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Abstract

The research described in this report is made in the framework of the project *Vervolgstudie inventarisatie en historische analyse slikken en schorren langs de Zeeschelde*. The main purpose of the project is to investigate why some of the evolutions of the slikke and schorre area in the past – described in the report *Van Braeckel et al. (2006)* – did occur. The main tools to investigate these evolutions are measured data from the past as well as numerical models.
With the numerical models different scenarios were studied in order to see how each of them influenced the tidal penetration in the Scheldt estuary. In fact it is change in tidal penetration that will affect the slikke and schorre area. In each scenario one possible cause of tidal change was implemented. A distinction was made between natural evolutions (sea level rise, changes in fresh water discharge) as well as human interventions in the estuary (poldering, straightening of the river, deepening of the navigation channel, …) in the scenarios.
In *Coen et al (2009)* the results of the 1D model are described. In *Ides et al. (2008)* a sensitivity analysis of the 2D model is carried out, in order to have an idea about the uncertainty interval of the results of the different scenarios. In this report the results of the scenarios will be given.

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1 Introduction

From the historical analysis of the slikke and schorre areas in the Sea Scheldt (*Van Braeckel et al.*, 2006) it is clear that the schorre, slikke and undeep sublitoral areas along the Scheldt estuary and its tidal tributaries strongly decreased over the passed 150 years. This is a result of the loss of habitats due to river straightening actions in the upper Sea Scheldt, poldering along the river, construction of dikes and other infrastructural works. In the last decades the relative importance of the indirect loss of habitats (i.e. loss of habitats because of erosion) strongly increased as a result of the increased tidal energy in the estuary. Different natural processes and human interventions in the estuary can be a reason for this. However up to this moment it is not clear what is the impact of the individual changes (both natural as human) on the observed evolution. But it is clear that the change in tidal penetration is an important factor contributing to this.

During the passed centuries the tidal regime of the Scheldt estuary has seriously changed. There are many factors that contributed to this, such as poldering, natural evolution of the estuary, enlargement of the navigation channel, continuous maintenance dredging, permanent withdrawal of sand from the estuary for different purposes, changed tidal conditions in the North Sea, changed upstream discharges etc. It is expected that all of these factors contributed to the changes of the tidal regime. Until now it is not clear how important the effect of all these individual factors on the observed evolution of the water levels in the estuary is.

The influence of different factors on the hydrodynamics of the estuary is studied in this report by the use of a 2D hydrodynamic model (NEVLA model). The objective of this study is to analyze how different human activities and natural changes in the estuary affect the tidal regime. The analysis is based mainly on the comparison of high and low water levels calculated for the reference situation (i.e. the situation anno 2006) and for the different scenarios (i.e. the situation anno 2006 with 1 factor changed in a schematic way).

The effects of the following changes in the Scheldt estuary were analyzed:

- The effect of sea level rise (including the amplification of the tidal amplitude);
- The depoldering of the areas Braakman, New-Westland, Tielrodebroek and Groot Schoor of St-Amands;
- The second enlargement of the navigation channel with and without disposal of the capital dredging material;
- Changes at the ebb-flood channel system Gat van Ossenisse - Middelgat;
- The effect of sand mining.

Human activities and natural changes can have both a direct and an indirect effect on the tidal regime in the estuary. They can result in the change of the hydrodynamics, which can lead to morphological adaptations of the system to the new situation. New morphological conditions can affect hydrodynamics again. Thus, hydrodynamics and morphology affect each other and therefore they should be studied together. Due to the uncertainty of the numerical morphological models, especially on the mid and long term, only the initial direct effect of the changes is studied in this report. Therefore a hydrodynamic numerical model is used.

2 Units and reference plane

Time is expressed in MET (Middle European Time).

Depth, height and water levels are expressed in meter NAP (Nieuw Amsterdams Peil). A bathymetric depth is positive below the reference plane, water levels are positive above the reference plane.

The horizontal coordinate system used for the model is RD Parijs.

3 The numerical model

3.1 The NEVLA model

At Flanders Hydraulics Research the NEVLA model was developed for the Western Scheldt, the Sea Scheldt and tidal tributaries. The results of 2D simulations of this model were used for analysis of the water levels in this report. The model was set up in the SIMONA software – a software developed by the Dutch Rijkswaterstaat – and it includes a broad sea area and all Flemish tidal rivers, such as Schelde, Durme, Rupel, Nete (Beneden, Grote and Kleine Nete), Dijle and Zenne. These rivers are represented until their tidal border (*Vanlede et al.,* 2008b).

The study area is shown on Figure 1. Figure 2 presents the grid of the NEVLA model. The number of grid points in the M-dimension is 341, in the N-dimension 2949. This gives more than 1 million grid points in total for the entire model. Because of the extended model domain parallel computing is used to speed up the calculations. While the original model grid includes the area from the Belgian – French border to Oostkapelle, the seaward boundary for this study is defined at the cross section Cadzand – Westkapelle. Since there are water level measurement stations of Hydro Meteo Centrum Zeeland at Westkapelle and Cadzand, it is possible to impose measured water levels at the seaward model boundary for a certain period.

3.2 The calibrated model

In the reports (*Vanlede et al.,* 2008a), (*Vanlede et al.*, 2008b), (*Maximova et al.*, 2009) and (*Ides et al.,* 2008) a sensitivity analysis and extended calibration of the NEVLA model were performed. In (*Vanlede et al.,* 2008b) the calibration was done for the water levels and discharges, based on the phase and magnitude of the most important harmonic tidal components of these parameters. The model was calibrated for the year 2006. In (*Maximova et al.,* 2009) the calibration of the NEVLA model was extended. The methodology of analysis in this study was based on the comparison of the phase and magnitude of the calculated and measured high and low water levels. The model was calibrated for June – July 2002. Since the simulation period is approximately 4 weeks the effect of the spring-neap tide cycle is included in the mean water level values, as well as a broad range of upstream discharges (Figures 4 and 5). Figure 5 shows that sometimes the discharge at Dendermonde is negative. This is not expected because there is a weir at Dendermonde which prevents tidal wave from penetrating to the Dender. However, the analysis in (*Maximova et al.,* 2009) shows that the discharge becomes negative if the weir is not closed in time. In this case the flood flow can come into the Dender river and the water level in the Dender follows the changes of the water level in the Scheldt. Therefore, the negative discharges in Dendermonde are kept as such in the input of the numerical model.

From Figure 5 it can be seen that the simulation period is a period with rather small upstream discharges, except a rain event in the beginning of July. After the two consecutive efforts to calibrate the model, the accuracy of simulating the tidal penetration in the Scheldt estuary improved for most stations. Table 3-1 shows the accuracy of the initial NEVLA model as described by (*Hartsuiker et al.,* 2004) and the model calibrated in *(Maximova et al.,* 2009).

From Table 3-1 it can be seen that the original model described in (*Hartsuiker et al.,* 2004) is not accurate in the Upper Sea Scheldt. This is because the model was not calibrated for this area. Only a calibration of the new 2D Nevla Scheldt model for the Western Scheldt and the Lower Sea Scheldt was done in (*Hartsuiker et al,.* 2004). Therefore, the model performance in the upstream part of the estuary is not good.

Table 3-1.Model accuracy before and after the calibration (simulation period: June – July 2002)

Station	**difference in high water (calculation - measurement) (cm)**		**difference in low water (calculation - measurement) (cm)**	
	before calibration (*Hartsuiker et al*., 2004)	after calibration (*Maximova et al*., 2009)	before calibration (*Hartsuiker et al*., 2004)	after calibration (*Maximova et al*., 2009)
Vlissingen	-11.4	2.4	6.9	1.0
Hansweert	0.7	-4.3	8.5	-0.2
Baalhoek	-5.6	-7.2	10.0	-4.8
Schaar van de Noord	-6.2	-7.4	10.6	-4.0
Bath	-4.1	-1.2	12.0	-3.1
Liefkenshoek	-3.6	-6.9	17.6	-0.3
Antwerp	-4.5	-6.7	27.6	1.5
Hemiksem	-28.4	-3.0	28.1	-7.0
Temse	-27.9	-11.9	12.3	-21.1
Schoonaarde	-13.3	1.1	-3.5	-9.1
Wetteren	-12.1	-3.5	41.5	-9.5
Melle	-5.0	-22.3	35.2	-11.0

3.3 The reference model simulation

In this study different scenarios are calculated with the numerical model. In order to determine the effect of each scenario, a comparison with a so-called reference scenario is made. This reference scenario is described very briefly in this paragraph.

3.3.1 The input data

In the NEVLA model new bathymetric data are used. These data are obtained after interpolation of the most recent topo-bathymetric measurements on the model grid:
- The Upper Sea Scheldt, Rupel and Durme: Single Beam measurements from 2001;
- The Lower Sea Scheldt: Single Beam measurements from 2004-2005;
- The Western Scheldt: Single Beam measurements from 2006, LIDAR survey of intertidal and supralitoral areas from 2003;
- The mouth area of the Western Scheldt: Single Beam measurements from 2002-2003.

The boundary conditions for the year 2002 are used in the reference run. The downstream boundary of the NEVLA model as it is used in this study is defined by the line Westkapelle - Cadzand. However, for some reason the station Cadzand is not exactly located on the model boundary (see Figure 3): as a consequence the measured time series of this station are a little bit shifted in time in the model. See (*Maximova et al.,* 2009) for more information about this time shift. The measured water levels at Cadzand and Westkapelle are available from the HMCZ database.

The NEVLA model has several upstream boundaries. The discharges at these upstream boundaries are available from the Hydrometry group of Flanders Hydraulics Research. Daily averaged discharges are used at the following stations: Grobbendonk (Kleine Nete), Itegem (Grote Nete), Zemst (Zenne) and Haacht (Dijle). Zero discharge is specified for Durme – Waasmunster, Schelde – Gentbrugge, Bovenschelde – Zwijnaarde because there was no or negligible discharge during the period of the analysis. 10 min discharge time series are available for Dendermonde (Appels), also measured by the Hydrometry group of Flanders Hydraulics Research.

The discharge at Merelbeke (the Upper Sea Scheldt and Leie) is the largest fresh water discharge coming to the Scheldt estuary. Thus, it has the most significant effect on the model output. Therefore, it is very important to have accurate and detailed time series of discharge for this location. The data series of the discharge at Merelbeke are available as 5 min values.

Wind is included in all model runs. The wind data are available from the Hydro Meteo Centrum Zeeland (HMCZ) database. The wind data measured at the station Hansweert are imposed as a uniform wind field influencing the whole model area. These data consist of wind magnitude and direction (10 minute average values).

The wind station Hansweert is chosen as being representative for the entire estuary. Figure 6 shows the comparison of the wind magnitude and direction for different stations along the Western Scheldt. The wind direction is very similar at all four locations. The differences between the wind magnitude at Hansweert and other stations are not large for most moments in time. The root mean squared error for different stations is about 2 m/s. Since the wind at Hansweert is the strongest, the calculation is conservative if the wind at this station is used as representative for the entire estuary.

For the reference model simulation the same bed roughness field as in the final calibration run in (*Maximova et al.,* 2009) is used. This roughness field varies in space along the estuary and in the transversal direction (the bed roughness used for ebb and flood channels in the Western Scheldt is different).

The time step used in the model simulations is 7.5 seconds. It is chosen based on the analysis of the Courant number (the ratio of a time step to a cell residence time). The Courant number specifies a maximum value of a time step; this number should be smaller than 10.

The effect of salinity and sediment transport is not included in the model simulations.

3.3.2 The simulation period

The simulation period chosen in this report is from 19/06/2002 12:30 to 17/07/2002 7:30. For this period 5 min averaged discharge time series are available at Merelbeke. From the sensitivity analysis *(Ides et al.*, 2008) it is found that the use of daily averaged discharges at this location worsens the calculated discharges in the Upper Sea Scheldt up to Hemiksem compared to hourly averaged discharges. When 5 min averaged discharges are used, the correspondence between calculation and measurement is even better; however the difference between the 2 results is small. For all simulations in this report, the 5 min averaged discharges at Merelbeke are used since these data are available.

3.3.3 Ebb and flood volumes for the reference run

A number of cross sections is defined in the model in order to find ebb and flood volumes in the estuary. These cross sections are defined at the location of the water level stations. Table A-1 in Appendix shows the calculated ebb and flood volumes for spring and neap tide. Flood volumes are considered positive; ebb volumes are considered negative. The absolute value of the ratio between flood and ebb volume is also calculated, which is expected to be approximately 1.

From the table it can be seen that tidal volumes as well as the flood-ebb ratio decrease in the upstream direction. The decrease of the volumes is to be expected. The flood-ebb ratio is different from 1 thanks to the fresh water discharge, which is significantly increasing the ebb volume in the more upstream part of the estuary.

