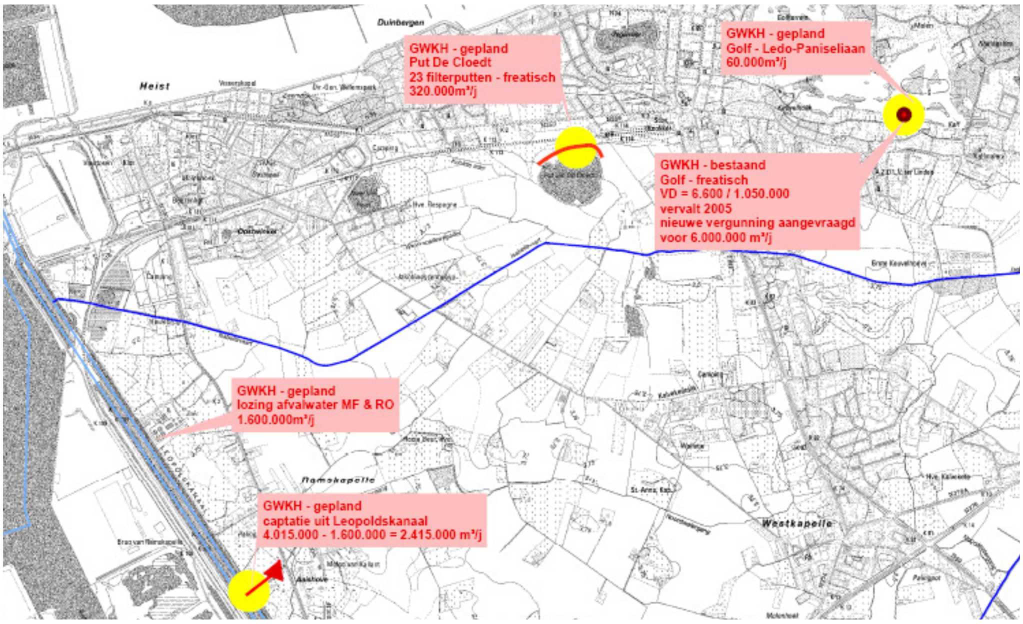

Fig. 19 - Drinking-water areas at Knokke-Heist, pumping-up from dunes at Golf (Vanden Bulck, 2004)

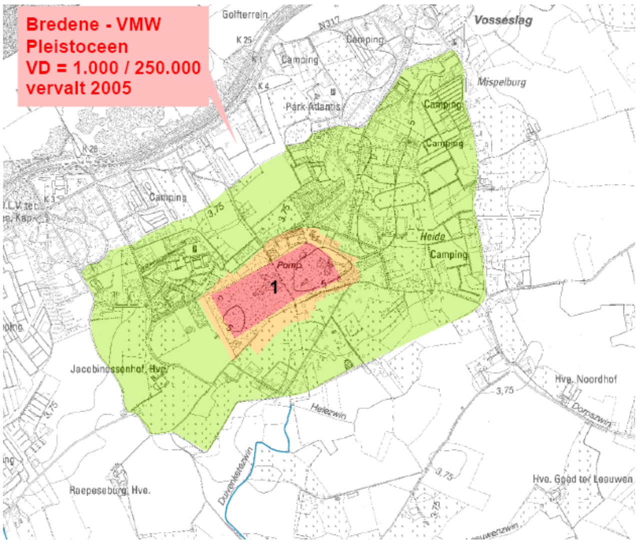

Fig. 20 - Drinking-water collection area at Bredene (Vanden Bulck, 2004)

Zone	Operator	Permitted flow (m^3/y)	Actual flow (m^3/y)	Depth groundwater (m TAW)
Westhoek*	IWVA	?	590 426	3,5
Sint-André*	IWVA	?	3 032 841	4,43
Bredene**	VMW	250 000	93 221	?
Knokke-	GWKH	1 050 000	600 000	?

*Table 6 - Drinking-water provision from Belgian dunes (*IWVA, 2006; ** Vanden Bulck, 2004)*

According to a recent research carried out by the Ohio State University, climate change could diminish drinking water up to 50% more than expected. Previously it was assumed that saltwater would penetrate underground only as far as it did above ground. Though, the research shows that the brackish mixture of saltwater and freshwater can extend 50% further inland underground than it does above ground (Fig. 21). The distance to where it extends depends on the texture of the sand along the coastline. According to the study, the more complex the underground structure is, the more saltwater and freshwater mix so that the brackish water penetrates further landwards. Fine sand tends to block more water, while coarse sand lets more water flow through (Ibaraki & Mizuno, 2007).

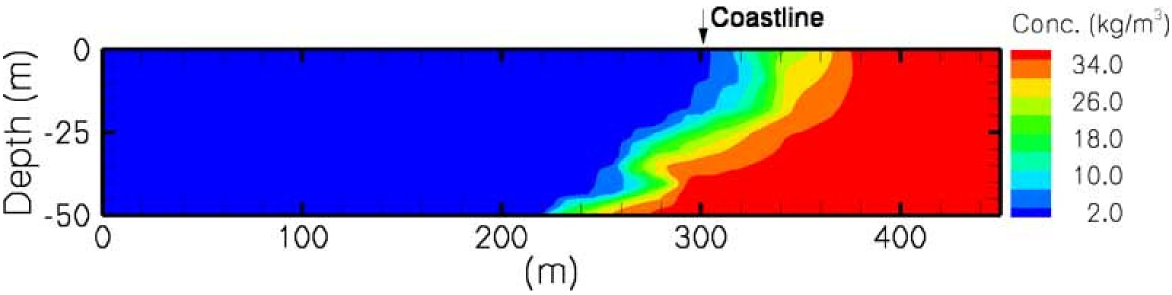

Fig. 21 - Simulation image of salt water intrusion into fresh water supplies along coastlines (Ibaraki & Mizuno, 2007)

1.3 BUILDINGS

1.3.1 Intensity

The sub-sector ‘buildings’ includes residential houses as well as shops, offices and public buildings such as town halls. It also takes into account the point elements castles, rest homes and hospitals (Vanneuville et al., 2006).

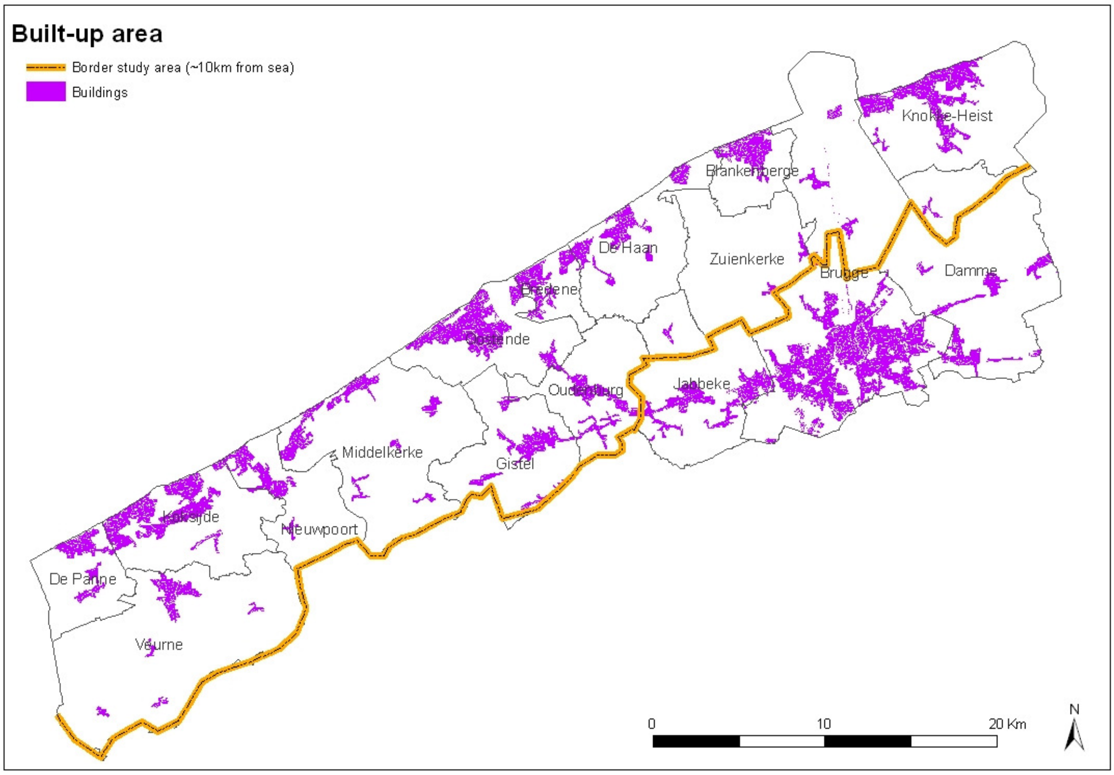

Fig. 22 - Built-up area in the Belgian coastal zone (KBG, 2007)

Besides damage to the house itself there will also be damage to moveables and to vehicles (cars and motorcycles) standing outside of the house or in the garage.

1.3.2 Economical importance

The maximal damage to houses is determined by the average house selling price of the community (Table 7). Besides damages to the house itself there will also be damage to the moveables. According to the Union of Assurance Companies (BVVO), the value of moveables can be approximated as 50% of the value of the house (Vanneuville et al., 2002). The damage calculation also takes into account an indirect damage cost for cleaning. At a relative low water depth the damage is assessed at 15% of the direct damage costs. At a water depth of 5m (maximal damage) the cleaning costs amount to 1% of the direct damage. An estimation of the indirect damage cost is made in function of the water depth by combining both extreme percentages (Vanneuville et al., 2006).

Town	Average house price € (2006)	Average value moveables €
Blankenberge	160 000	80 000
Bredene	146 250	73 125
De Haan	155 000	77 500
De Panne	150 000	75 000
Dudzele (Brugge)	*170 000*	*85 000*
Gistel	135 000	67 500
Knokke-Heist	264 000	132 000
Koksijde	214 445	107 223
Lissewege & Zeebrugge (Brugge)	*170 000*	*85 000*
Middelkerke	155 000	77 500
Nieuwpoort	155 000	77 500
Oostende	150 000	75 000
Oostkerke & Hoeke (Damme)	*180 000*	*90 000*
Oudenburg	143 778	71 889
Stalhille (Jabbeke)	*150 000*	*75 000*
Veurne	135 671	67 836
Zuienkerke	150 813	75 407

Table 7 - Average value of a house and its moveables (STADIM, 2006; BVVO)
(Italic: value of amalgamated municipality)

The damage function α of houses (including buildings such as castles, schools and rest houses), is calculated as follows (Van der Sande, 2001):

$$\alpha = \frac{5}{10000}d \qquad \text{voor } 0 \le d \le 100$$

$$\alpha = \frac{6}{10000}d - 0{,}01 \qquad \text{voor } 100 \le d \le 200$$

$$\alpha = \frac{24}{10000}d - 0{,}37 \qquad \text{voor } 200 \le d \le 300$$

$$\alpha = \frac{33}{10000}d - 0{,}64 \qquad \text{voor } 300 \le d \le 400$$

$$\alpha = \frac{32}{10000}d - 0{,}6 \qquad \text{voor } 400 \le d \le 500$$

$$\alpha = 1 \qquad \text{voor } 500 \le d$$

where d = water depth in cm

Except for apartment buildings the maximal damage to houses (average selling price) is reached at a water depth of 5m. In Table 8 the total number of buildings and the number of apartment buildings (3 or more residences per building) per community is given.

Town	# buildings (2001)	# apartment buildings (2001)
Blankenberge	8 165	3 854
Bredene	5 700	1 176
De Haan	4 933	1 519
De Panne	4 523	1 825
Dudzele (Brugge)	840	19
Gistel	4 215	426
Knokke-Heist	15 047	7 119
Koksijde	8 807	3 237
Lissewege & Zeebrugge (Brugge)	3 047	758
Middelkerke	7 413	2 421
Nieuwpoort	4 479	1 570
Oostende	32 029	16 557
Oostkerke & Hoeke (Damme)	261	7
Oudenburg	3 375	203
Stalhille (Jabbeke)	251	6
Veurne	4 406	373
Zuienkerke	1 032	56

Table 8 - Number of buildings and number of apartment buildings (2 or more residences per building) within the study-area (FOD, 2001)

The damage function α of moveables is calculated as follows (Van der Sande, 2001):

$$\alpha = \frac{47}{10000}d \qquad \text{voor } 0 \leq d \leq 100$$

$$\alpha = \frac{3}{10000}d + 0{,}44 \qquad \text{voor } 100 \leq d \leq 200$$

$$\alpha = \frac{16}{10000}d + 0{,}18 \qquad \text{voor } 200 \leq d \leq 300$$

$$\alpha = \frac{17}{10000}d + 0{,}15 \qquad \text{voor } 300 \leq d \leq 500$$

$$\alpha = 1 \qquad \text{voor } 500 \leq d$$

where d = water depth in cm

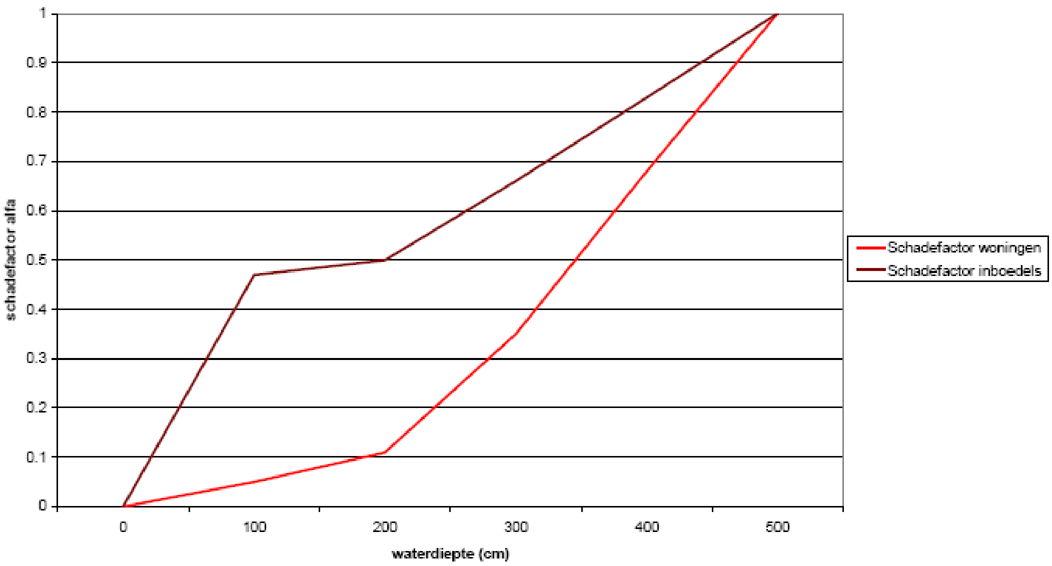

Fig. 23 – Damage factor for houses and moveables (Vanneuville et al., 2006)

Besides damage to houses and moveables there will also be damages to vehicles (cars and motorbikes) standing outside of the house or in the garage. The average maximal damage to personal vehicles is fixed to 4500€ (Vanneuville et al., 2006). The total number of personal cars and motorbikes per community is given in Table 9. The damage factor is calculated as follows:

$$\alpha = \frac{5}{1000}d \qquad \text{voor } 0 \leq d \leq 200$$

$$\alpha = 1 \qquad \text{voor } 200 \leq d$$

where d = water depth in cm
(Van der Sande, 2001)

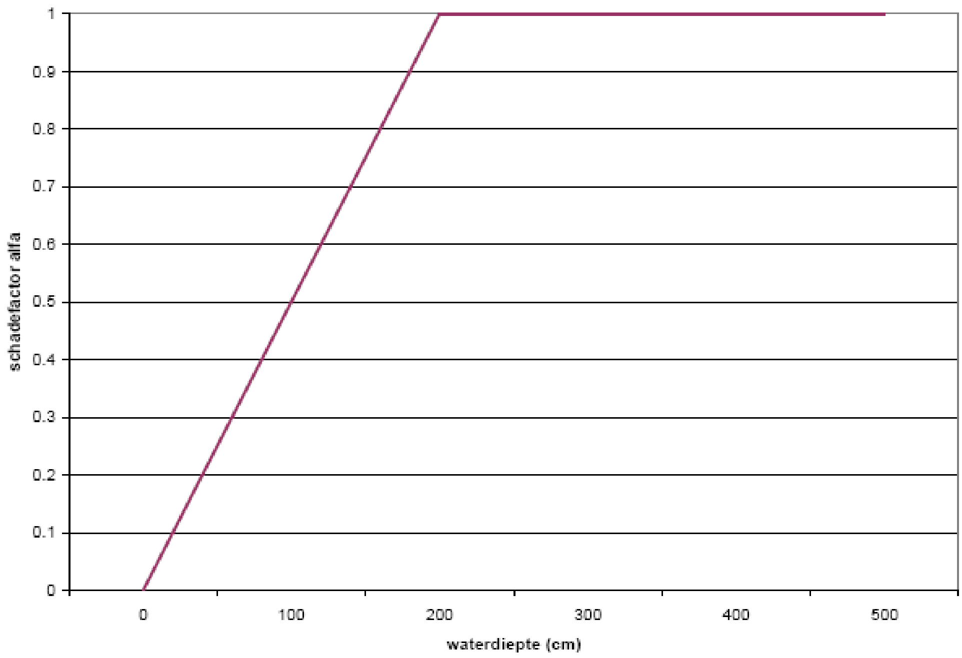

Fig. 24 - Damage factor to vehicles (Vanneuville et al, 2006)

Town	# vehicles (2007)
Blankenberge	6 772
Bredene	6 599
De Haan	5 705
De Panne	4 338
Dudzele (Brugge)	*1 090*
Gistel	5 221
Knokke-Heist	16 244
Koksijde	10 817
Lissewege & Zeebrugge (Brugge)	*4 865*
Middelkerke	816
Nieuwpoort	5 089
Oostende	25 811
Oostkerke & Hoeke (Damme)	*398*
Oudenburg	4 224
Stalhille (Jabbeke)	*324*
Veurne	5 396
Zuienkerke	1 401

Table 9 - Number of vehicles in the Belgian coastal zone (SVR, 2007). (Italic: estimation based on value amalgamated municipality)

1.3.3 Social importance

<u>Welfare</u>

Damages to houses and casualties as consequences of flooding have a negative effect on welfare of people. Damage to one house is supposed to influence the welfare of the people living in that house, sc. the household. The table below gives an overview of the number of households living in the study-area.

Town	# households (2006)
Blankenberge	9 017
Bredene	6 389
De Haan	5 522
De Panne	4 879
Dudzele (Brugge)	*1 077*
Gistel	4 455
Knokke-Heist	16 334
Koksijde	10 095
Lissewege & Zeebrugge (Brugge)	*4 807*
Middelkerke	8 500
Nieuwpoort	5 085
Oostende	34 947
Oostkerke & Hoeke (Damme)	*309*
Oudenburg	3 543
Stalhille (Jabbeke)	*245*
Veurne	4 680
Zuienkerke	1 078

Table 10 - Number of households living in the coastal zone (SVR, 2007)
(Italic: estimation based on value amalgamated municipality)

1.4 INDUSTRY AND BUSINESS

1.4.1 Intensity

According to Belpaeme & Konings (2004), the main economic asset of the Belgian coastal region is its geo-economic central location between the economic poles of the European core area. In addition, the extensive transport facilities enhance the possibilities for economic developments in the coastal zone.

In the Belgian coastal zone, the most important industrial activities are located in the main port areas of *Zeebrugge* and *Oostende*. Other industrial activities are generally concentrated in local SME estates (small and medium enterprises).