The flood-ebb ratio is larger for spring tide than for neap tide. This is because the selected spring tide is rather symmetrical, while the analyzed neap tide is not symmetrical. This can be seen from Figure 7, which shows the time series of discharge and water level at Vlissingen for the analyzed spring tide and neap tide. During the neap tide high water in the beginning of the ebb is higher than high water in the end of flood. This results in a larger ebb volume compared to the flood volume for this neap tide.

During the neap tide the flood-ebb ratio decreases upstream Vlissingen, which is expected. During the spring tide the flood-ebb ratio decreases only upstream St-Amands. From Vlissingen to St-Amands it changes in the range from 1.00 to 1.02. This is because the selected spring tide is a little asymmetrical for some stations (Temse, Tielrode, …). The high water in the beginning of the ebb is lower than the high water in the end of the flood at these stations. This results in a larger flood-ebb ratio than more downstream (where the tide is more symmetrical). Upstream St-Amands the flood volume decreases, which results in decrease of the flood-ebb ratio. This ratio becomes smaller than 1.

For most stations the spring flood and ebb volumes are larger than the neap flood and ebb volumes respectively. However, for some stations (from Dendermonde to Melle, Hombeek, Emblem and Kessel) the neap ebb volume is larger than the spring ebb volume. These stations are located close to the tidal boundary of the estuary. Therefore, the ebb volumes at these stations can be strongly affected by the upstream river discharges. Table A-2 in Appendix shows the relation between the volume of fresh water discharge during the ebb period and the total ebb volume at a certain station. The fresh water discharge composes a large part of the ebb volume at these stations during neap tide. Therefore, it is possible that the neap ebb volume becomes larger than the spring ebb volume.

4 Methodology of analysis

The effects of the different changes in the estuary that happened during the last century are analyzed. Therefore some of these changes are implemented in a schematic way in the numerical model (adaptation of grid, bathymetry, bed roughness or boundary conditions). To study the effect of a certain change, only the adaptations necessary for this scenario are made in the model. All other parameters are left the same as in the reference model run. Therefore, the change in the model output is only the result of the certain scenario change.

The following parameters are calculated for different scenarios and compared with the reference situation:

- *phase and magnitude of the high and low water levels.*

  The average differences between the phase and magnitude of high and low waters for the reference run and scenario simulations are found for every station. Table 4-1 shows the list of the stations used in the analysis.
  The time and magnitude of the low and high water levels are found using Matlab, based on the sign of the first derivative of the water level time series. High and/or low waters for some locations are not found due to the limitations of the Matlab script: this is the case for locations where the transition from rising water to falling water (or the opposite) is not very clear. For these stations the sign of the first derivative can not be used to determine the high and low water levels.
  10 minute time series of the water levels are used for the analysis. We studied the effect of this time interval on the calculated magnitude and phase of high and low waters for some scenarios. The results of the analysis of 1 minute and 10 minute time series were compared (Appendix A). The differences between the use of the 1 minute and 10 minute time series are small. The differences in high and low water magnitude are zero for most stations, a maximal difference of 3 cm is observed at Melle. The differences in the phase are 1 to 2 minutes. From these results it is concluded that it is sufficient to use 10 minute time series for the analysis of phase and magnitude of high and low water levels.

- *tidal asymmetry.*

  Tidal asymmetry is defined as the ratio of the duration of falling water to the duration of rising water. Therefore, if ebb is dominant, tidal asymmetry is larger than one. If flood is dominant, tidal asymmetry is smaller than one.

- *tidal volumes.*

- *flow velocities.*

Table 4-1. Water level stations along the Scheldt estuary used in this report

	River	**Station**
1	Western Scheldt	Vlissingen
2		Terneuzen
3		Hansweert
4		Baalhoek
5		Schaar van de Noord
6		Bath
7	Lower Sea Scheldt	Liefkenshoek
8		Antwerp
9		Hemiksem
10	Upper Sea Scheldt	Temse
11		Dendermonde
12		Schoonaarde
13		Wetteren
14		Melle
15	Durme	Waasmunster
16	Rupel	Boom
17		Walem
18	Dijle	Mechelen
19	Zenne	Hombeek
20	Nete	Duffel (Beneden Nete)
21		Kessel (Grote Nete)
22		Emblem (Kleine Nete)

5 Scenario analysis

5.1 Sea level rise scenarios

5.1.1 Introduction

Observations of the tide in the North Sea during the last decades indicate an increase of the sea level, both high and low waters (*Lebbe and Van Meir*, 2000). The global mean level of the North Sea has increased by 0.1 - 0.2 cm per year during the 20th century. The Intergovernmental Panel on Climate Change (IPCC) predicts that it will rise further between 14 - 80 cm by the year 2100 as a result of thermal expansion and melting of ice sheets. Coastal areas could face an increasingly significant risk of flooding, inundation and erosion as a result of sea level rise, with or without more frequent and severe storm surges (*Flanders Marine Institute*, 2009).

According to the KNMI scenarios, the sea level rise by 2050 is estimated to be 15 - 25 cm in the case of an increase of the world temperature by 1°C, and 20 - 35 cm in the case of an increase of the temperature by 2°C. For 2100 the KNMI predicts a sea level rise at the Dutch coast by a range of 35 - 85 cm (*Van den Hurk et al.,* 2006).

According to the research of the Gent university (*Lebbe and Van Meir*, 2000), the projected regional sea level rise in the North Sea is thought to be of the order of 40 to 70 cm by the year 2100.

Table 5-1. Overview of the model simulations for the sea level change scenarios

Name	Description
run 11	sea level rise of 25 cm (~ the year 2050)
run 12	sea level rise of 60 cm (~ the year 2100)
run 13	sea level decrease of 25 cm (~ the year 1900)
run 14	increase of the tidal amplitude by 5% and sea level rise of 50 cm (~ the year 2100)

Table 5-1 presents an overview of the model simulations for the sea level change scenarios. In this report the effect of sea level rise on the high and low water levels in the Scheldt estuary is studied based on the average values of an increase of 25 cm for the year 2050 (run 11) and 60 cm for the year 2100 (run 12). The measured water levels at the seaward model boundary (Westkappele and Cadzand) of the year 2002 are simply increased with these values in the respective runs. This is a simplification of the reality since the sea level rise will have another effect on the low water levels of the sea compared to the high water levels. This is due to the amplification of the tidal amplitude which is coupled with the sea level rise.

The changes of high and low waters of the sea level can be different from the change of the mean sea level (which is given in all studies about sea level changes mentioned before). This can result in an increase of the tidal amplitude. From 1860 to 2000 the tidal amplitude increased by about 25 cm. This is about 18 cm/century or a relative increase of approximately 5% per century (*Jeuken et al*., 2007).

To take into account the increase of the tidal amplitude together with the sea level rise of the North Sea, the measured time series of the water levels of 2002 at the seaward model boundary are multiplied by 1.05. Since the water levels in the model are referred to the NAP vertical reference plane – which corresponds approximately to the mean water level – multiplication of the time series with a factor of 1.05 corresponds more or less to an increase of the high waters by 5% and a decrease of the low waters by 5%. Besides this multiplication, the time series are afterwards shifted up by 50 cm in the model run 14. This scenario represents the sea level rise in the year 2100 taking into account an increase of the tidal amplitude in the North Sea of 5%. As a result of the changes at the seaward boundary, the high waters at Cadzand increase on average by 60 cm, while the low waters increase only by 41 cm.

The effect of a rise of the sea level is similar to the effect of a storm, but both phenomena occur on a different time scale. The time scale of the sea level rise is so large that the morphology of the river can slowly adapt to this change. However, it is very difficult to predict these morphological changes on the longer term (especially on the new slikke and schorre area due to the sea level rise), and as a consequence this effect is not taken into account in the hydrodynamic model that is used in this study. In order to have an idea about the effect of the adaptation of the slikke and schorre area due to sea level rise, a sensitivity analysis was carried out. Besides the sea level rise scenario with an increase of 25 cm of the sea level (run 11) also the effect of a sea level decrease of -25 cm was studied (run 13). In run 11 supratidal area (which was never intertidal before) will become intertidal, in run 13 subtidal area (which was intertidal in the past) will become intertidal. In both cases the morphological adaptation of the new slikke and schorre area is not taken into account. The difference between both runs will give an indication about the effect of this morphological process.

As mentioned before, in the sea level decrease scenario the water levels at the seaward model boundary are decreased by 25 cm. According to measurements from station Vlissingen, the sea level has been rising steadily since 1900 by an average of 0.2 cm/year in relation to the NAP *(Proudman Oceanographic Laboratory,* 2009). Therefore, the situation with a decrease of 25 cm represents approximately the sea level at the beginning of the 20th century.

5.1.2 Relevant previous studies

(Dillingh and Heinen, 1994) studied how the water levels in the Western Scheldt changed during the past century. They concluded that the mean high water levels in the Western Scheldt increase faster than the mean sea level. The mean low waters increase slower than the mean sea level. This results in increase of the tidal amplitude.

The high waters increase more in the upstream direction. Since 1900 the high waters at Bath increased about 20 cm more than the high water at Vlissingen. (*Dillingh and Heinen,* 1994) concluded that this can be related to a stronger increase of the high waters in the eastern part of the Western Scheldt. The high waters increase there by 50 cm per century which is about two times more than along the Dutch coast of the North sea and Wadden sea (25 cm per century).

Since 1960 the increase in low waters in the eastern part of the Western Scheldt changed into decrease. Combined with a relatively strong increase of the high waters, this results in a strong increase of the tidal amplitude in this part of the Western Scheldt.

The tide penetrates the estuary stronger than in the past because the estuary has become deeper and narrower. The storage areas decreased while the channels where the water flow is transported increased (*Vroon et al*.,1997).

The velocity of the tidal wave in the Scheldt estuary increased. In 1985 the high water went from Vlissingen to Hansweert on average 15 min faster than in 1895 and from Vlissingen to Antwerp 40 minutes faster than in 1895 (*Vroon et al*., 1997). The increase of the tidal wave velocity means that the estuary is filled “better”. At the moment of the high water at Antwerp the water level at Vlissingen is higher than in the past. In 1895 at the time of high water at Antwerp the water at Vlissingen was decreasing for already 2 hours 24 minutes, while now it is 1 hour and 44 minutes. Therefore, there is more water in the estuary. The tide fills the estuary “better” because of a faster propagation of the tidal wave.

The conclusions in *(Dillingh and Heinen*, 1994) and (*Vroon et al*., 1997) were made based on the comparison of the measured water levels in the Scheldt estuary. Therefore, their results include not only the effect of the sea level rise but also the effects of all other natural and human changes in the estuary. The analysis in the following chapter will be based on numerical modeling and only the effect of the sea level change will be studied.

5.1.3 High and low water levels for sea level rise (runs 11 and 12)

The comparison of the model results for the sea level rise scenarios with the reference run is presented in Tables A-3 and A-4. Figures 8 - 12 show the average change in high and low waters relative to the water level change imposed at Cadzand. This relative change is calculated as the water level change at a certain station minus the imposed sea level change.

From point of view of the high waters the imposed sea level rise is almost without change noticeable up to Hansweert. At the stations Vlissingen, Terneuzen and Hansweert the high waters increase even a little bit more than the imposed water levels at the seaward model boundary. This difference in water level increase is not high (a few millimeters for 2050, up to 1 cm for 2100).

At Baalhoek the relative change in high water compared to the imposed sea level rise is zero. From Baalhoek to Temse the increase of the high waters is slowly reducing. At Antwerp the high waters increase by 57 cm and the same value can be found at Temse in run 12. This increase is a little smaller than the one calculated by the 1 D model (*Coen et al*., 2009), where high waters increased by 60 cm at Antwerp and 59 cm at Temse for a similar scenario.

Upstream Temse the effect of sea level rise diminishes. In the Upper Sea Scheldt and tributaries high water levels increase by 2 to 7 cm less compared to the imposed water level rise at Cadzand. At Dendermonde – where the effect of the sea level rise on the high waters is the smallest – the high waters increase by 51 cm in run 12. At Schoonaarde the high waters increase by 53 cm in run 12. The results of the 1 D model (*Coen et al.,* 2009) showed a stronger increase of the high waters for these stations for the year 2100: an average increase of 59 cm for Dendermonde and 62 cm for Schoonaarde.

There is a higher increase in high waters at Wetteren and Melle than at other stations in the Upper Sea Scheldt. High waters at Melle increase even by 64 cm in 2100, which is more than the imposed sea level rise. However a similar increase in high waters at Melle was calculated with the 1D model (*Coen et al.,* 2009).

The strongest effect on the low waters is observed at Vlissingen. An increase of low waters at this station has the same value as the imposed sea level rise. From Vlissingen up to Temse there is a slight decrease in the relative change of the low water levels. At Antwerp low waters increase by 56 cm in run 12. The same average change in low waters at Antwerp was calculated by the 1 D model (56 cm for the year 2100). At Temse low waters increase by 55 cm in run 12 (this is 5 cm more than the result of the 1D model for the year 2100).