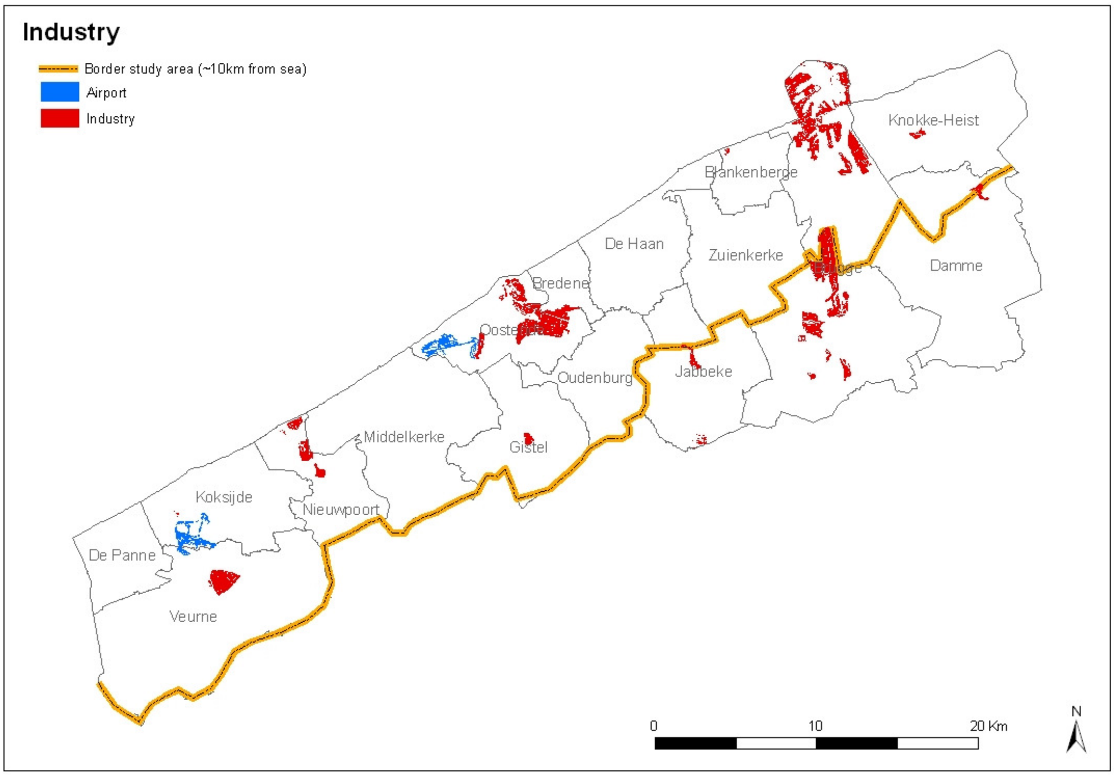

Fig. 25 - Industrial areas in the Belgian coastal zone (KBG, 2001)

The port of *Zeebrugge* is a multifunctional deep-water port up to 52 feet deep. The port is specialised in the treatment of roll-on roll-off shipping, containers, general cargo, liquid bulk and solid bulk (Coens J., 2008). Two third of the traded goods have an origin/destination relation within Europe. The service sector has the highest employment rate (67%) and total added value (63%) of all the sea port activities carried out by the private sector. In the inland port extension towards *Brugge* the share of industry increases (Idea Consult, 2002). In 2007, the port of *Zeebrugge* handled a total cargo volume of over 42 millions tons (Table 11).

Total **Break up into IN-OUT**

	2007	2006	+/-	%-difference
Roro	12,999,789	12,244,198	755,591	6.17%
Containers	20,323,002	17,985,690	2,337,312	13.00%
General Cargo	884,749	1,039,396	-154,647	-14.88%
Liquid Bulk	5,858,234	6,247,082	-388,848	-6.22%
Dry Bulk	2,011,462	1,956,411	55,051	2.81%
Total	42,077,236	39,472,777	2,604,459	6.60%

Table 11 - Total handled cargo volume in tons of the port of Zeebrugge (Coens J., 2008)

The port of *Oostende* is a "short-sea shipping" port. The main activity consists of roll-on roll-off shipping and cargo transportation to Great-Brittain (Table 12). Besides the sea port, Oostende also harbours a regional airport *Brugge-Oostende* (Table 13). At the airport, passengers as well as cargo are transported.

	Δ % 2005-2006	2006	2005
Passengers	+ 7,7 %	231 364	214 794
Passenger cars	+ 124 %	28 710	12 814
Roro-Freight (Tons)	+ 1,0 %	6 207 524	6 145 676
New cars (units)	+ 100 %	22 826	-
Containers lo-lo (ton)	- 45,5 %	24 103	44 266
General Cargo	+ 5,0 %	1 552 038	1 478 382
General total	+ 1,7 %	7 812 375	7 681 138

Table 12 - Traffic data of Oostende Port in 2006 (Haven Oostende, 2008)

	2006	2005	2004
Freight (tons)	98 525	108 260	97 582
Passengers (number)	146 355	126 144	111 275
Movements (number)	26 850	25 132	32 982

Table 13 - Traffic data of Ostende- Bruges International Airport (Ostend-Bruges International Airport, 2008)

Other industrial activities are mainly concentrated on local SME industrial estates. The most important estates can be found in *Nieuwpoort, Veurne, Westkapelle* and *Gistel.*

1.4.2 Economical importance

According to the National Bank of Belgium, the direct added value produced by the Flemish sea ports *Zeebrugge* and *Oostende* accounts for 7,7% of the total added value produced on Flemish territory. The table below gives an overview of the economical significance of the Belgian sea ports in terms of added value, proceeds and profit. A distinction is made between direct and indirect added value. The direct added value is produced by private and public companies within the port area, while indirect added value is produced by companies outside of the port area but generated because of the port.

	Direct Added Value (million €)	Indirect Added Value (million €)	Proceeds (million €)	Profit (€)
Port of Zeebrugge	799,7 ('05) (NBB, 2007)	618,5 ('05) (NBB, 2007)	?	13 106 795 ('06) (Port of Zeebrugge, 2008)
Port of Oostende	418,7 ('05) (NBB, 2007)	337,9 ('05) (NBB, 2007)	9,75 ('06) (Port of Oostende, 2006)	451 853 ('06) (Port of Oostende, 2006)

Table 14 - Economical data on ports and airport in the Flemish coastal region

The monetary damage to industry caused by flooding can be calculated as a function of the surface area or as a function of the number of employees.

Surface:

$$\alpha = \frac{4}{1000} d \qquad \text{voor } 0 \le d \le 200$$

$$\alpha = \frac{1}{1000} d + 0{,}6 \qquad \text{voor } 200 \le d \le 400$$

$$\alpha = 1 \qquad \text{voor } 400 \le d$$

where d = water depth in cm

Employees:

$$\alpha = \frac{1}{1000} d \qquad \text{voor } 0 \le d \le 100$$

$$\alpha = \frac{6}{10000} d + 0{,}04 \qquad \text{voor } 100 \le d \le 300$$

$$\alpha = \frac{39}{10000} d - 0{,}95 \qquad \text{voor } 300 \le d \le 500$$

$$\alpha = 1 \qquad \text{voor } 500 \le d$$

where d = water depth in cm
(Van der Sande, 2001)

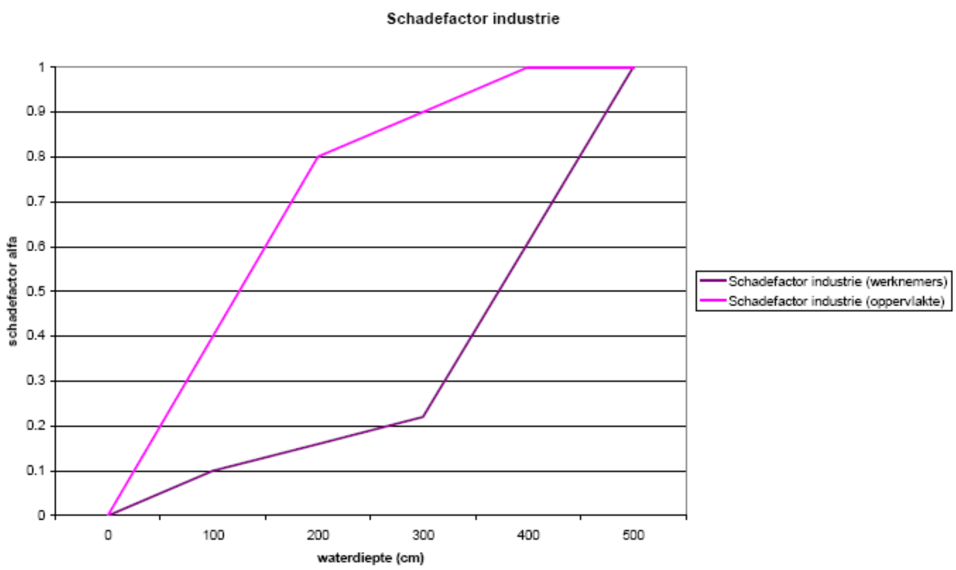

Fig. 26 - Damage factor α for industry (employees and surface area), Vanneuville et al. (2006)

1.4.3 Social importance

The two Belgian sea ports constitute major poles for employment and welfare in the Flemish region. Not only employment is created within the port area itself but also in supply companies in the hinterland.

	# employees	# companies	# indirect employees
Port of Zeebrugge	10 658 ('05)*	350 ('04)**	9 761 ('05)*
Port of Oostende	4 550 ('05)*	300 ('05)°	4 122 ('05)*
International Airport Ostend-Bruges	130 ('06)°°	-	-

*Table 15 - Number of employees and companies created by port activities within the study area (*NBB, 2007; **Coens J., 2008; °Haven Oostende, 2008; °°Ostend-Bruges International Airport, 2008)*

Table 16 gives an overview of the total number of employees within the study area by sector (except primary sector). Beside ports also industry, SME areas, service sector, creative sector, non-profit and independent are taken into account in the total number of working people.

Town	Second.	Tert.	Quat.	Indep.	TOTAL # working people
Blankenberge	188	2 948	1 373	1 392	6 966
Bredene	276	1 245	769	782	6 460
De Haan	185	1 960	1 013	1 178	4 698
De Panne	187	2 037	843	835	3 569
Dudzele (Brugge)	*162*	*1 078*	*604*	*164*	*1 060*
Gistel	584	1 287	717	891	4 797
Knokke-Heist	839	7 825	3 082	4 013	12 835
Koksijde	290	4 272	2 406	2 073	7 876
Middelkerke	314	2 616	1 117	1 565	6 663
Nieuwpoort	481	2 935	1 633	962	4 080
Oostende	3 875	22 671	10 676	3 712	25 340
Oostkerke & Hoeke (Damme)	*25*	*133*	*96*	*93*	*361*
Oudenburg	470	1 110	313	705	3 834
Stalhille (Jabbeke)	*42*	*69*	*105*	*96*	*299*
Veurne	1 742	4 223	2 485	1 104	5 118
Zuienkerke	85	218	74	412	1 337

Table 16 - Number of people working in secondary, tertiary, quaternary and independent sector in the study-area in 2005 (SVR, 2008). Zeebrugge is discussed separately above. (Italic: estimation based on value amalgamated municipality)

The number of companies in the study area (Table 17) is given as additional information but is not used in the damage calculations carried out by WL and UGent.

Town	# active companies
Blankenberge	1 233
Bredene	698
De Haan	1 047
De Panne	766
Dudzele (Brugge)	*180*
Gistel	883
Knokke-Heist	3 432
Koksijde	1 661
Middelkerke	1 435
Nieuwpoort	1 030
Oostende	4 126
Oostkerke & Hoeke (Damme)	*81*
Oudenburg	667
Stahille (Jabbeke)	*55*
Veurne	1 087
Zuienkerke	300

Table 17 - Number of active companies in 2005 (SVR, 2008).
Zeebrugge is discussed separately above.
(Italic: estimation based on value amalgamated municipality)

1.5 AGRICULTURE

1.5.1 Intensity

As shown in Fig. 27, the coastal plain is one of the most important agricultural areas of Flanders. Within a majority of the towns, farming land accounts for more then 50% of the total area (Vriesacker et al., 2007). Pastures and grasslands constitute about 40% of the farmland while 60% is used as arable land mainly to cultivate grain crops (Belpaeme & Konigs, 2004), see Fig. 28.

The main reason why the coastal plain constitutes a major agrarian area is the presence of very fertile polder soil. According to Belpaeme & Konings (2004), polders are pieces of land previously reclaimed from the sea by systematic dike construction and drainage. Areas with a higher elevation are rather used for cultivating crops, whereas pasturelands will be found in the lower-lying areas.

The most cultivated crops in the Flemish coastal polder area are corn and grain (Fig. 29).

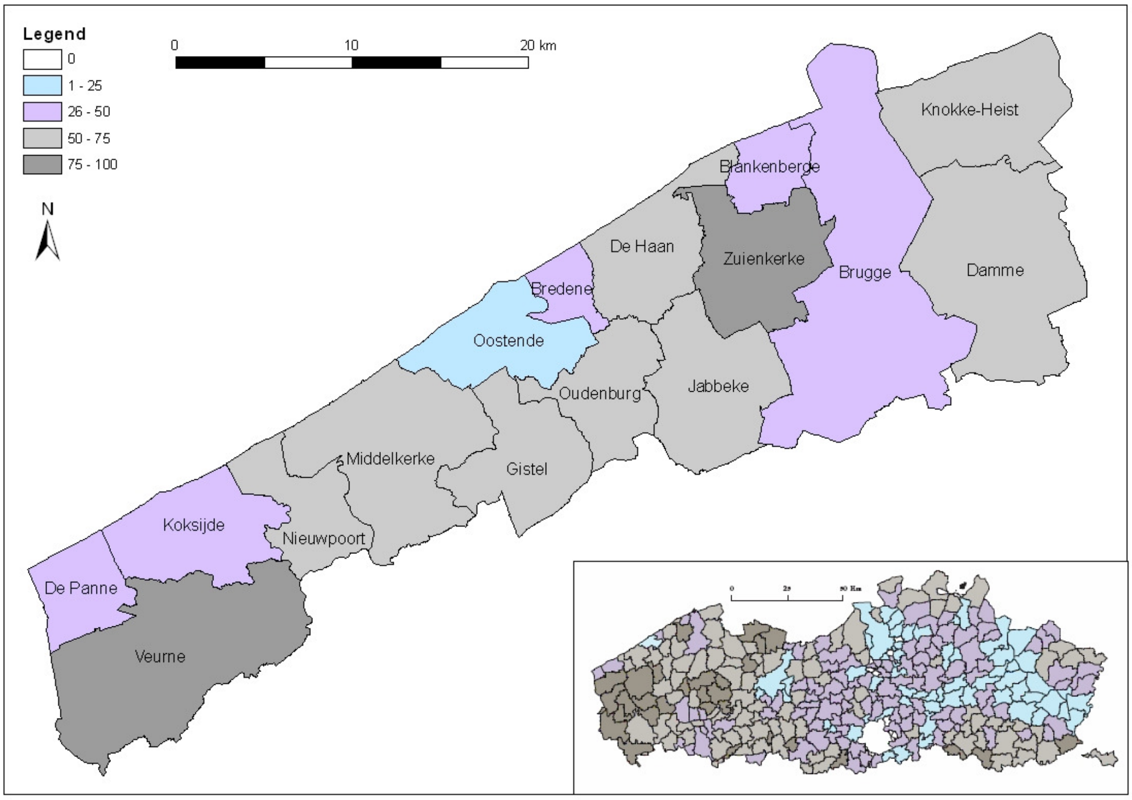

Fig. 27 - Percentage agricultural area / total surface area per town in 2006 (based on Vriesacker et al., 2007)

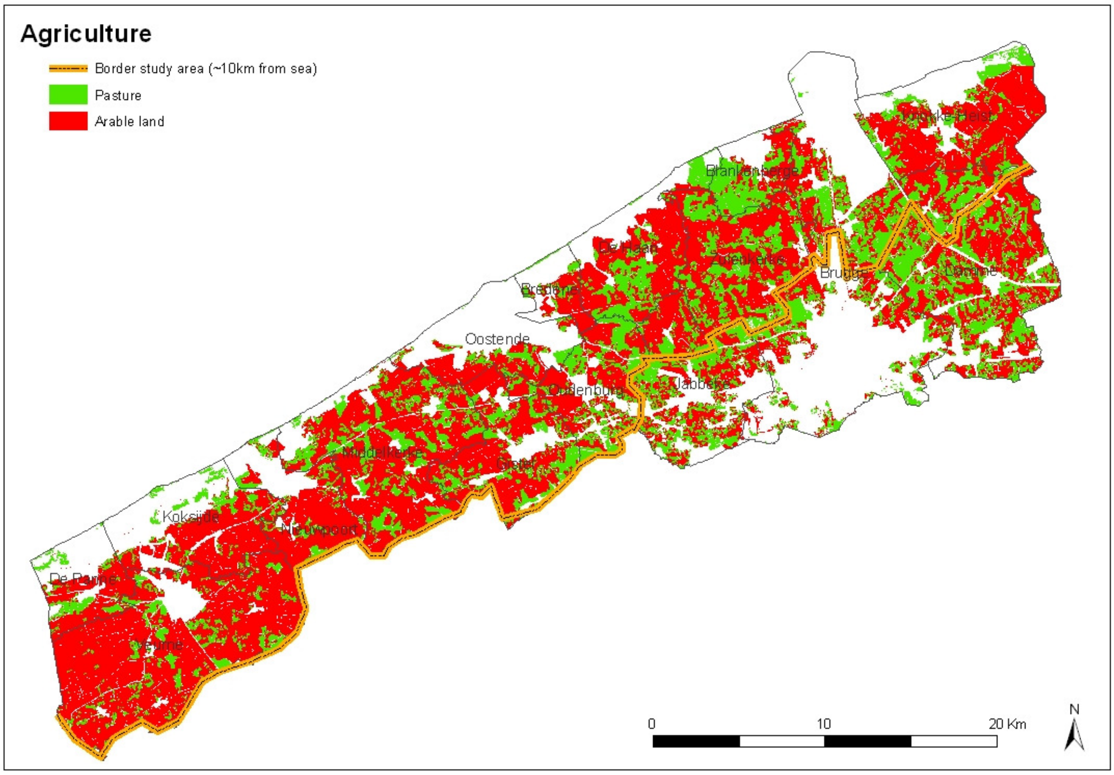

Fig. 28 - Agriculture in the Belgian coastal zone (KBG, 2007)

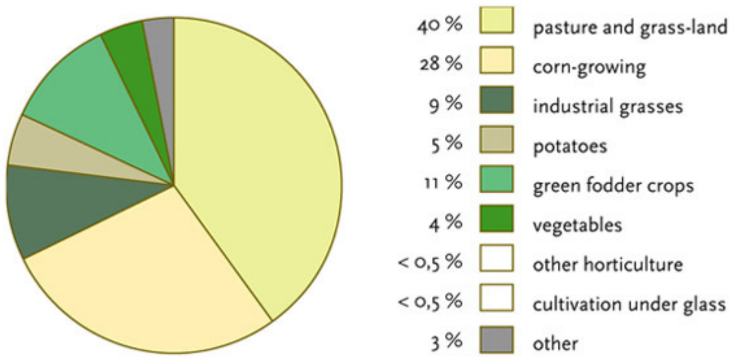

Fig. 29 - Cultivation structure of agricultural crops in the polders (Belpaeme & Konings, 2004)

1.5.2 Economical importance

The maximal damage costs to arable land are estimated as a function of crop type, yield per hectare and price per kilogram. For Flanders, the damage to arable land is assessed at 0,5 €/m² (Vanneuville et al., 2006).