Upstream Temse the relative difference in low water levels becomes more negative. This means that low waters along the Scheldt estuary increase less than the imposed sea level rise. The largest differences are observed in Schoonaarde: for run 12 the low waters increase only by 37 cm. At Wetteren and Melle the increase in low water levels becomes more pronounced compared to Schoonaarde. The calculated change of low waters at Schoonaarde and Wetteren is again similar to the results of the 1D model (*Coen et al.,* 2009). At Melle low waters increase by 39 cm, while the 1 D model calculated an increase of only 34 cm.

The results obtained in our study are different from (*Dillingh and Heinen,* 1994). They concluded that high waters increase more in upstream direction. However, the model simulations described in this chapter show that the effect of the sea level rise decreases more upstream. This can be related to the fact that the analysis in (*Dillingh and Heinen,* 1994) was based on the comparison of the measured water levels. Therefore, their results include not only the effect of the sea level rise but also the effects of all other natural and human changes in the estuary. On the other hand the fact that the sea level rise will cause morphological changes, which on their turn can affect the tidal penetration, is not included in the numerical scenarios. Therefore it is also possible that the effect of the model scenario is somehow different from the effect in nature.

Figure 10 shows the effect on the tidal amplitude of the different sea level rise scenarios. This Figure is the result of the change in high waters as well as the change in low waters. It can be seen that between Vlissingen and Temse the tidal amplitude is quite similar to the reference simulation: only a small increase in tidal amplitude can be found for this reach of the estuary. Upstream Temse the increase in tidal amplitude becomes more pronounced, with a maximum value in Melle of 24 cm for run 12.

According to (*Dillingh and Heinen,* 1994) the tidal amplitude increases already in the Western Scheldt because the mean high water levels in the Western Scheldt increase faster than the mean sea level while the mean low waters increase slower than the mean sea level.

The sea level change has only a very small effect on the phase of the high waters. The changes in the phase of low water are small in the Western Scheldt (a negative phase shift up to 5 min in Bath for run 12). Between Bath and Temse the phase shift of the low waters is between 5 to 6 min for run 12: the low water levels occur earlier in this region compared to the reference scenario. The differences become even more negative upstream with a maximum value for Melle. This means that in the Upper Sea Scheldt and tributaries it can be expected that low waters will be observed earlier in the case of the sea level rise (10 to 25 min earlier for scenario 2100).

5.1.4 High and low water levels for sea level decrease (run 13)

In run 13 the water levels at the seaward model boundary are decreased by 25 cm. Tables A-3, A-4 and Figures 8 - 12 show that the decrease and increase of the sea level by 25 cm result in very similar changes (but with opposite signs) as well in the magnitude as in the phase of the high and low waters. This result gives an indication that the effect of the morphological adaptation of the zones which change from sub- or supratidal to intertidal areas is rather small on the tidal penetration. However, this does not mean that the morphological effect of a sea level rise on the estuary as a whole has only a small impact on the tidal penetration. After all the flow conveying capacity of the new intertidal area is only small compared to the flow conveying capacity of the subtidal areas (with the main channels as the most important players).

From Vlissingen to Hansweert the high waters decrease a little bit more than the water level at Cadzand. In the Lower Sea Scheldt and the Upper Sea Scheldt high waters decrease less than at the seaward model boundary. At Melle the effect of the sea level change becomes stronger again. High waters at this station decrease more than the water level at Cadzand.

The relative change in low waters is about zero at Vlissingen and increases more upstream. This means that low waters along the Scheldt estuary decrease less than the imposed sea level at Cadzand.

The difference in the phase of the low water is positive and it increases in the upstream direction. Therefore, low waters in the beginning of the century (run 13) were observed later than now.

5.1.5 High and low water levels for sea level rise including the effect of tidal amplification (run 14)

The comparison of the model results for run 14 to the reference run is presented in Tables A-3 and A-4. Figures 8 - 12 show the average change in high and low waters relative to the water level change imposed at Cadzand. This relative change is calculated as the water level change at a certain station minus the water level change at Cadzand (60 cm for high waters and 41 cm for low waters).

The relative change of the high waters for this scenario is comparable with run 12: almost no change compared to imposed water levels between Vlissingen and Hansweert, increase between 1 and 5 cm less between Hansweert and Temse compared to Cadzand and the smallest increase between Temse and Schoonaarde. At Melle high waters increase by 59 cm. This is only 1 cm less than at Cadzand.

The relative change of the low waters is comparable with the results of run 11. At Vlissingen the increase of the low waters is comparable to the one imposed at Cadzand, while the increase of the low waters is slowly getting smaller between Vlissingen and Temse. From Temse on the increase of the low waters is suddenly smaller. A minimal increase of low waters is observed at Duffel (11 cm less than at Cadzand). In the Upper Sea Scheldt low waters increase only by 32 - 33 cm (this is 8 to 9 cm less than at the seaward boundary).

Accordingly to the model results, a smaller increase of high and low waters is expected in 2100 if the increase of the tidal amplitude is taken into account. In model run 12 both high and low waters at the seaward boundary increase by 60 cm. In run 14 increase of the tidal amplitude by 5% and shift of the sea level by 50 cm result in an increase of the high waters by 60 cm and an increase of the low waters by only 41 cm at Cadzand. This results in smaller changes of the low water levels in the Scheldt, the changes in the high water levels are quite comparable. However, the tidal amplitude increases much stronger compared to run 12: an increase of about 20 cm in the Western Scheldt is found, while the increase in the Sea Scheldt becomes smaller up to Dendermonde (approximately 16 cm) and increases again upstream Dendermonde.

5.1.6 Tidal asymmetry

Figure 13 shows the tidal asymmetry calculated for the scenarios with the sea level change. The tidal asymmetry is defined as the ratio of the duration of falling water to the duration of rising water. Therefore, if ebb is dominant, the tidal asymmetry is larger than one. If flood is dominant, the tidal asymmetry is smaller than one. From the results of the reference simulation (Figure 13) it can be seen that the Scheldt estuary is mainly ebb dominated. This ebb domination becomes more pronounced in the Sea Scheldt upstream Temse.

The tidal asymmetry increases upstream as ebb becomes more dominant (Figure 13). The changes in the tidal asymmetry are very small in the Western Scheldt and they increase upstream. The largest changes are observed upstream Temse. The tidal asymmetry is maximal in the case of sea level decrease (run 13) and it decreases in 2050 and 2100 in the sea level increase scenarios. This indicates that sea level rise results in a larger duration of rising water.

If the increase of the tidal amplitude is taken into account (run 14), the tidal asymmetry in the year 2100 decreases less than in the model run without the increase of the tidal amplitude (run 12). Therefore, increase of the duration of rising water due to the sea level rise is stronger in run 12 than in run 14.

(Vroon et al., 1997) analyzed the changes of the tidal asymmetry during the 20th century based on measurements. They concluded that at Vlissingen and Hansweert the changes in the tidal asymmetry are very small. At Bath and Antwerp the duration of flood decreased since 1895. The ebb lasts longer now than in the beginning of the century.

The model results in our study show that the tidal asymmetry at Vlissingen and Hansweert changed only a little since 1900. At Bath it did not change (run 13). The tidal asymmetry at Antwerp decreased a little bit during the passed century. This indicates that duration of the flood increased. This is opposite to the result of (*Vroon et al.,* 1997).

5.1.7 Tidal volumes

Table A-5 shows the calculated flood volumes for the sea level rise scenarios. Figure 14 shows the differences in the flood volumes (spring tide) for the different sea level change scenarios. The tidal volumes decrease in the upstream direction. Sea level rise results in an increase of the tidal volumes, while sea level decrease leads to a decrease of the volumes. This effect is possibly related to the shape of the cross sections of the estuary: the higher the water level, the wider the wet cross section will be.

The changes in the tidal volumes for the sea level rise and decrease of 25 cm are similar but have opposite signs. The sea level decrease has a little stronger effect on the tidal volume than the sea level increase, although this effect is not very pronounced. When the sea level rise in 2100 is implemented in the model taking into account the increase of the tidal amplitude (run 14), the tidal volumes increase more than in run 12 (Figure 14).

5.1.8 Effect of the sea level rise on velocity

The analysis of the changes in velocity can help to understand the morphological changes which can be expected. The changes in morphology are governed by the changes in the erosion and sedimentation rates, i.e. by the flow. It is remarked that the flow velocities on the intertidal area are not yet validated in the current model: the results for this zone should be used in a critical way.

The sea level rise scenarios were studied by the use of the hydrodynamic numerical model. Therefore, the morphological effects could not be taken into account. The observations in the Scheldt estuary show that the level of the intertidal areas rises with a similar rate to the sea level due to sedimentation. The sea level rise results in a higher import of sediment into the basin and increases the duration of inundation on the intertidal areas. Therefore, sedimentation due to settling of sediment increases. The important issue is whether the intertidal areas will rise as fast as the sea level in the future. If the sea level and the intertidal areas rise with a similar rate, than erosion of the intertidal areas is not expected. If the sea level rises faster than the intertidal areas, than increased velocities on the intertidal areas can result in erosion.

The increase of the level of the intertidal areas can not be analyzed with our model, since it is only a hydrodynamic model. In the model simulations the level of the intertidal areas is the same as in the reference situation.

The effect of the sea level rise on the velocity field in the estuary is studied based on the analysis of the velocity fields of the whole region. First, the Sea Scheldt is divided in four zones for the analysis: Bath - Hemiksem, Hemiksem - Sint-Amands, Sint-Amands - Schoonaarde and Schoonaarde - Melle. This is done in order to be able to distinguish between the flood and ebb periods. Afterwards, the average and maximal spring flood and spring ebb velocity are calculated for the whole reach. Finally, the mean values of the maximal velocity and the average velocity are found for the 4 zones: a distinction is made between the intertidal area (only the slikke area without schorre) and the river channel (Tables 6 and 7). The slikke area is defined as the area between the mean neap high water and mean spring low water at a certain location. The river channel is an area deeper than the mean spring low water.

This analysis is performed twice for the sea level rise scenarios. First, it is analyzed how the velocity on the current intertidal area and the current river channel do change due to the sea level change. For this analysis the level between river channel and intertidal area is not changed. Afterwards, the level between the river channel and the intertidal area is increased accordingly to the sea level rise (decreased for the scenario with the sea level decrease) and velocities are analyzed again. From this analysis the velocities on the different zones (intertidal area, river channel) can be compared between the present situation and the scenario situation.

The analysis shows that the velocities on the present intertidal areas and in the present channel (i.e. no change of the level in between two heigth classes) increase when the sea level increases and decrease when the sea level decreases (Table 6 and Figures 15, 17). The change in velocity is more pronounced on the intertidal areas. This is because the increase in water level is relatively more important compared to the river channel area.

Table 7 and Figures 16, 18 represent the reality in a better way. The level between the intertidal area and the river channel is increased for the sea level rise scenarios and it is decreased for the sea level decrease scenario. The changes in velocity are much smaller than in the first case.
Therefore, we can expect that the sea level rise will not result in large changes of the velocity on the intertidal areas and in the channel if the level of the intertidal area is adapted together with the sea level rise. The velocities on the intertidal areas are not strong enough to result in erosion.

5.1.9 Conclusion

A sea level change has a different effect on the water levels along the Scheldt estuary. The largest effect is observed in the Western Scheldt where the effect of the imposed water level change is almost integrally noticed. From Bath up to Temse the effect becomes smaller; however the decrease of the effect is rather small. In the upper Sea Scheldt and the Rupel the effect decreases more pronounced. However, the difference in high waters increases again upstream Schoonaarde, The tidal amplitude does not change very much from Vlissingen up to Temse. Upstream Temse it increases strongly with a maximum value at Melle of 24 cm for the 2100 scenario. These results are similar to the results of the 1D model simulations for most stations (*Coen et al.,* 2009).

The sea level rise is implemented in the model with and without changes of the tidal amplitude. If an increase of the tidal amplitude is taken into account, the model simulation represents reality better. In this case the changes in the low water levels are smaller than in the scenario without the increase of the tidal amplitude, the results of the high water levels are comparable. This results in a higher increase of the tidal amplitude throughout the estuary.

The results of the sea level rise are compared with the results of the sea level decrease. Both scenarios give similar results, but the observed changes are opposite. This result gives an indication that the effect of the morphological adaptation of the zones, which change from sub- or supratidal to intertidal areas, on the tidal penetration is rather small. However, this does not mean that the morphological effect of a sea level rise on the estuary as a whole has only a small impact on the tidal penetration. After all the flow conveying capacity of the new intertidal area is only small compared to the flow conveying capacity of the subtidal areas (with the main channels as the most important players).

5.2 Polder scenarios

5.2.1 Introduction

In the passed centuries large areas along the Scheldt estuary were reclaimed. Polders were created by building dikes and by drainage to prevent the low lying areas from being inundated during floods. It can be expected that the poldering of large areas did affect the tidal penetration in the Scheldt estuary. Examples of some large polders in the Scheldt estuary are presented in Table 5-2. In this table only the year in which the poldering of each area was completed is given. It is remarked that the poldering is an intervention which took several years to decades.