Flooding of arable land will directly lead to loss of the yield growing at the moment of flooding and consequently loss of proceeds. Indirectly, flooding by the sea will cause loss of soil fertility due to salinization of the ground water and structural decay of clayey polder soils. It is expected that desalinization of arable land requires 1 to 4 years whereas recovery of the soil structure by spreading gypsum over the field costs about 500 €/ha (Nieuwhuizen et al., 2003). Damage costs to pasture land are deduced from the production of hay per hectare and the price per kilogram. For Flanders this leads to an average maximal damage of 0,08 €/m² and an extra 10% for indirect damage. The latter is related to the fact that during and after flooding the cattle can not be put to pasture. Also, hay can not be mowed after the flooding due to silty deposits (Vanneuville et al., 2006).

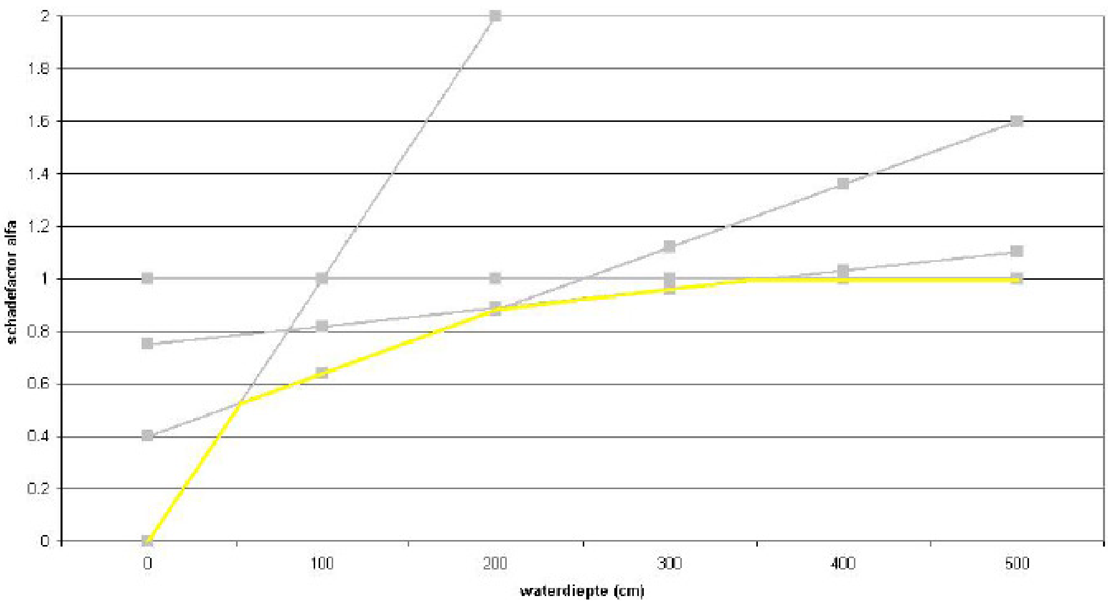

Fig. 30 - Damage function to agriculture (Vanneuville et al., 2006)

The damage function for arable and pasture land is calculated as follows:

$$\alpha = MIN\left(\frac{d}{100};0,24*\frac{d}{100}+0,4;0,07*\frac{d}{100}+0,75;1\right)$$

where d = water depth in cm

(Vrisou Van Eck et al., 1999)

At a water depth of 375 cm agricultural lands suffer from maximal damage (Vrisou van Eck et al., 1999).

1.5.3 Social importance

Flooding of farm land will cause temporarily and/or permanent loss of jobs in the agricultural sector. The maximal number of people in the sector who can be affected by flooding events is shown in the table below.

Town	# farms	# people working in agriculture
Blankenberge	31	42
Bredene	19	41
De Haan	81	133
De Panne	23	35
Dudzele (Brugge)	4	6
Gistel	114	197
Knokke-Heist	112	203
Koksijde	57	112
Lissewege & Zeebrugge (Brugge)	17	29
Middelkerke	175	323
Nieuwpoort	65	124
Oostende	27	48
Oostkerke & Hoeke (Damme)	18	33
Oudenburg	105	188
Stahille (Jabbeke)	10	21
Veurne	241	490
Zuienkerke	115	219

Table 18 - Number of people working in agriculture and number of farms in 2005 (SVR, 2008) (Italic: estimation based on value amalgamated municipality)

1.6 TRANSPORT AND SERVICE NETWORKS

1.6.1 Intensity

1.6.1.1 Roads, railroads and tramways

According to Belpaeme & Konings (2004), the Belgian coastal zone is regarded as an urban network with two major cities (*Oostende* and *Brugge*) and a few smaller towns (*Blankenberge* and *Knokke-Heist*). Overland transport facilities between and within the towns include roads, railroads and tramways (Fig. 31). In total, about 2600 km major roads, 3900 km minor roads and 180 km railways and tramways can be found within the study area. Flooding of the coastal zone will cause damage not only to the network connections but also to associated infrastructure such as railway stations, platforms, bush shelters, vehicles, etc. ….

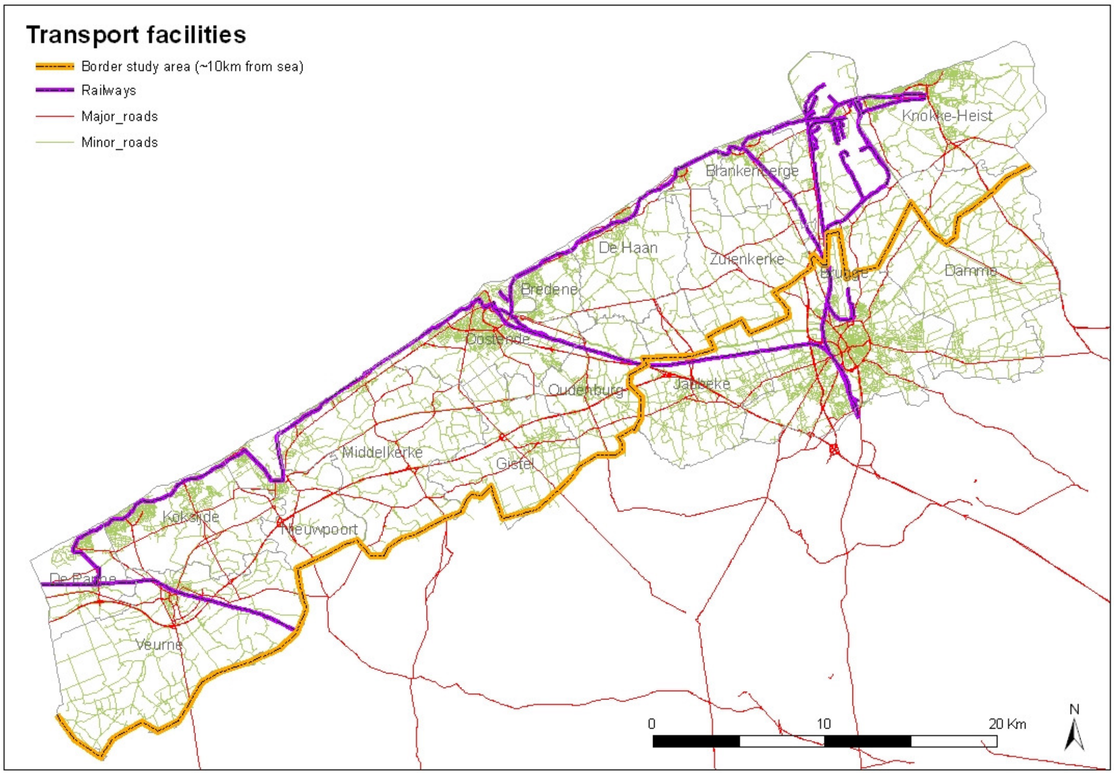

Fig. 31 - Overland transport facilities in the Belgian coastal zone (Mercator Database: Verkeer 2006)

1.6.1.2 Service networks

Service networks include gas, telecommunications, electricity and water. Following information on this subject is available for the Belgian coastal zone: high tension network (> 70kv), mobile phone masts and wind turbines (Fig. 32). In total, about 120 km high tension cables, 100 mobile phone masts and 250 wind turbines can be found within the coastal study area.

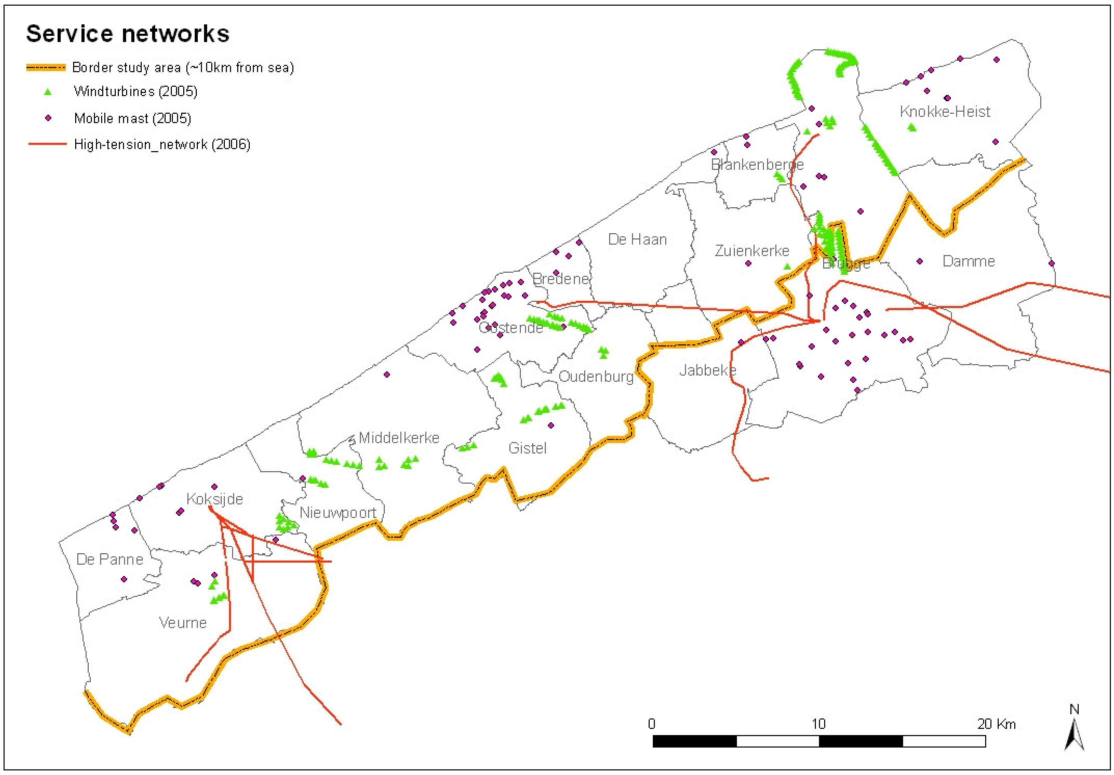

Fig. 32 - Service networks in the Belgian coastal zone
(Mercator Database: Hoogspanningskabels 2006, GSM pylonen 2005, Windturbines 2005)

1.6.2 Economical importance

Damage to transport infrastructure will indirectly lead to economic losses in companies which depend on ports, airports, roads and railroads for goods transport. The importance of ports and airports in the Flemish coastal region is stated under 1.4.1. No data is available on goods transport by roads and railroads.

Roads, railroads and tramways

The damage function to roads, railroads and tramways is calculated as follows:

$$\alpha = MIN\left(0,28 * \frac{d}{100} ; 0,18 * \frac{d}{100} + 0,1 ; 1\right)$$

where d = water depth in cm
(Vrisou Van Eck et al., 1999)

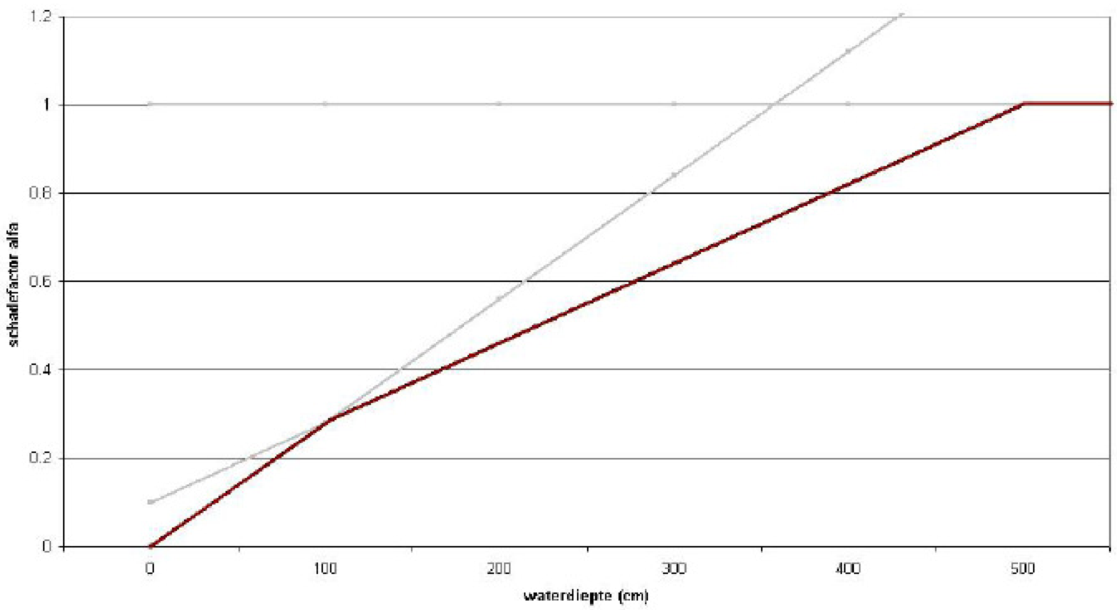

Fig. 33 - Damage factor for roads and railroads (Vanneuville et al., 2006)

Service networks

The damage function to service networks is calculated as follows:

$$\alpha = MIN\left(0,8 * \frac{d}{100} ; 0,34 * \frac{d}{100} + 0,15 ; 1\right)$$

where d = water depth in cm
(Vrisou Van Eck et al., 1999)

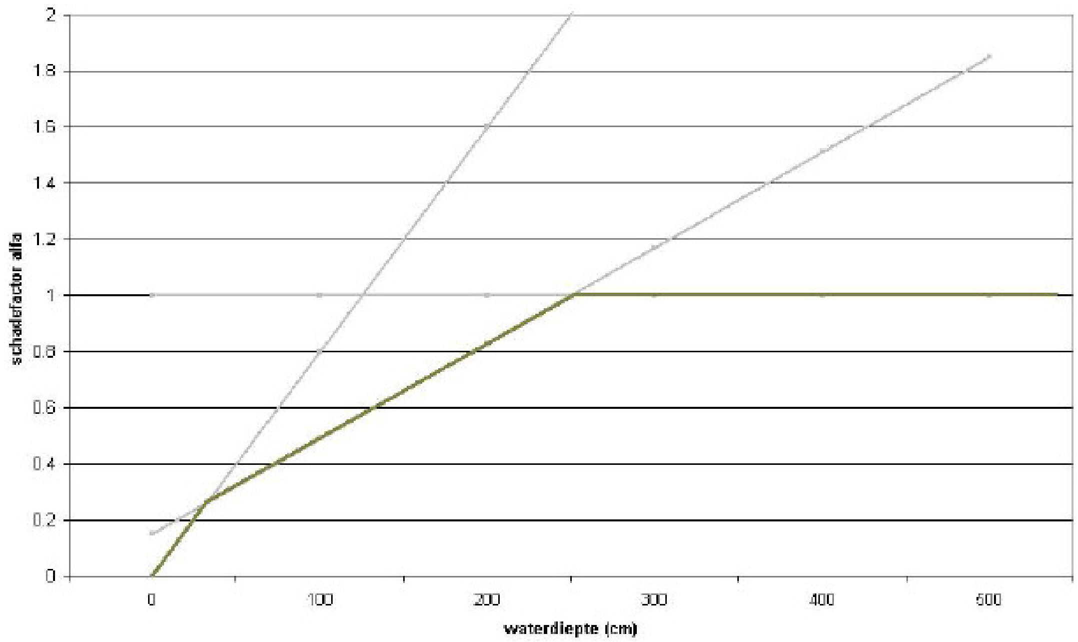

Fig. 34 - Damage factor for transmitting stations and wind turbines (Vanneuville et al., 2006)

The damage function for water supply wells, underground parking garages and metro stations is a binary function. There is no damage when there is no water and total damage (α = 1) when flooding occurs. However, the flood water possibly has to overflow a threshold before it flows into the well, garage or station.

1.6.3 Social importance

<u>Accessibility</u>

The tables below list the total number of vehicles on highways and district roads in the coastal region. Statistic data on the number of passengers using trains within the study area can be found in the subdocument of tourism.

Nr. telpost	Sectie	Kmpt	Werkdag	Zaterdag	Zondag	Weekdag
E40/A10 :	**Brussel - Gent – Oostende**					
39015-39016	Brugge (E403/A17) - Loppem	84,3	51.300	46.700	50.000	50.500
39023-39024	Loppem - Jabbeke/De Haan	90,2	66.000	58.900	62.000	64.400
39031-39032	Jabbeke (E40/A18) - Zandvoorde	100,5	26.700	22.900	23.900	25.800
39035-39036	Zandvoorde - Oostende	101,8	26.500	24.700	25.200	26.100

E40/A18 : Calais (F.) - Veurne - Jabbeke

39129-39130	Franse grens - Adinkerke	7,7	17.000	19.200	18.500	17.500
39133-39134	Adinkerke - Veurne	9,7	18.000	18.200	17.000	17.900
39137-39138	Veurne - Oostduinkerke	16,7	21.200	20.600	20.300	21.000
39145-39146	Oostduinkerke - Nieuwpoort	21,4	26.100	25.100	24.800	25.700
39149-39150	Nieuwpoort - Middelkerke	23,0	30.900	30.900	32.200	31.100
39153-39154	Middelkerke - Gistel	35,4	35.600	35.800	37.400	35.900
39161-39162	Gistel - Brugge (A10)	36,7	35.100	35.100	37.000	35.400

Table 19 - Daily averages of number of vehicles on highways in the coastal zone between 6am and 10pm, for the year 2006. Kmpt= kilometre point of the counter (Verkeerstellingen, 2006)

Nr. telpost	Plaats	Weg	Kmpt	Werkdag	Zaterdag	Zondag	Weekdag
30199-30200	Klemskerke	N9	107,9	6900	5600	4700	6400
30201-30202	Klemskerke	N9	108,1	10400	10400	10300	10400
30123-30124	Oostende	N33	3	19900	19700	13400	18900
30125-30126	Oostende	N33	3,2	19000	18000	14500	18200
30029-30030	Gistel	N33	10,6	12300	11900	10100	11900
30137-30138	Gistel	N33	10,9	11100	11000	9700	10900
30071-30072	Ichtegem	N33	20,9	10400	10700	9400	10300
30073-30074	Ichtegem	N33	21	13800	13900	12000	13600
30009-30010	Knokke-Heist	N34	1,3	10100	10500	9800	10100
30093-30094	Zeebrugge	N34	7,8	20000	14100	13100	18100
30107-30108	Zeebrugge	N34	10,1	10100	8700	8700	9700
30189-?????	De Haan	N34	20,2	4900	4400	4200	4700
30031-30032	Bredene	N34	27,3	10200	10300	9300	10100
30085-30086	Mariakerke	N34	37,5	7500	8000	7400	7600
30095-30096	Westende	N34	45	6100	6600	6300	6200
30039-30040	Lombardsijde	N34	48	5700	6100	6000	5800
30049-30050	Oostduinkerke	N34	59	8000	9100	8500	8200
30011-30012	De Panne	N34	64,2	6000	7500	6800	6300
30089-30090	Lapscheure	N49	74,8	18500	18600	23400	19200
30051-30052	Westkapelle	N49	82,3	24700	25200	26300	25000
30213-30214	Ramskapelle	N300	5,1	6200	5400	5000	5900
30127-30128	Oostende	N341	2,3	9600	10100	6800	9300
30139-30140	Gistel	N367	19,7	6500	6600	4600	6200
30141-30142	Gistel	N367	19,9	6500	6000	3900	6000

30249-30250	Knokke-Heist	N374	12,9	4600	4400	4200	4500
30215-30216	Ramskapelle	N376	9,9	17600	13000	12500	16200
30217-30218	Ramskapelle	N376	10,1	12700	9600	10000	11900
30251-30252	Knokke-Heist	N376	12,8	13000	10600	11200	12400
30253-30254	Knokke-Heist	N376	13	13200	11100	12000	12700
30043-30044	Knokke-Heist	N376	15,1	7800	9000	9800	8300
30203-30204	Klemskerke	N377	6,8	9000	9500	10400	9300
30219-30220	Ramskapelle	N378	0,1	1500	1200	1200	1400

Table 20 - Daily averages of number of vehicles on district roads in the coastal zone between 6am and 10pm, for the year 2006 (Verkeerstellingen, 2006)

2 EXTERNAL FACTORS

Beside the effects of climate change, other factors may also play an important role in the future development of coastal flooding risks.