Table 5-2. Examples of large polders in the Scheldt estuary

Name of polder	Area (ha)	Year final poldering
Braakman	6188	1952
Kreekrak	3025	1970
Saeftinge	3016	1907
Sloe	1295	1961
Zwin	1280	1873
Hellegat	595	1926

A polder affects water movement in the estuary. It works as a storage volume if the water level in the estuary is higher than the level of the poldered area. First signs of land reclamation are found in the Middle Ages. Due to this poldering in the past centuries, the storage volume of the estuary decreased. It is expected that modeling of the situation when water can flow into a poldered area would result in decrease of the high water levels in the estuary.

When considering the effect of a polder on the tidal penetration, two factors can be distinguished which influence this effect. On the one hand the size of a polder, on the other hand the location of a polder. In order to be able to compare the effect of different polders, these two factors should be taken into account. One way to do this is to study the effect of polders which ratio of the storage volume to the local flood volume is comparable.

Table 5-3. Overview of the model simulations to analyse the effect of poldering

Name	Description
run 21	depoldering of the Braakman polder
run 22	depoldering of the New - Westland polder
run 23	depoldering of the Braakman and New - Westland polders together
run 24	depoldering of the area Tielrodebroek
run 25	depoldering of the Groot Schoor of St-Amands
run 26	depoldering of all polders together (Braakman, New-Westland, Tielrodebroek and Groot Schoor of St-Amands)

An overview of the model simulations with depoldered areas is presented in Table 5-3. In this study the polders Braakman, New-Westland, Tielrodebroek and Groot Schoor of St-Amands are analyzed. To study the effects of poldering on the water levels in the estuary, it is necessary to adapt the model grid and to define a certain bed roughness for a polder.

Polders have a relatively high bed roughness because of the vegetation cover. The information about the roughness coefficients for the polders is not available and a certain bed roughness coefficient is assumed. A Manning bed roughness of 0.029 $m^{-1/3}s$ is defined for all polders.

The available samples are used to define a bathymetry for the poldered areas. Special attention is given to the connection of the polders to the river Scheldt. For the rest of the Scheldt the same bathymetry as in the reference run is used.

5.2.2 Effect of the depoldering on tidal volume and amplitude

Depoldering results in an increase of the storage volume of the estuary and an increase of the tidal volume downstream the polder. This increase of the tidal volume means higher velocity downstream the polder, which results in an increase of the bottom friction. The increased bottom friction leads to decrease of the tidal amplitude downstream and upstream the polder. This decrease of the tidal amplitude depends on the relation between the extra tidal volume as a result of the poldering and the local tidal volume (*Jeuken et al.*, 2004).
The flow cross section upstream the polder becomes larger than the initial equilibrium flow cross section. This results in initial sedimentation in this area.

The initial decrease of the tidal amplitude downstream the polder means also decrease of the tidal volume. This decrease is always smaller than the increase of the tidal volume because of the extra storage in the depoldered area. Therefore, the tidal volume increases initially downstream the polder. A larger tidal volume means increase of the equilibrium flow cross section. The area downstream the polder will be eroded (*Jeuken et al.*, 2004).

The initial erosion of the area downstream the polder results in final effects of the depoldering which are different from the initial effects. The erosion of this area is coupled with the decrease of the flow velocities and the bottom friction. Due to this the tidal amplitude increases and the tide can penetrate the estuary stronger (in comparison to the initial situation).

After some time the tidal amplitude increases also upstream the polder. The tidal volume and equilibrium flow cross section become larger and the area upstream the polder after the period of initial sedimentation will be eroded again. The results of the morphological model in *Jeuken et al.* (2004) for the scenario with Braakman polder show that the sedimentation velocity is already decreasing in 30 years after depoldering but erosion is not observed yet. It is expected that erosion will start at the Braakman polder in 50 to 100 years.

In our study we use a hydrodynamic model. Therefore, only the initial effect of the polder can be analyzed. The morphological changes described in (*Jeuken et al.,* 2004) can not be taken into account.

5.2.3 Braakman polder

The polder Braakman was reclaimed in two parts: the first part in the second half of the 19th century and the second part between 1938 and 1952. To study the effect of the Braakman polder, the model grid is extended to include the poldered area (Figure 19). The bathymetry for the year 1931 is available and is used for the polder. It is shown on Figure 24.

The volume of the poldered area is calculated taking into account a small volume of the Braakman polder area that is still present in the current situation (Table 5-4). This small volume is subtracted from the volume calculated for the bathymetry of 1931. The polder has a net volume of 44.5 Mm³ below +2.5 m NAP (the spring high water level at this location). The net intertidal volume is 46 Mm³, which is about 4.3% of the local spring flood volume. The net intertidal volume is 1.5 Mm³ larger than the total volume of the polder underneath the high water level. This is because the volume of the polder under the low water level (-2 m NAP) is 1.5 Mm³ larger now than in 1931. In the present situation the largest part of Braakman is poldered. However, a small area with a channel is deeper now than it was in 1931 (Figures 23 and 24).

Table 5-4. Calculation of the volumes for the Braakman polder

	Volume below +2.5 m NAP (Mm³)	*Volume below -2 m NAP*	*Intertidal volume (Mm³)*
1931	62.4	7.3	55.1
2006	17.9	8.8	9.1
Net volume	44.5	-1.5	46.0

The calculated area for the year 1931 is about 2500 ha. This is approximately 2/5th of the entire original area of the polder (6188 ha). This means that by 1931 about 2/5th of the Braakman polder was reclaimed.

High and low water levels

Tables A-8 - A-10 in Appendix and Figures 31 - 35 present the results of the comparison of magnitude and phase of high and low waters calculated for the situations before (1931) and after poldering (2002). The effect of the Braakman polder in 1931 can be seen already at Vlissingen. As expected the polder mainly affects the high water levels, while there is almost no effect on the low water levels. In run 21 high waters decrease by 3 to 4 cm in the Western Scheldt, the Lower Sea Scheldt and Rupel. The time of the high waters is also delayed for 2 to 5 min in this region. The effect of the polder becomes less pronounced upstream in the Upper Sea Scheldt and the Nete river. In Melle even a small increase of the high water levels is observed. The changes in low waters are not significant. The low waters did not change at most stations. In the Upper Sea Scheldt the low waters increased by 1 to 2 cm.

The analysis of the situation for 1931 shows that a percentage of the tidal flow goes into the poldered area during flood (Figures 41 and 42). In the beginning of flood, the flow goes into the polder only through the channel connecting the estuary and the Braakman polder. When the water level rises, the water flow can enter the polder through a larger area. The high water levels in the estuary decrease. There is a little delay (1 to 5 min) in high waters due to the polder. The effect of Braakman on the phase of low waters is not significant.

Tidal volumes

Table A-11 presents the flood and ebb volumes calculated for the reference situation and for the situation with the Braakman polder. The differences in the flood volumes for the scenario with the polder and the reference run are shown in Table A-12 and Figure 49. Depoldering of the Braakman area in the model results in an increase of both flood and ebb volumes downstream the polder and in a smaller decrease of the tidal volumes upstream the polder.

The tidal volumes at the cross section Hoofdplaat increase by about 3.9% of the reference volume. The flood volumes upstream the polder decrease by about 0.7% at Terneuzen to 1.7% at Temse. The effect of the Braakman polder on the flood volumes increases from Terneuzen to Temse and upstream Temse it decreases. The effect of the polder on the ebb volumes upstream the polder changes from 0.5% at Terneuzen to 1.0% at Temse. Upstream Temse the effect diminishes.

Finally it is mentioned that the Braakman polder is not very far from the downstream boundary of the model (approximately 35 km). Therefore it is possible that the downstream water level imposed at Cadzand and Westkapelle can slightly influence the results of this simulation.

5.2.4 New-Westland polder

To study the effect of the New-Westland polder the model grid and bathymetry are changed (Figures 20, 25 and 26). The bathymetry for the year 1931 is used for the polder. The New-Westland polder has a volume of 14.1 Mm³ below +2.9 m NAP (the spring high water level at this location). The entire volume is intertidal. It is about 5% of the local spring flood volume. This relative ratio is similar to the polder Braakman. The calculated area of the New-Westland polder for the year 1931 is about 1220 ha.

High and low water levels

The results of the analysis of changes in water levels are presented in Tables A-8 - A-10 and on Figures 31 - 35. Similar to the Braakman polder, the New-Westland polder mainly affects high water levels. During the flood period the New-Westland polder area is inundated (Figure 43). Less water goes upstream the polder location during flood. This results in a decrease of high water levels in the estuary.

There is no change in high waters near Vlissingen and Terneuzen in run 22. The polder is located more upstream and does not affect these two stations. A maximum decrease of high waters (5 cm) is observed at Baalhoek, downstream the polder location. In the Lower Sea Scheldt high water levels decrease by 2 to 3 cm. The effect of the polder decreases more upstream. However, at Mechelen and Hombeek changes in high water become higher (4 to 5 cm).

The low waters do not change downstream Hemiksem in this scenario. Upstream Hemiksem the low waters increase by 1 cm, which is still very small.

From point of view of the phase of the tidal signal it can be seen from Figure 34 that the high waters in Terneuzen and Hansweert are slightly earlier compared to the reference run, while from Baalhoek on the high waters are delayed.

The phase shift is the most pronounced between Schaar van de Noord and Hemiksem and goes up to 4 min. From point of view of the low waters no significant time shift of the low waters can be noticed.

Tidal volumes

Table A-11 presents the flood and ebb volumes calculated for the reference situation and for the scenario with the New-Westland polder. The differences in the flood volumes are shown in Table A-12 and Figure 49. Similar to the Braakman polder, depoldering of the New-Westland area in the model results in an increase of the tidal volumes downstream the polder and in a smaller decrease of the volumes upstream the polder. The tidal volumes at the cross section Overloop van Valkenisse, located downstream the polder, increase by about 3.7%. At Terneuzen and Gat van Ossenisse the tidal volumes increase less because these cross sections are located further from the polder. At the cross section Bath (which is located in front of the polder) the tidal volumes increase as well. Upstream the polder the volumes decrease. A maximal decrease (1.1% for the flood volume and 0.7% for the ebb volume) is observed near Temse.

The New-Westland polder has a smaller volume and area than the Braakman polder. However, these two polders have similar effects on the water levels in the estuary. This is because both polders have a similar percentile relation between the intertidal volume of the polder area and the local flood volume. The New-Westland polder is located more upstream than Braakman. Tidal volumes decrease upstream (Table A-1). Therefore, a smaller intertidal volume of the flow that goes into the New-Westland polder has a similar effect on the water levels in the estuary as a larger volume going into the Braakman polder.

5.2.5 Tielrodebroek

To study the effect of the Tielrodebroek polder on the water levels, the model grid is extended (Figure 21) and the area of this polder is depoldered in the model. The bathymetrical samples from the Mercator 2 database (DTM Flanders 2006) are used to define the bathymetry for this area (Figures 27, 28).

To have comparable model results for the run with the Tielrodebroek polder and runs 21 and 22, the intertidal volume of Tielrodebroek should be about 5% of the local spring flood volume (a similar percentage as for the Braakman and New-Westland polders). This makes it possible to compare the effect of the 3 polders. The bathymetry of Tielrodebroek had to be adapted. Before the bathymetry adaptation the intertidal volume of Tielrodebroek was 2.6 Mm³ (about 10% of the local flood volume).

After adaptation of the bathymetry Tielrodebroek has a volume of 1.8 Mm³ below +3.5 m NAP (the spring high water at this location). The area of the polder is 81 ha. During the ebb period not all water leaves the polder and a certain volume of water is constantly stored there (Figure 45). This reduces the available intertidal volume of the polder. The lowest water level in Tielrodebroek during the ebb period is +1.6 m NAP. The intertidal volume of the polder (between +1.6 m NAP and the high water level) is 1.5 Mm³. This is about 6% of the local spring flood volume.

High and low water levels

The results of the model run with Tielrodebroek are presented in Tables A-8 - A-10 and on Figures 31 - 35. Depoldering of Tielrodebroek results in a decrease of the high waters at all stations upstream Antwerp. Downstream Antwerp the water levels do not change. The strongest effect is observed at Hemiksem and in the Rupel river and its tributaries. High waters decrease there by 5 to 6 cm. The effect of the polder on the high waters at Melle is opposite: high waters even increase by 1 cm as a consequence of the depoldering. However this effect is very small.

Depoldering of the Tielrodebroek area has almost no effect on the low waters. In the Upper Sea Scheldt low waters increase by 1 cm. At other stations they do not change.

High waters are delayed a little in the Upper Sea Scheldt due to the depoldering, although this is not very pronounced (1 up to 4 min delay compared to reference simulation). There is almost no change in the phase of low waters.