2.1 DEMOGRAPHIC DEVELOPMENTS

Since risk equals probability times impact, an increase in population in the coastal zone will amplify the risk of flooding hazards (Fig. 35). On the one hand, the probability of flooding is expected to rise due to primary effects of climate change such as sea level rise, increased storminess and coastal erosion. On the other hand, the impact of a flooding event will be more severe since a more densely populated coastal zone will suffer more casualties.

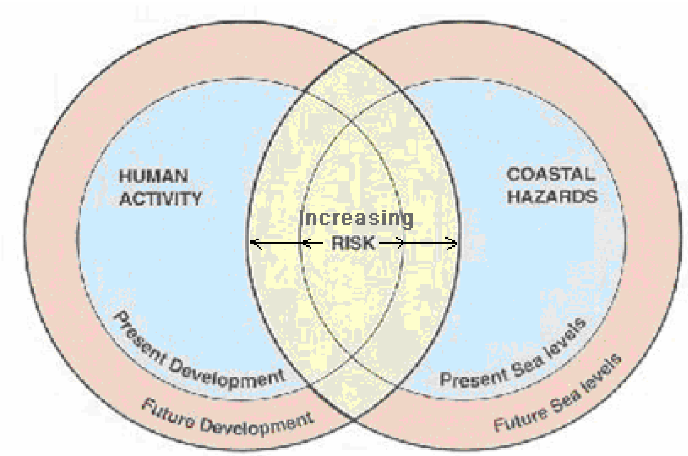

Fig. 35 - Interaction between coastal hazards, human activity and risk (McInnes R., 2006),

As shown in Table 21, the total population within the Belgian coastal zone is expected to decrease slightly with 2% by the year 2025 (SVR, 2007).

Town	Estimated population by 2025	Evolution 2008-2025
Blankenberge	19 684	- 7%
Bredene	17 536	- 13%
De Haan	12 451	- 2%
De Panne	10 217	- 1%
Dudzele (Brugge)	*2 463*	*0*
Gistel	11 480	- 3%
Knokke-Heist	33 087	+ 3%
Koksijde	22 650	- 5%
Lissewege & Zeebrugge (Brugge)	*10 993*	*0*
Middelkerke	19 100	- 5%
Nieuwpoort	11 505	- 5%
Oostende	67 746	+ 2%
Oostkerke & Hoeke (Damme)	*760*	*+ 6%*
Oudenburg	8 850	- 1%
Stalhille (Jabbeke)	*639*	*+ 2%*
Veurne	11 903	- 1%
Zuienkerke	2 637	+ 4%
TOTAL	**259 328**	**- 2%**

Table 21 - Estimated population by 2025 (SVR, 2007)
(Italic: estimation based on value amalgamated municipality)

2.2 ECONOMIC DEVELOPMENTS

Besides population growth, expansion of industry and business will likewise augment flooding risks. Increasing economical importance of ports will not only cause more damages to port infrastructure but will also indirectly effect the whole Flemish economy due to its high contribution to the total added value.

2.2.1 Port of Zeebrugge

According to the Port of Zeebrugge, it will further specialise in some specific regular traffics which makes it necessary for the infrastructure to be adjusted to the anticipated growth of these traffics. These changes include among other things:

- The creation of new grounds for roro traffic in the Albert II dock in the outer port
- The conversion of part of the current inner port into a tidal port. The elimination of the Visart lock can in the long term result in an area of 340 ha without locks and independent of the tides, which can be used for the expansive roro traffic
- The construction of a third large container terminal in the outport. Zeebrugge is one of the few European ports with sufficient depth to handle large container ships (14,000 TEU) without any problem
- The further expansion of the inner port; the extension of the Southern Canal Dock, the construction of quay walls and the creation of a new distribution area

2.2.2 Port of Oostende

The channel to the Port of Oostende will be deepened and widened to 125m to be able to receive larger cargo vessels, ferries and cruiseships (Fig. 36). Two new dams will be built: the Westdam located at *Capucijnenstraat* and the Eastdam as a continuation of the *Hendrik Baelskaai*. The eastern palisade will be abolished while the western palisade will be preserved as national heritage. This new port entrance will give *Oostende* a greater economical drive and benefit the employment in the region (www.portofoostende.be, 2008).

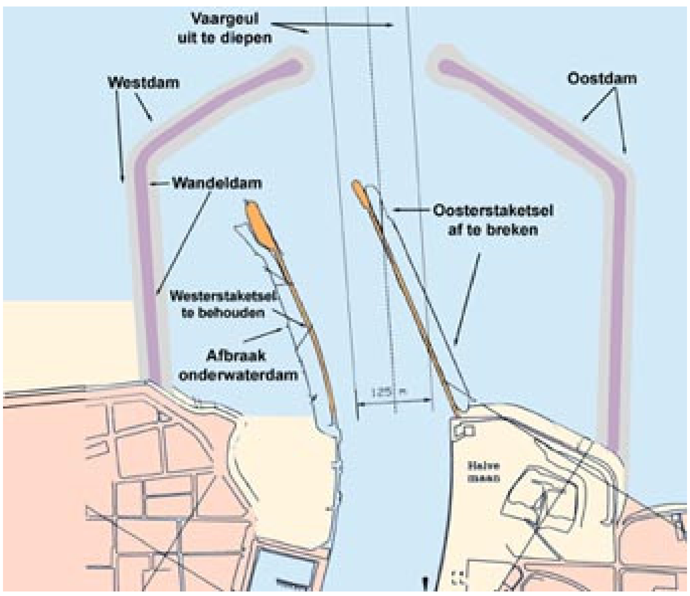

Fig. 36 - Future development of the Port of Oostende (www.portofoostende.be, 2008)

A business development company, *nv Plassendale,* was established in 1997 in order to manage and commercialize the inner port area of *Oostende*. Table 22 gives an overview of the number of people working in the companies at the industrial zone *Plassendale* and the number of people that in the future could be employed at the harbour companies.

Nr.	Company Name	Employment		
		2001	2008	Capacity
1.	Bonar - Xirion	40	103	120
2.	Fitco	20	44	50
3.	Natuursteenzagerij Plassendale	0	0	20
4.	Huber	42	46	46
5.	Proviron Group	303	300	300
6.	Seminck Gas	0	0	100
7.	SKB	0	10	15
8.	Damen Shipyards Oostende	0	50	70
9.	Incubatiecentrum	0	5	40
10.	TMC Belgium	5	5	5
11.	Telindus	0	35	60
12.	Europal	0	45	65
13.	Seagate	0	13	300
14.	Duranet	4	15	15
15.	De Bree	0	4	40
16.	Electrawinds nv	0	69	100
17.	Flanders Bakery	0	50	100
18.	Verhoek Oostende	12	39	80
19.	Fides Petfood	0	8	20
20.	XL Video	0	35	100
21.	Methapharma	0	30	50
22.	Delta Transport nv	0	0	70
23.	Icemark	0	15	15
24.	Zargal	0	0	49
25.	Bedrijvencentrum	0	0	100
26.	Genia	0	0	15
27.	Fire Technics	15	22	50
28.	Cool Solutions nv	0	0	35
29.	nv Algemene Ondernemingen Soetaert	0	0	100

30.	Betonijzerbuigcentrale Inter nv	0	0	39
31.	Snoep- en Horecacenter Lingier	0	0	30
32.	Transport Maenhout	0	0	300
Totaal		441	943	2499

Table 22 - Companies at Plassendale, already established and with agreement for establishment (Plassendale nv, 2008)

2.3 BUDGET FOR NEW DEFENCE STRUCTURES

The type of sea defence which will be used to better protect the coastline against flooding and coastal erosion depends partly on the availability of funds. Managed retreat is an alternative and less expensive protection measure for dikes and beach replenishments. Though, one of the main disadvantages of the method is the loss of land which has been reclaimed from the sea previously for the purpose of agriculture or settlements. For example, the creation of a drainage basin within the reserve *Zwin* to prevent it from silting up requires partly flooding of the Willem-Leopoldpolder. This could lead to loss of more than 120ha polder land that is currently occupied with farmland (Van Bossuyt P., 2007).

2.4 CHANGES IN CIRCULATION PATTERNS

2.4.1 North Sea sand and gravel extraction

An environmental impact statement carried out by Ecolas NV (2006) reveals that sand extraction is believed to be volumetrically an irreversible process. Within the period 1987-1994, *Kwintebank* (sector 2A and 2B, see Fig. 37) has decreased in volume with approximately 2% per year. Additional lowering at the southern part of the sandbank is attributed to sand extraction. At *Buitenratel* (sector 2C) an overall accretion of 1% is found while at *Oostdyck* (sector 2C) no changes have been stated. *Gootebank* (sector 1B) has broadened significantly.