Because of a similar relative ratio between the intertidal volume and the local flood volume, the Tielrodebroek, Braakman and New-Westland polders have a similar effect on the water levels (high waters decrease by 2 - 5 cm). However, the effect of Tielrodebroek is limited only to the Upper Sea Scheldt and Rupel while the Braakman and New-Westland polders affect a larger area (Figures 31, 32).

Tidal volumes

Depoldering of the Tielrodebroek area in the model affects the tidal volumes (Tables 13, 14 and Figure 50). The implementation of the Tielrodebroek in the model results in an increase of the intertidal volumes downstream the polder and a small decrease of the volumes upstream the polder.

A maximal increase of the flood volume (5.3%) is observed at Tielrode. This cross section is located in front of the polder, so this result is as expected. At Temse the flood volumes increase by 4.6%. More downstream the flood volumes increase less and downstream Zandvliet they even decrease. However, the changes downstream Zandvliet are only very small (0.1 to 0.2% of the reference volume). Upstream the Tielrodebroek polder the flood volumes decrease by about 1.0%. The effect of the polder decreases with increase of the distance from the polder.

A maximal increase of the ebb volume (4.8%) is observed at Temse. At Tielrode the ebb volume decreases (this is opposite to the effect of the polder on the flood volume at this cross section). However, the decrease is very small (0.3%). At other cross sections the ebb volumes change similar to the flood volumes: they increase downstream the polder until Zandvliet, decrease a little downstream Zandvliet and decrease upstream the polder.

5.2.6 Groot Schoor of St-Amands

The model grid is extended for the model simulation with the Groot Schoor (Figure 22). The bathymetry for the Groot Schoor (Figures 29, 30) is defined based on the samples from the Mercator 2 database (DTM Flanders 2006).

The intertidal volume of the Groot Schoor is 0.19 Mm³, which is less than 2% of the local spring flood volume. This volume is too small to have a significant effect on the water levels in the estuary. To have comparable results for the simulation with the Groot Schoor and model runs 21, 22 and 24, the intertidal volume of the Groot Schoor should be about 5 to 6% of the local flood volume. To obtain this volume, the bathymetry of the Groot Schoor is deepened. After the adaptations the Groot Schoor has a volume of 1.2 Mm³ below + 3.4 m NAP (the spring high water at this location). The area is 20 ha. Similar to Tielrodebroek, a certain volume of water is constantly stored in the Groot Schoor (the minimal water level during ebb is -0.9 m NAP) (Figure 47). The intertidal volume of the Groot Schoor (between -0.9 m NAP and high water level) is 1.1 Mm³. This is about 7% of the local spring flood volume.

High and low water levels

Depoldering of the Groot Schoor has no effect on the water levels in the Western Scheldt (Tables A-8 - A-10, Figures 31 - 35). The largest changes in the water levels are observed upstream Hemiksem. The high waters in the Upper Sea Scheldt and Rupel decrease by 2 to 3 cm. The low waters at Dendermonde increase by 2 cm. At other stations the low waters increase by 1 cm or do not change.

Depoldering of the Groot Schoor results in smaller changes of the water levels than depoldering of the Braakman, New-Westland or Tielrodebroek polders. However, the effect of the Groot Schoor on the high waters stays constant up to Melle and does not decrease as in the case of Tielrodebroek. This is due to the location of the Groot Schoor which is much closer to Melle. Although the effect is still small, it is noticed that the effect on the low waters is a little bit bigger compared to the other polder scenarios.

Tidal volumes

The effect of the Groot Schoor of St-Amands on the tidal volumes is shown in Tables 13, 14 and on Figure 50. As a result of depoldering of the Groot Schoor area in the model the tidal volumes increase downstream the polder (by maximum 6.3 to 6.9% at St-Amands) and decrease upstream the polder by about 1.0%. The change in tidal volumes downstream the Groot Schoor decreases with increase of the distance from the polder. At Antwerp the tidal volumes increase by less than 1.0%. Downstream Zandvliet the tidal volumes decrease but only a little (less than 0.2%).

5.2.7 Hypsometric curves of the polders

A hypsometric curve of a polder shows the relation between the water level and the water volume stored in the polder underneath a certain water level. The storage volumes are calculated relatively to the local flood volumes. The water levels are plotted relatively to the high water at the location of the polder. The hypsometric curves help to assess the similarity of the polders from point of view of the storage capacity.

The hypsometric curves calculated for the 4 polders used in the scenario analysis are shown on Figure 51. Since the bathymetry for the Tielrodebroek and Groot Schoor polders was adapted, two hypsometric curves are plotted for these polders: one for the original bathymetry and one after adaptation of the bathymetry.

After the adaptation of Tielrodebroek and the Groot Schoor, all 4 analyzed polders have a similar relative ratio between the intertidal volume of the polder area and the local flood volume. However, the hypsometric curves for the 4 polders are different (Figure 51).

This means that different relative volumes of the water are stored underneath a certain water level, which might affect the effect of the polder on the tidal penetration in the estuary. This is due to the fact that the bathymetry of the polders is different. Therefore, the water volume stored in the polders is distributed differently underneath certain water levels and the hypsometric curves have a different shape.

After adaptation of the bathymetry water can flow into the Groot Schoor already at the moment when water in the estuary reaches the level of the local high water minus 5 m. The Braakman, New-Westland and Tielrodebroek polders affect the water flow only when water reaches the level of the local high water minus 3 m. Larger relative volumes are stored in Tielrodebroek and Groot Schoor than in the Braakman and New-Westland polders.

The water can be stored in the Tielrodebroek polder with the original bathymetry when the water level in the estuary is approximately at the local high water minus 4 m. Large relative volumes of water can go in this polder: about 11% of the local flood volume can be stored underneath the high water. The original hypsometric curve for the Groot Schoor is very different. This polder has only a very small effect on the water levels in the estuary. Only about 2% of the local flood volume can be stored underneath the high water in this polder.

The volumes stored underneath the high water in the Braakman and New-Westland polders are similar to the intertidal volumes (4 to 5% of the local flood volume). For the adapted Groot Schoor and Tielrodebroek the volumes stored underneath the high water are larger than the intertidal volumes. This is because a certain water volume is constantly stored in these 2 polders. This reduces the intertidal volume.

The analysis of the hypsometric curves showed that even though the polders have a similar relative ratio between the intertidal volumes and the local flood volumes, they can have different effects on the water levels in the estuary. The shape of the hypsometric curves is different. This means that different relative water volumes are stored in the polders underneath a certain water level.

5.2.8 Effect of the polders on the flow velocity

The maps with differences in the flow velocity between the scenarios with polders and the reference situation are created. The analysis of these maps shows that depoldering of the low lying areas in the model affects mainly the velocities during the flood period. At other moments in time the differences in the flow velocity are very small.

During the period with flood peak velocities, the velocity increases downstream the polder and it decreases upstream (Figures 52 - 55). The increased velocity downstream the polder is expected because depoldering results in an increase of the storage volume of the estuary and an increase of the tidal volume downstream the polder.

In (*Jeuken et al.,* 2004), it is explained that the higher velocity downstream the polder results in a decrease of the tidal amplitude downstream and upstream the polder. Upstream the polder the flow cross section becomes larger than the initial equilibrium flow cross section. This results in a decrease of the flow velocity upstream the polder and initial sedimentation in this area.

5.2.9 Simultaneous effect of the polders

A simultaneous effect of the 4 polders described above (Braakman, New-Westland, Tielrodebroek and Groot Schoor of St-Amands) is analyzed in run 26. Furthermore, in run 23 a simultaneous implementation of only the Braakman and New-Westland polder is studied.

Model runs 23 and 26 show that the simultaneous implementation of the polders results in changes which are more or less equal to the arithmetical sum of the individual effects of each polder (Tables A-8 - A-10, Figures 36 - 40).

In run 23 a maximal decrease (7 cm) of high waters is observed at Baalhoek, Schaar van de Noord and Liefkenshoek. The difference in high waters decreases upstream. However, the effect of the polders becomes stronger again at the rivers Durme, Zenne and Dijle.

The high waters are delayed at all stations except Vlissingen. Maximum delay of 7 min is observed from Baalhoek to Hemiksem. The low waters in the Western Scheldt and the Lower Sea Scheldt do not change. The low waters in the Upper Sea Scheldt and tributaries increase by 1 to 3 cm. The changes in the phase of low waters are not significant.

In run 26, the largest changes in high waters are observed at Hemiksem, Temse, Waasmunster and in the Rupel river and its tributaries. At these stations simultaneous depoldering of four polders results in a decrease of high waters by 11 to 15 cm. At other stations this decrease is smaller and varies between 3 and 8 cm. At Melle the high waters increased a little.

The effect of the polders on the low waters is smaller than on the high waters. In run 26 low waters increase by 1 to 5 cm. The largest changes are observed in the Upper Sea Scheldt. The differences in the phase show that both high and low waters are delayed as a result of the depoldering in the model. The strongest delay is observed in the Upper Sea Scheldt (10 to 12 minutes for the high waters and 3 to 4 minutes for the low waters). As a consequence the tidal asymmetry also changes and becomes smaller.

5.2.10 Comparison with other studies

The depoldering of the poldered areas New-Westland, Tielrodebroek and the Groot Schoor of St-Amands is also studied with the 1D model (*Coen et al.,* 2009). The intertidal volumes of these polders calculated in the 1D and 2D models are similar, which shows that the implementation of the polder areas in both models is comparable despite the difference in discretization:

- New-Westland polder: 14.1 Mm³ in 1D model, 14 Mm³ in 2D model;
- Tielrodebroek: 1.8 Mm³ in 1D model, 1.5 Mm³ in 2D model;
- Groot Schoor of St-Amands: 1.1 Mm³ in both 2D and 1D models.

The depoldering of the New-Westland polder in the 1D model results in a decrease of the high waters by 8 cm at Liefkenshoek and Antwerp, 6 cm at Temse and 4 cm at Dendermonde. These changes are larger than the ones calculated with the 2D model (Table A-8 in Appendix). The 1D and 2D models show that the New-Westland polder has no effect on the low waters downstream Antwerp, upstream Antwerp the low waters increase a little bit.

The implementation of the New-Westland polder in the 1D model results in a decrease of the flood and ebb volumes upstream the polder at Prosperpolder. The results of the 2D model are in agreement with the 1D model for this location. However, in the 1D model the tidal volumes at Bath decrease, while the 2D model calculates an increase of the volumes at this cross section.

The 1D model run with the Tielrodebroek polder shows that the strongest effect of this polder on the water levels is observed at Temse and Dendermonde. The high waters decrease there by 3 to 6 cm. In the 2D model the maximal decrease of the high waters (5cm) is observed at Hemiksem (this station was not analyzed in the 1D model). At Temse and Dendermonde high waters change less than in the 1D model (decrease by 2 to 3 cm). Both 1D and 2D models calculate a small increase (1 cm) of the low waters upstream Temse. Both models confirm that Tielrodebroek has no effect on the water levels downstream Antwerp.

The results of the 1D model show that the depoldering of Tielrodebroek results in a small decrease of the tidal volumes at Vlissingen, Terneuzen, Hansweert, Bath en Prosperpolder. The tidal volumes increase at Antwerp and Temse. Upstream Tielrodebroek the volumes decrease. These results are in agreement with the results of our study. The 2D model calculates a small decrease of the tidal volumes downstream Zandvliet, an increase of the volumes from Antwerp to Tielrode and a decrease of the volumes upstream Tielrodebroek.

The implementation of the Groot Schoor in the 1D model results in a decrease of the high waters by 2 to 3 cm and an increase of the low waters by 1 to 2 cm upstream Temse. These results are similar to the results of the 2D calculations.

The 1D and 2D models calculate similar effects of the Groot Schoor on the tidal volumes in the estuary. The volumes decrease a little in the Western Scheldt and increase from Antwerp to St-Amands. Upstream the polder the tidal volumes decrease.

(*Witteveen and Bos*, 1999) studied the effect of a decrease of the storage volume due to the poldering near Bath (Ossendrecht) and near Braakman (de Mosselbanken). Both areas where poldered in the year 1976. The poldered area is around 900 ha in total (148 ha for the Braakman area, 782 ha for the Bath area). However, no information about the intertidal storage volume of these areas is given.

In their report Witteveen and Bos used the situation of 1968 (before poldering) as the reference situation. To study the influence of the poldered areas, a scenario in which the two poldered areas where closed was carried out. According to their results, the change in the high waters at Baalhoek and Bath was about 2 to 4 cm. As a result of the poldering action, the storage volume decreased, which resulted in an increase of the high waters in the estuary. These results are comparable with the results obtained in our study, but are smaller then the calculated change in the high waters in our study. However, both results can not be compared in detail because the size of the polders used in (*Witteveen and Bos*, 1999) is different from the one used in our study.

(*Jeuken et al.,* 2004) studied the effect of the depoldering of the Braakman polder with the use of a morphological model. Therefore, they could predict both the initial and future effects of the depoldering. The results of the analysis show that as an initial effect of the depoldering the tidal amplitude decreases upstream the polder (by 0.5 to 1.5 cm at Terneuzen, Bath and Antwerp) and downstream the polder (by 2 cm at Vlissingen), The tidal volumes downstream the polder increase by about 1.5%, while the tidal volumes upstream the polder decrease a little.

The initial changes due to the Braakman polder described in (*Jeuken et al.,* 2004) are smaller than in our study. In our study the tidal amplitude upstream and downstream the Braakman polder decreases by 2 to 4 cm. The tidal volumes downstream the polder increase by about 4.0% and they decrease upstream the polder by about 1.0%.

This may be explained by the fact that (*Jeuken et al.,* 2004) analyzed the depoldering of the area of 2000 ha. This is only a part of the Braakman polder as studied in this report. In our study the Braakman area of 2500 ha is analyzed. Therefore, the changes due to the polder described in this report are larger than in (*Jeuken et al.,* 2004).

5.2.11 Conclusion

The analysis of the schematic scenarios with the different depoldered areas shows that poldering during the last centuries affected mainly the high water levels in the estuary. The changes of the low waters due to the polders were smaller. The depoldering of the low lying areas in the model results in a decrease of the high waters, a small increase of the low waters and a delay of the high water phase in the estuary. This is because a certain water volume can be stored in the polders in the model during the flood period, resulting in less water penetrating the estuary upstream the polder. Thus, poldering of the low lying areas during the last centuries has probably decreased this storage volume and resulted in an increase of the high waters and a smaller decrease of the low waters in the estuary.

Table A-15 shows the effect of the polders on the water levels at different distances from the polders. The Braakman and New-Westland polders have the largest influence areas. The Braakman polder affects high waters at a distance of 140 km (from 10 km downstream the polder to 130 km upstream). The New-Westland polder affects high waters at a similar distance (130 km). But the influence area of this polder is located 20 - 30 km more upstream in comparison to the Braakman polder.

The Braakman and New-Westland polders influence low waters in the most upstream 40 and 70 km of the estuary respectively.

The Tielrodebroek polder and the Groot Schoor affect high waters at a shorter distance than the Braakman and New-Westland polders. The influence area of Tielrodebroek and Groot Schoor is located upstream Antwerp. The high waters and low waters are affected by Tielrodebroek at a distance of 70 km and 60 km respectively. The Groot Schoor influences both high and low waters at 90 km.

The effect of the Groot Schoor on the water levels is a little bit smaller than the effects of the other analyzed polders despite the fact that the intertidal volume – local flood volume ratio is similar. However, as mentioned above, the Groot Schoor affects a larger area in comparison to Tielrodebroek.

5.3 Enlargement of the navigation channel scenarios

5.3.1 Introduction

The effect of an enlargement of the navigation channel to the Port of Antwerp on the hydrodynamics of the Scheldt estuary is studied using the numerical model. Dredging works have been performed in the Scheldt estuary since 1895. Dredging includes the maintenance works on the sills in the navigation channel as well as capital dredging to enlarge the navigation channel. The maintenance works are performed to keep a necessary depth and width of the navigation channel.

A capital enlargement is performed to obtain a new necessary depth and width of the channel.

Until now two capital enlargements were performed in the Scheldt estuary. With the first enlargement in the middle of 1970s a large part of the dredged sediment was permanently extracted from the estuary. About 100% of the dredged sediment was extracted from the Sea Scheldt (so no disposal of the dredged material) and 15 to 20% of the dredged material was extracted from the Western Scheldt (*Van Braeckel et al*., 2007). Opposite to this, with the second channel enlargement in July 1997 - July 1998 almost all of the dredged material was disposed back into the estuary. In both enlargement campaigns, the sills in the Western Scheldt were deepened by approximately 1.0 to 1.5 m. This allowed larger ships to access the port of Antwerp.

In this report the bathymetric changes of the second enlargement are used to study the effect with the numerical model (table 5-5). As a reference simulation, the bathymetry for 1990 (the Sea Scheldt) and 1994-1995 (the Western Scheldt) is used. The enlargement is carried out by simply removing material within the navigation channel - only necessary on the so-called sills – in order that the depth of this channel fulfills the depth criteria after the 1997-1998 enlargement. Two scenarios are calculated: the enlargement without and with disposal of the dredged sediments.

Table 5-5. Overview of the model runs with the enlargement of the navigation channel

Name	Description
run 31	reference simulation with bathymetry of 1990 (Sea Scheldt) and 1994-1995 (Western Scheldt)
run 32	second capital enlargement of the navigation channel without disposal of the capital dredged material
run 33	second capital enlargement of the navigation channel with disposal of the capital dredged material

5.3.2 Effects of dredging and disposing of dredged material on hydrodynamics

The morphology of the Western Scheldt is characterized by an ebb-flood channel system. The flood channel is open to the flood current and exhibits a sill at the upstream end. The ebb channel is open to the ebb current and exhibits a sill at the seaward end (*Van Veen*, 1950). In most parts of the estuary, the ebb channel is deeper than the flood channel and provides the main navigational route to the port of Antwerp. Connecting channels form a link between the main ebb and flood channels by intersecting the shallow subtidal and intertidal areas between the two channels. They induce water exchange between two main channels, and thereby redistribute the tidal flow in the channel system (*Swinkels et al.,* 2007).

Dredging is performed in the main river channel to guarantee the necessary depth and width for navigation. Dredged material is either removed out of the estuary system or disposed on specific, licensed locations: these locations are mainly located in the secondary channel (usually flood channel) or on the sides of the main channel in the deepest parts. Since the flood and ebb channels are not only conveying flood respectively ebb flow, changes in the ebb and flood channels affect both high and low waters in the estuary.

As a result of the channel enlargement, the cross section of the navigation channel increases on the sills (i.e. area smaller than 10% of the total estuary reach). Because of this, for the same discharge velocities will decrease on these locations. Due to the increase of the water level on the sills, the celerity of the tidal wave (which can be calculated as the root mean square of *g* times the water level) will increase here. So the effect of deepening will result in a higher speed of the tidal wave on the sills, which can also be seen as a lower resistance of the bed to the penetration of the tidal wave. Therefore, it is expected that channel enlargement can result in an increase of the high waters in the estuary. However, due to the lower resistance the flow can also leave the estuary faster during ebb. This can result in a decrease of the low waters. Following this reasoning, it is difficult to predict the effect of the enlargement on the high and low waters because of a complicated distribution of the flow between flood and ebb channels. It is stressed that the explanation given above only accounts for the sills, which represents less than 10% of the total estuary reach.

Disposal and dredging of material have opposite effects on the river hydraulics. As a result of disposal, resistance increases with decrease of the depth. It becomes more difficult for the flow to penetrate the estuary during the flood period and the flow is retained in the estuary longer during the ebb. Therefore, disposal of material can result in a decrease of the high waters and an increase of the low waters (if we do not take dredging into account).

So as a conclusion it is stated that the simultaneous effect of dredging and disposal depends on how the changes in the ebb and flood channels due to the dredging and disposal affect the tidal penetration in the estuary. It is hard – not to say impossible – to predict in advance how the system will react in reality. However, a numerical model can help in this issue to give an answer.

5.3.3 Volumes and locations of dredged and disposed material

Tables A-16 and A-17 present an overview of the volumes of the disposed and dredged material, the areas and heights of the disposed material, the depth of the dredging locations in the Scheldt estuary.

To create the bathymetry for the enlargement scenarios, the reference bathymetry is adapted. First, the navigation channel is deepened so that the necessary depth and width for navigation can be guaranteed. Afterwards the total volume of the dredged material is distributed between the disposal locations (for the scenario with disposal).

To distribute the dredged material over the several disposal locations, the data from the report (*Dam and Van Prooijen,* 2006) are used. However, this report contains information about the total volumes from the capital dredging and maintenance dredging together during the second enlargement period. These volumes are used to calculate the percentage of the disposed material for each location. Afterwards the volumes disposed at these locations only during the capital dredging are calculated as a certain percent of the total volume of the dredged capital material. The disposal is done based on the bathymetry of the disposal locations: the deeper parts of the disposal locations are filled first.

The total volume of the disposed material (16 Mm³) is a little bit larger than the total volume of the dredged material (15.6 Mm³) because of the interpolation used for schematization of the dredging and disposal areas in the numerical model. Figures 56 - 58 show the locations where material is dredged and disposed. These Figures present the differences in bathymetry between the reference situation before the enlargement (bathymetry 1990 for the Sea Scheldt, 1994-1995 for the Western Scheldt) and the enlargement scenario (1997-1998).

5.3.4 Limitations of the analysis

Disposal is implemented in the model by change of the depth of the disposal locations. Different from reality, the bottom of the Scheldt estuary in the model is immobile. Therefore, the disposed material in the model does not move and stays in the same location where it was deposited. However, in reality the disposed sediment - as well as the sediment on every location on the river bed - can be transported by the water flow and eventually it can settle back in the navigation channel. So only the initial effect of a certain disposal activity can be studied. Moreover in reality the capital dredging works were spread in time over a 12 months period, while this anthropogenic intervention is carried out instantaneous in the model.

The dredged material consists of both sand and silt. In the Western Scheldt mainly sand is dredged and upstream Bath sand as well as silt. In the model silt is not taken into account because when disposing silt on a disposal location, almost 100% of the disposed volume is transported by the water flow before it can even reach the river bottom. This simplification should not have a strong effect on the model results because during the capital dredging mainly sand is dredged.

5.3.5 High and low water levels for channel enlargement without disposal

The comparison of the results of the reference run 31 and two enlargement scenario runs 32 and 33 is presented in Table A-18 and on Figures 59 - 63. The changes in high and low water levels are very small for both scenarios.

The channel enlargement without disposal does not affect high and low water levels at Vlissingen and Terneuzen. The high water levels at other stations in the Western Scheldt and the Lower Sea Scheldt increase by only 1 cm in run 32. The largest increase of almost 2 cm is observed at Liefkenshoek. In the Upper Sea Scheldt and tributaries the high water levels increase by 1 cm. An increase of the high waters is expected because of a decreased resistance to the tidal wave to penetrate in the estuary due to dredging.

The channel enlargement results in a small decrease of the low waters because the water flow can leave the estuary faster due to the lower resistance. In run 32 the low waters decrease by 1 cm from Hansweert to Schaar van de Noord and by 2 cm in the Lower Sea Scheldt. More upstream changes in the low water levels diminish. Upstream Dendermonde the low water levels are hardly affected by the enlargement operation.

The difference in the tidal amplitude varies between 0 and 3 cm for most stations. From Terneuzen to Liefkenshoek the tidal amplitude increases gradually from 0 cm to a maximum value of 4 cm. Upstream Liefkenshoek the tidal amplitude decreases to reach a more or less constant value of 1 cm from Dendermonde on.

The changes in the phase of high and low waters are not significant compared to the reference simulation.

5.3.6 High and low water levels for channel enlargement with disposal

The effect of the channel enlargement with disposal is smaller than the effect of the enlargement without disposal. The changes in high and low waters do not exceed 1 cm in run 33: as a consequence also changes in tidal amplitude remain very small (Table A-18, Figures 59 - 61).

For the high waters a small reduction (< 1 cm) is observed at all stations. This is opposite to what is observed in the first enlargement scenario without disposal (run 32), however the mentioned decrease is not significant. The low waters in the Western Scheldt and the Upper Sea Scheldt do not change. In the Lower Sea Scheldt – between Liefkenshoek and Temse – low waters decrease by 1 cm. The differences in the phase of high and low waters are not significant (Figures 62 and 63).

Thus, the channel enlargement with disposal has a very small effect on the water levels in the estuary. Both high and low waters either do not change or decrease. The largest changes are observed in the Lower Sea Scheldt, but they do not exceed 1 cm. The differences are very small and their values are in the accuracy range of the model.

Decrease of high waters can be explained by the increased resistance to the tidal wave due to the disposal of sediment in the flood channel. In some parts of the estuary high waters almost did not change because the changes due to disposal were compensated by the opposite effect of dredging. An observed decrease of low waters at some stations can be an effect of dredging in the ebb channel. A decreased resistance to the ebb flow resulted in the lower low waters.

The model results showed that the enlargement with disposal in the Scheldt estuary has a smaller effect on the water levels than the enlargement without disposal. This can be related to the fact that dredging and disposal of material have opposite effects on the hydrodynamics of the estuary.

5.3.7 Tidal volumes

Table A-19 presents the flood and ebb volumes calculated for the scenarios with the enlargement of the navigation channel. The differences in the flood volumes for the scenarios with the enlargement and the reference run are shown on Figure 64. The channel enlargement scenarios result only in very small changes of the tidal volumes. The enlargement without disposal has a stronger effect on the tidal volumes than the enlargement with disposal, although the changes remain small as well in this scenario.