An increase in storminess could lead to severe reduction of the height of the sandbanks. For example, the *Middelkerkebank* lowered with about 1,2m after one heavy storm. Further reduction of the volume of sandbanks due to extraction could lead to intensified wave action along the Belgian coastline during extreme events such as storms and to modification of the hydrodynamic equilibrium and bathymetry.

Sea level rise as a consequence of climate change is expected not to alter the present current pattern in a significant way (Ecolas NV, 2006).

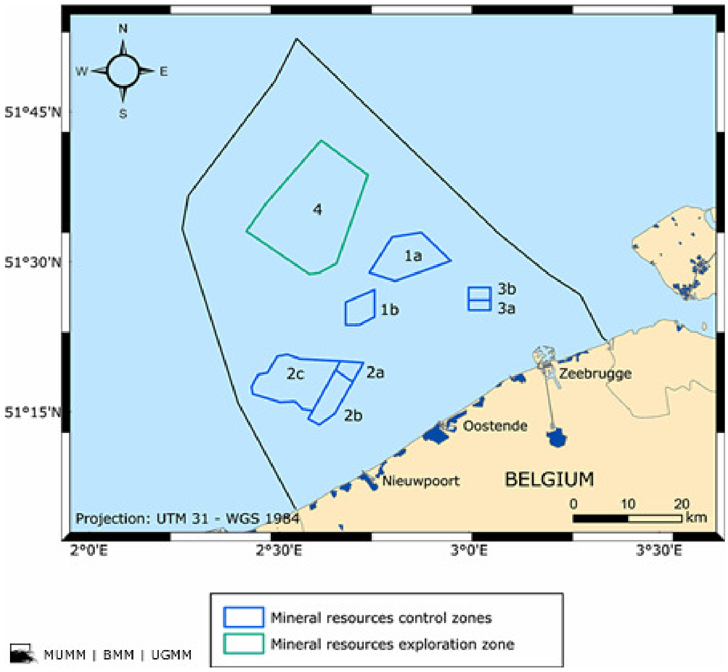

Fig. 37 - Map of permitted extraction areas on the BCP (ICES, 2007)

2.4.2 Offshore economic constructions

It could be expected that offshore economic constructions such as wind farms possibly alter hydro- and morphodynamic characteristics of the BPNS (Du: BDNZ). These changes at its turn could affect golf conditions along the shoreline.

According to an environmental impact assessment carried out by Ecolas NV in 2003, the construction of a wind farm on the *Thorntonbank* has negligible and temporary effects on the global hydro- and morphodynamics of the BCP. The study reveals that the pile constructions only alter erosion and sedimentation patterns very locally. Hydrodynamic characteristics such as current velocity and direction are also modified locally. Furthermore, a slight sea level rise due to global warming is expected not to have considerable influence on sediment transport nor on the hydrodynamic regime on the BCP.

3 SECUNDARY IMPACTS OF CLIMATE CHANGE ON COASTAL FLOODING RISKS AND COASTAL INFRASTRUCTURE

The most important primary effects of climate change that have a determinant influence on flood risks along the Belgian coastline are sea level rise, changes in hydrodynamic climate (increase in storminess), changes in wave climate (increased wave height) and changes in circulation patterns (orientation and velocity of ocean currents).

These primary physical effects will directly result in flooding of the coastline and the lower coastal hinterland and to increasing coastal erosion due to increasing frequency and severity of storms.

3.1 ECOLOGICAL EFFECT CATEGORIES

3.1.1 Water quality

In order to protect the Belgian coastal zone against flooding due to sea level rise and increasing coastal erosion, there will be a need for better and more regular maintenance of existing defence structure. Beside, it will be necessary to build new and/or greater defence structures. One of the most common present-day protection measures along the Belgian coastline are sand nourishments. Sand is extracted from the bottom of the North Sea and deposited on the beach to make it higher, broader and/or larger. In some cases the sand can also be deposited on foreshore, though in Belgium this is a less common technique. The sand nourishments act as buffers for wave action and prevent further erosion from beach and dune. Though, dredging of sand causes changes of the North Sea bathymetry, which lead to alteration of water circulation patterns. Beside, foreshore nourishment itself leads to changes in circulation patterns.

The construction of offshore defence structures (e.g. breakwaters) can also cause moderation of water and sediment transport patterns.

Regular dredging on the same location may also cause increase in turbidity of the sea water. This will negatively influence the marine ecosystem and associated fauna and flora.

3.1.2 Habitat change

Due to the construction of hard defence structures to prevent the coastal zone from flooding, natural geomorphologic processes and ecosystems are interrupted and will eventually degrade. For example, dune slacks ('duinpannen') can only be formed when the sea enters the low laying dune area during spring tide.

On the other hand, an increase in sea level will lead to a permanent loss of certain specific coastal habitats like e.g. wetlands ('slikke en schorre'). This loss could be compensated by allowing the sea and coastal habitats to advance landward under managed retreat like e.g. the natural reserve 'Zwin'.

The usage of sand nourishment as protection measure leads to disturbance of benthic ecosystems and loss of associated fauna and flora at the location of sand extraction in the North Sea. The deposition of sand on foreshore also disturbs the benthic habitat at the location of nourishment and buries besides benthic fauna and flora also fishes. On the other hand, the total beach area increases because of sand nourishments.

A new ecological opportunity can be found in the creation of new marine habitat on offshore defence structure. This habitat is characterised by intense wave action, high oxygen rates in the water and tidal influence. These conditions are particularly suitable for e.g. mussels, barnacles, certain types of algae, …

The construction of greater and new defence structures to protect ports against the consequences of climate change leads to erosion or accretion of beaches in the vicinity of these constructions (e.g. Bay of Heist, Knokke).

3.1.3 Biodiversity

Due to sea level rise and extremer weather conditions, certain specific coastal habitats will be lost by flooding and increased erosion. This can locally lead to permanent loss of rare fauna and flora restricted to these habitats, and so loss of biodiversity. On the other hand, landward migration of coastal habitats under managed retreat can lead to an increase in biodiversity due to creation of new coastal habitats.

3.2 ECONOMICAL EFFECT CATEGORIES

3.2.1 Change in production

Due to the increase of frequency and intensity of storms, coastal erosion rates will be higher, leading to more damage to offshore infrastructure of aquaculture, wind turbines etc. On its turn, this damage can lead to temporary lower production rates.

3.2.2 Production value

Due to the necessity for greater defence structures around offshore infrastructure for economical activities (aquaculture, energy sector etc.), the exploitation costs will increase, leading to a higher price of the product (ex.: price of mussels, wind energy). This secondary effect is indirectly a consequence of sea level rise and increased storminess. Beside, ports will also need to be protected by new and greater defence structures. This will increase the price of products transported by shipping.

3.2.3 Damage costs

Flooding and coastal erosion lead to many types of damages: to coastal defence structures, service networks, transport infrastructure, private and public buildings, industry, aquaculture and agriculture. These higher damage and maintenance costs are a direct consequence of the primary effects of climate change. Indirectly, these damages also lead to economic losses: due to the permanent or temporary closure of companies, other companies (customers, suppliers) can experience economic difficulties and losses.

The construction of new and greater defence structures around ports to protect against sea level rise and increased coastal erosion lead to silting up of channels and port entrances. The regular need for dredging increases the maintenance costs of port infrastructure. This effect is an indirect secondary result of the adaptation measures to the primary effects of climate change (flooding, coastal erosion).

3.2.4 New opportunities

The adaptation measures to protect the Belgian coastline from flooding as a result of climate change can clear the way for new opportunities. The construction of new innovative offshore defence structures can be coupled with diverse economical or ecological activities. For example, hard constructions built to absorb the wave energy before they reach the beach could be used to breed mussels or oysters. Also, the developing of man-made islands in front of the coast could create new opportunities, as example for agriculture or wind energy.

Another innovative adaptation strategy to sea level rise which offers new opportunities is managed retreat. This measure allows a low-laying area to become flooded in a controlled way by removing coastal protection. In these areas susceptible to flooding, the natural intertidal ecosystem can restore itself or expand (ex.: Zwin).

At the other hand, already existing defence measure types like beach nourishments give the opportunity to the recreational sector to expand their activities on the new or broadened beaches. Another example are the artificial reefs built to protect the shoreline on which also recreational diving could be organised.

3.3 SOCIAL EFFECT CATEGORIES

3.3.1 Attractiveness coastal & marine area

Due to sea level rise and increased coastal erosion, a certain amount of beach area and thus space for leisure activities will be lost. At the other hand, sand nourishments create new and broader beaches. Though, sand nourishments have different disturbing social effects. The sand that is used for the nourishments is generally coarser and darker then the original beach sand. It can make the beach less attractive. Also, during summer beach cabins will be at a higher level because of the nourishment, so that the sea view for people on the dike terraces is disturbed. Tourists and residents can also find the Belgian coastline less attractive due to the presence of concrete dikes which interrupt the natural ecosystem or due to the presence of offshore defence structures.

The attraction value of the coastline can increase in account of the alternative defence strategy of managed retreat. The creation or restoration of particular intertidal habitats can attract more tourists.

3.3.2 Employment

Due to the necessity of building greater and new defence structures and the maintenance of existing infrastructure to protect against sea level rise and increased storminess, there can be expected more jobs available in the construction and dredging sector.

At the other hand, damages to business properties caused by flooding will lead to a permanent or temporary loss of jobs in the affected areas.

3.3.3 Safety

Flooding of the coastal zone can directly result in casualties on the coastline and in the hinterland. Casualties can also occur on the coastline due to wave overtopping during less intense storms.

3.3.4 Accessibility

Due to the presence of hard defence structures around ports, the navigation of ships through the channels can be hampered.

When coastal transport infrastructure is damaged due to flooding, wave overtopping or coastal erosion, the accessibility to the coastal zone will be obstructed.

3.3.5 Welfare

Damages to properties and casualties resulting from flooding and/or coastal erosion will indirectly influence the life quality of people. The deceasing of economical active people leads to a decrease of the financial status of families.

Damage to business properties due to flooding will also lead to temporary or permanent loss of employment in the affected areas.

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