The enlargement without disposal results in an increase of the flood volumes because flood can penetrate the estuary easier. This effect can be noticed from the mouth of the estuary (0.4% extra flood discharge at Hoofdplaat) until Antwerp (0.6% extra flood discharge at Antwerp). The enlargement with disposal has an opposite effect and it is much smaller. At Hoofdplaat there is a decrease of the flood volume of only 0.2%. In Antwerp the decrease (0.1%) is already negligible.

The change in the ebb volumes in the scenarios with the enlargement of the navigation channel is similar to the change of the flood volumes (Table A-19). The enlargement without disposal results in an increase of the ebb volumes. Similar to the change of the flood volumes, this increase does not exceed 1.0% of the ebb volume of the reference run. The enlargement with disposal has an opposite effect. The ebb volumes decrease but this effect is rather small (less than 0.2% of the ebb volume in the reference run).

The flood and ebb volumes through the ebb and flood channel for the scenarios with the enlargement are presented in Tables A-20 and A-21. Figure 66 shows the differences in the spring flood and ebb volumes through the ebb and flood channels at the four cross sections in the Western Scheldt. The location of these cross sections is shown on Figure 65. The flood volumes for the scenarios with the enlargement are compared with the reference situation (bathymetry 1994-1995). The differences in flood volumes are very small. They do not exceed 1.5% of the reference flood volume for most locations.

The largest changes are observed at the cross section Everingen – Pas van Terneuzen. As a result of the channel enlargement with disposal, the flood volume through the cross section Everingen located in the flood channel decreases by about 2.0%. The volume through the Pas van Terneuzen located in the ebb channel increases by almost 4.0%. This is because two large disposal locations are located in the flood channel Everingen (Vloedschaar Everingen and Ellewoutsdijk). The disposal of sediment in the flood channel reduces the channel depth and results in an increased flow through the ebb channel.

At other cross sections the changes in the flood volumes through the flood and ebb channels are very small. The enlargement without disposal results in an increase of the flow volumes through the main channel and a decrease of the volumes through the secondary channel because the main channel is enlarged.

In the scenario with disposal, the differences in the flood volumes through the ebb and flood channel are almost opposite to each other, which indicates that the total flood volume through the cross section does not change too much. In the scenario without disposal, this is not always the case.

The ebb volumes through the ebb and flood channel in the scenarios with enlargement change very similar to the flood volumes (Figure 66). The largest changes happen at the cross section Everingen – Pas van Terneuzen in the scenario with disposal. The ebb volume through the cross section Everingen decreases by 1.9%. The volume through the Pas van Terneuzen increases by 2.1%. These changes are smaller than the changes of the flood volumes. The differences in the ebb volumes at other cross sections are smaller than 1.5% of the ebb volume in the reference run.

5.3.8 Velocities at dredging and disposal locations

To analyze the effect of the river enlargement on the velocities, monitoring stations are put in the model at some dredging and disposal locations in the Western Scheldt and the Lower Sea Scheldt (Figure 56). Figures 67 and 68 show the comparison of the velocities calculated for the reference run and for the scenarios with the enlargement for one tidal cycle. It is expected that velocities at the dredging locations decrease a little bit because of an increased depth and velocities at the disposal locations increase. However, since the disposal locations are immobile in the model – which is clearly different from reality – these locations are not very well reproduced in the model. It is to be expected that the disposed material will be transported due to an increase in velocity on a short term. Only the velocities at dredging locations will be analyzed in this paragraph.

The analysis of the model results shows that the river enlargement does not have a strong effect on the velocities at most locations. The change in the velocities is the largest at dredging locations Drempel van Hansweert, Drempel van Valkenisse, Drempel van Zandvliet and Drempel Frederik. As expected, both enlargements without disposal and with disposal result in a small decrease of the velocities at most dredging locations (Figure 67). Only at dredging location Plaat van Ossenisse the velocity increases as a result of the enlargement with disposal (Figure 68). This is probably related to the deposition of sediment at disposal location Gat van Ossenisse located close to this dredging location. At most locations the change of the velocities due to the enlargement with disposal is a little smaller than without disposal.

The changes in the velocity and water level are related. The largest change of the velocity is observed at dredging location Drempel Frederick, which is located in the Lower Sea Scheldt close to Liefkenshoek. Both enlargements with and without disposal result in the largest changes of the water levels in the Lower Sea Scheldt. In the case of the enlargement without disposal the largest change of the water level is observed at Liefkenshoek.

5.3.9 Analysis of the velocity maps

The mean values of the average and maximal velocity are calculated for the spring flood and ebb periods for the scenarios with enlargement and compared to the reference run (Table 22). Velocities are calculated for the intertidal zone (only slikke area, the schorre area was not included due to practical reasons) and for the river channel. The Sea Scheldt is divided in 4 zones for the analysis: Bath - Hemiksem, Hemiksem - Sint-Amands, Sint-Amands - Schoonaarde and Schoonaarde - Melle. This is done in order to be able to distinguish between the flood and ebb periods.

The analysis of the velocity maps shows that velocity almost does not change in the scenarios with the enlargement. Some of the velocities calculated in scenarios with enlargement decrease by 1 cm/s. However, in general the changes in the velocity due to the enlargement are very small.

5.3.10 Comparison with other studies

The results obtained in this study for the scenario of the channel enlargement without disposal (run 32) are similar to the results of (*Witteveen and Bos,* 1999). They studied the effect of the first enlargement in a schematic way; the results were compared with the reference situation (bathymetry for 1968, boundary conditions for 1989). The effect of the enlargement on the high waters in the Western Scheldt was analyzed. The changes at Vlissingen, Terneuzen, Hansweert and Baalhoek were very small (order of magnitude mm). The largest effect of the channel enlargement on high waters was observed at Bath: after the enlargement high waters increased there by about 1 cm.

(*Dekker,* 1995) studied the effect of the enlargement of 1997-1998 on the water levels in the Scheldt estuary. The numerical model Scaldis100 was used for the analysis. (*Dekker*, 1995) concluded that the enlargement resulted in an increase of the high waters by 5 cm and decrease of the low waters by 10 cm at most stations in the Western Scheldt.

These differences are larger than the ones calculated by the model in our study. However, the results of (*Dekker*, 1995) are not very trustworthy because of the limitations of the analysis. First of all, the resolution of the model grid used for the analysis was 500x500 m. This grid is too rough to represent correctly the changes in the bathymetry due to the enlargement. Secondly, the bathymetry of only the eastern part of the Western Scheldt was changed. The bathymetry of the western part of the Western Scheldt and the Sea Scheldt was not adapted.

In (*MAS*, 1998) the effects of the different alternatives of the enlargement with disposal were studied. They analyzed the effect of the capital enlargement and maintenance dredging on the water levels in the Western Scheldt over a period of 10 years. Different alternatives of the sediment disposal between the disposal locations were analyzed with the use of a hydrodynamic model. Only the initial effect of the enlargement was analyzed; morphological changes were not taken into account. The bathymetry was adapted to represent the situation after 10 years. The model results for the scenarios with enlargement were compared with the water levels for 1992.

The analysis in (*MAS*, 1998) showed that tide penetrates the estuary easier due to the enlargement. This means that high waters increase. This results in an increase of the tidal amplitude. The enlargement with disposal has only a very small effect on the water levels at Terneuzen and Hansweert. At Bath this effect is larger. The high waters at this station increase by 7 to 12 cm in 10 years. The effect on the low waters is smaller. They increase or decrease by 1 to 2 cm for different alternatives. Therefore, the tidal amplitude at Bath increases by 6 to 14 cm.

Since (*MAS*, 1998) analyzed the effect of the enlargement after 10 years taking into account maintenance dredging, it is necessary to express their results in cm per year to be able to compare them with the results of our study. According to (*MAS*, 1998) the low waters change only a little bit during one year (order of magnitude mm/year), while the high waters increase at Bath by 0.7 to 1.2 cm/year.

The results of our study for low waters are similar to (*MAS*, 1998). The low waters in the Western Scheldt and the Upper Sea Scheldt do not change. However, the results for the high waters are not in agreement with (*MAS*, 1998). The enlargement with disposal of sediment results in a small decrease (< 1 cm) of the high waters at all stations.

In (*Jeuken et al,* 2004) the impact of the enlargement on morphology was studied. Furthermore, the changes of the tidal volume and the tidal amplitude were analyzed. Both initial and future effects (in 2010 and 2030) of the enlargement were studied with the use of a morphological model. In our study we use a hydrodynamic model and analyze only the initial effect of the enlargement.

The results of (*Jeuken et al,* 2004) show that the tidal volumes and tidal amplitude increase as an initial effect of the enlargement. The tidal volumes increase by 0.3% to 1.6%. The tidal amplitude increases by 1 to 7 cm. The effect of the enlargement on the tidal volumes increases from Vlissingen to more upstream and reaches a maximum of 1.6% near Schaar van de Noord. At Bath the change of the volumes decreases. The increase of the tidal amplitude and volumes diminishes in the future. In 2010 the tidal volumes calculated for most enlargement alternatives still increase, while in 2030 they decrease for most scenarios.

(*Jeuken et al,* 2004) concluded that the disposal of sediment outside the estuary results in a decrease of the changes in the tidal amplitude and tidal volumes compared to the disposal inside the estuary. This is opposite to the results of our study, where the effect of the enlargement without disposal was larger than with disposal.

(*Jeuken et al,* 2004) concluded that the effect of all studied enlargement alternatives are small in comparison to the expected future changes in the reference zero alternative (scenario without enlargement but with present policy of maintenance dredging and sand mining). This is similar to the results of our study. In our scenario only the effect of the capital enlargement is analyzed. Maintenance dredging and sand mining are not taken into account. The modeled changes in the water levels due to the capital enlargement are very small.

Different conclusions about the effects of the navigation channel enlargement can be found in reports. Several Flemish publications conclude that the enlargement of the navigation channel has a very small or even no effect on the tidal regime (*Taverniers,* 1998; *Peters et al.,* 2001 and *Blomme,* 2001). In Dutch publications of (*Pieters,* 2002) it is concluded on basis of the tidal observations that maintenance dredging and capital enlargement have been dominant in the evolution of the tidal regime and increasing penetration of storm floods (*Jeuken et al.,* 2007).

In the MOVE final report (*Van Eck and Holzhauer*, 2007) it is concluded – based on monitoring – that due to the morphological impacts in the Western Scheldt yearly average low water levels in Hansweert and especially in Bath decreased since 1996. Yearly average high waters did not change.

Due to this decrease in low waters, the tidal difference between Bath and Vlissingen increased by about 6 cm. The difference in time of low waters at Vlissingen and Bath decreased by 5 minutes after the second enlargement.

These changes are larger than the ones obtained in our study. This may be explained by the fact that (*Van Eck and Holzhauer*, 2007) analyzed the total effect of the morphological changes for a period of 10 years, which included also maintenance dredging, sand mining, natural evolutions as well the effect of morphological evolutions due to changes from the past. In runs 32 and 33 of our study only the effect of the capital enlargement was analyzed.

If we express the result of the MOVE report as a change per year, than we have results which are more comparable to the results of our study. The tidal difference between Bath and Vlissingen increased by less than 1 cm per year because of a decrease of the low waters at Bath. The average high waters did not change. The difference in time of the low waters at Vlissingen and Bath decreased by 0.5 min. In our study the low waters at Bath decrease by 1 cm relative to Vlissingen, the high waters do not change in the scenario of the enlargement with disposal. This is similar to the MOVE report. The phase difference is very small.

In the next paragraph, an extra simulation is carried out in order to try to distinguish between the different causes for the changes observed by (*Van Eck and Holzhauer,* 2007).

5.3.11 Comparison of the water levels for years 2006, 1999 and 1995

To check why there is a difference between the model results (this study as well as (*Witteveen and Bos,* 1999)) and the observations, an extra analysis is carried out. Comparison of the results of the reference run (bathymetry around 2005-2006, described in chapter 3.3) with the results of run 31 (bathymetry of 1994-1995) should give similar results as the results of (*Van Eck and Holzhauer*, 2007). The differences in high and low waters between both model runs are presented on Figures 69 - 73 and in Table A-23. As a result of all morphological changes in the Scheldt estuary during the 10 years, high waters increased and low waters decreased at most stations. In 2006 high and low waters are also observed earlier than in 1995. There is almost no change in the water levels downstream Terneuzen. The largest changes in high waters are observed upstream Liefkenshoek. The high waters increased by 8 to 9 cm. The low water decreased at all stations downstream Dendermonde. A maximal decrease of 15 cm is observed at Hemiksem. Therefore, the tidal amplitude significantly increased at most stations as a result of the morphological changes. Near Bath high waters increased by 6 cm, low waters decreased by 10 cm. These changes are larger than the ones described in the MOVE final report (*Van Eck and Holzhauer*, 2007).

Besides the comparison of the bathymetry of 2005-2006 with run 31, also another comparison is carried out. For this a simulation with the bathymetry of 1999 is executed. On Figures 69 - 73 and in Table A-23 the results of this simulation are compared to run 31. Comparison of the model results for 1999 to the results of 1995 shows the effect of the enlargement of the navigation channel, as well as the natural morphological changes that happened in the estuary in this period. In the year 1999 high waters increased by 1 to 6 cm, low waters decreased by 1 to 9 cm in comparison to the year 1995.

From the comparison of the bathymetry in 1999 and 2006 to 1995 it can be concluded that the changes in water levels are much more pronounced compared to the simulations only taking into account the effect of the enlargement.

This is due to morphological changes which occured in the estuary during the analyzed periods and which are not related to the enlargement (sand mining, effect of historical interventions, natural morphological evolutions, …). Possibly also the enlargement causes an indirect morphological effect (and thus is partly responsible for the changes in water levels) which can not be taken into account in the numerical model.

To compare the changes in water levels for different periods (from 1995 to 2006 and from 1995 to 1999) with the changes only due to the enlargement (run 33) the results were expressed as a change per year (Tables A-24 and A-25).

The changes per year in the high water magnitude and phase are very similar for both analyzed periods. The high waters increased by 1 cm/year for most stations starting from 1995. However, when we analyze the initial effect of only enlargement with disposal (run 33) the result is opposite: the high waters decreased by 1 cm or did not change. Therefore, the initial effect of the enlargement on the high waters in the estuary is less important than other morphological changes that happened during the analyzed periods (from 1995 to 1999 and from 1995 to 2006).

The low waters decreased or did not change for most stations as a result of the enlargement of 1998 and all morphological changes from 1995 to 1999 and 1995 to 2006. The changes in low water magnitude per year from 1995 to 1999 are a little larger than from 1995 to 2006 for some stations.

The differences in low water phase per year for the period from 1995 to 1999 are 2 to 3 times larger for all stations upstream Liefkenshoek than for the period from 1995 to 2006. The possible explanation for this is the fact that the short term morphological effect of the capital enlargement – which is included in the periode 1995 to 1999 – is causing a bigger change than natural changes in the bathymetry.

The direct effect of the capital enlargement on the water level magnitude and phase is zero for some stations. However, the changes per year from 1995 to 1999 are larger than from 1995 to 2006. This means that some important changes in the bathymetry happened from 1995 to 1999 which had an effect on the water levels. In the period from 1999 to 2006 the changes in the bathymetry were smaller. The model results show that the capital enlargement of 1998 had only a small direct effect on the magnitude and phase of the water levels. However, the hydrodynamic model used in this study can analyze only the initial effect of the enlargement. The morphologic changes induced by the capital enlargement are not taken into account.

5.3.12 Conclusion

The model results show that the direct effect of an enlargement of the navigation channel does not have a strong effect on the water levels in the estuary. The differences in high and low water levels calculated for both enlargement scenarios (with or without disposal of the dredged material into the estuary) compared to the reference run are very small. They do not exceed 2 cm. The enlargement without disposal of sediment has a stronger effect on the water levels, velocities and tidal volumes than the enlargement with disposal. The enlargement without disposal results in an increase of high waters and a decrease of low waters. The largest changes are observed at Liefkenshoek. As a result of the enlargement with disposal, high and low waters either do not change or decrease. The largest differences are observed in the Lower Sea Scheldt.

From observations (*Van Eck and Holzhauer,* 2007) it is concluded that the enlargement of the navigation channel causes a decrease of the low water levels. However, from this study it is concluded that this decrease is not caused by the direct effect of the enlargement itself. The morphological evolutions of the estuary during the enlargement period (evolutions not related to the enlargement itself as well as evolutions initiated by the enlargement) are mainly responsible for these observed evolutions.

5.4 Changes at the Gat van Ossenisse – Middelgat

5.4.1 Introduction

In the 1970s natural morphological changes happened at the reach Gat van Ossenisse – Middelgat in the Western Scheldt, which resulted in the relocation of the navigation channel from the ebb channel to the flood channel.

From 1938 on, the development of the channel system became progressively more controlled by the layout of the embankments, but also influenced by the continuing reclamation of polders and the closure of remaining creeks. The Gat van Ossenisse received more flood flow from both Pas van Terneuzen and Everingen and it could finally cut through its delta and became the main navigation route.

The evolution of the Middelgat and Gat van Ossenisse was also influenced by the construction of the jetties for the harbour of Hansweert, protruding on the bank-line. Due to these changes in morphology, the Gat van Ossenisse flood channel formed a smooth transition with the ebb channel Zuidergat and with the flood channel Schaar van Waarde, while the Middelgat presented in its plan form a discontinuity with both (*Peters et al.,* 2000).

In the same period with these natural changes the first capital enlargement of the Scheldt estuary was performed. To study the effect of these changes on the hydrodynamics of the estuary, four scenarios are analyzed (Table 5-6). The bathymetry for these scenarios is made by the adaptation of the bathymetry for the years 1970-1971. Different changes are implemented in each scenario, such as replacement of the navigation channel and its enlargement with or without disposal of the dredged material. The results of four scenarios are compared with the reference run, which has bathymetry for 1970-1971 without changes.

In the first scenario the change of the navigation channel from the Middelgat to the Gat van Ossenisse is studied, without the enlargement of this navigation channel. This situation represents more or less the natural evolution of the river channel. A small amount of sediment had to be dredged in this scenario in order to obtain the necessary draught in the new navigation channel. In the second scenario, the enlargement of the river channel with disposal of material is implemented while the navigation channel is located in the Middelgat. This scenario represents more or less the human impact. In the third scenario, the same enlargement with disposal is studied while the navigation channel is located in the Gat van Ossenisse. This situation shows the effect of both natural evolution and human intervention. In the fourth scenario, the enlargement without disposal of material is implemented.

The navigation channel is located in the Gat van Osenisse. This scenario shows both human and natural changes and represents reality.

Table A-26 shows the volumes of the dredged and disposed material for the different scenarios. Figures 74 - 77 show the differences between the original bathymetry for 1970-1971 (reference situation) and the changed bathymetry used in the scenarios.

Table 5-6. Overview of the model runs with the simulated changes at the Gat van Ossenisse – Middelgat

Name	Description
run 40	reference simulation with the bathymetry for 1970 - 1971
run 41	Scenario 1 - change of the navigation channel from the Middelgat to the Gat van Ossenisse without enlargement
run 42	Scenario 2 - the navigation channel is in the Middelgat, enlargement with disposal of material
run 43	Scenario 3 - the navigation channel is in the Gat van Ossenisse, enlargement with disposal of material
run 44	Scenario 4 - the navigation channel is in the Gat van Ossenisse, enlargement without disposal of material (reality)

5.4.2 High and low water levels

Tables A-27, A-28 and Figures 78 - 82 show the results of comparison of the high and low water levels for the scenarios and the reference run. The station Baalhoek is excluded from the analysis because in the reference scenario with the bathymetry for 1970 - 1971 (and in all scenarios with bathymetries made by the adaptation of the bathymetry for 1970 - 1971) this point is dry at low water. The results show that changes of the navigation channel at the Gat van Ossenisse - Middelgat almost did not have effect on the water levels in the estuary. The differences for all stations are very small; they do not exceed 8 mm.

Since differences are so small, they are not significant: these values lie within the accuracy of the numerical model.

In the first scenario there are almost no changes in comparison to the reference run. The high waters decrease by 0 to 2 mm in run 41, the low waters almost do not change.

In the second scenario (run 42) the high waters decrease a little in comparison to the reference run. The change in the high waters does not exceed 6 mm. The low waters increase by 1 to 4 mm everywhere except Schoonaarde, Wetteren, Melle and Duffel where the low waters decrease a little.

The results of the third scenario are similar to the second one. The high waters decrease and the low waters increase at most stations except upstream Schoonaarde. The changes in run 43 are a little larger than in run 42. The largest changes are observed near Hansweert.

The results of scenario 4 are opposite to the results of scenarios 2 and 3. The high waters increase by 2 to 4 mm at most stations upstream Hansweert. The low waters decrease or do not change at most stations.

Therefore, the enlargement of the navigation channel at the Gat van Ossenisse and Middelgat with disposal of material (runs 42 and 43) results in a small decrease of high waters. The enlargement of the navigation channel without disposal of material (run 44) results in a small increase of high waters. This is similar to the results described in chapter 5.3., where the enlargement of 1997 – 1998 is studied. However, the differences observed in the different scenarios remain very small and are most likely not significant.

5.4.3 Tidal volumes

The flood and ebb volumes calculated for the scenarios with the changes at the Gat van Ossenisse – Middelgat are presented in Table A-29. Figure 83 shows the differences between the flood volumes calculated for the scenarios with the changes at the Gat van Ossenisse - Middelgat and for the reference run.

In the first scenario (natural changes) the tidal volumes decrease only a little in comparison to the reference situation. The ebb and flood volumes at most cross sections change by less than 0.1% of the reference ebb and flood volume respectively. In the second and third scenarios (enlargement of the navigation channel with disposal) the flood volumes decrease by maximum 0.4%; the ebb volumes decrease by maximum 0.3%. At the cross section Gat van Ossenisse the ebb volumes decrease a little more than the flood volumes in the second and third scenarios (0.2 and 0.3% for flood volumes, 0.3% for ebb volumes). As a result of the forth scenario (enlargement without disposal) the flood volumes increase by 0.1 to 0.3%; flood can penetrate the estuary easier. The ebb volumes increase a little less than the flood volumes (by 0.1 to 0.2%).

The changes of the tidal volumes in four scenarios are similar to the results of the scenario runs with enlargement of the navigation channel in 1997-1998. Enlargements with disposal and without disposal have opposite effects on the tidal volumes. However, for all scenarios the differences compared to the reference simulation remain very small.

Tables A-30 and A-31 present the results of the analysis of the flood and ebb volumes through the cross sections in the ebb and flood channels. The locations of the cross sections are shown on Figure 65. The differences between these volumes calculated for the scenarios and reference run are presented on Figure 84. The changes that happened at the Gat van Ossenisse - Middelgat had only a local effect on the tidal volumes through the ebb and flood channels. At most cross sections there is a very small change in volumes.

At the Middelgat the flood volume decreases while it increases at the Gat van Ossenisse in all four scenarios. This change is the largest in scenario 3 (4.0% decrease at the Middelgat and 3.0% increase at the Gat van Ossenisse) and the smallest in scenario 2 (0.4% decrease at the Middelgat and 0.1% increase at the Gat van Ossenisse). This is because in the third scenario the Gat van Ossenisse changed not only naturally but was also deepened. In scenario 2 the navigation channel is still located in the Middelgat, therefore the changes in the flood volumes are very small.

The changes in the ebb volumes at the Middelgat - Gat van Ossenisse are smaller than the changes of the flood volumes. However, the changes at Everingen - Terneuzen are larger.

The largest differences are observed in scenarios 2, 3 and 4. In the second scenario the ebb volume through the Middelgat increases by 1.3% while it decreases at the Gat van Ossenisse by about 2.0%. This is related to the fact that the navigation channel in scenario 2 is located in the Middelgat.

In scenarios 3 and 4 the ebb volumes decrease at the Middelgat by 2.0 and 1.3% respectively and increase at the Gat van Ossenisse by 1.7% because the Gat van Ossenisse is deepened.

The ebb volumes at Everingen decrease in scenarios 1, 2 and 3 and they increase a little in scenario 4. The ebb volumes at Terneuzen increase in all four scenarios. The largest changes are observed in the third scenario: the ebb volume at Everingen decreases by 1.5% of the ebb volume in the reference run, the ebb volume at Terneuzen increases by about 1.0%.

5.4.4 Velocities at dredging locations

Figures 85 and 86 show the velocities calculated for the reference run and for four scenarios with the changes at the Gat van Ossenisse - Middelgat. Several monitoring stations are placed at the dredging locations in the model to analyze the effect of the bathymetrical changes on the velocity. The velocities at disposal locations are not analyzed because they are not well represented in the model. The model has a fixed bed and the effect of erosion of the disposal locations can not be taken into account.

At most locations dredging results in a decrease of the velocities (Figure 85). However, at some dredging locations only the flood velocities decrease a little while the ebb velocities increase (Figure 86). This can be explained by the fact that these dredging locations are close to the disposal locations, which can influence the velocities in this area.

5.4.5 Comparison with other studies

The changes of the navigation channel at the Gat van Ossenisse - Middelgat were analyzed in (*Witteveen and Bos*, 1999). They studied the effect of the natural evolution of the Gat van Ossenisse and Middelgat on the high waters in the Western Scheldt. Their analysis showed that these changes had only a very small effect on the water levels. Downstream Baalhoek maximal change of high waters was only 2 mm. At Baalhoek and Bath some of the calculated high waters did not change, some of them increased by maximum 5 mm. These results are similar to the results of run 44 analyzed in our report.

5.4.6 Comparison with other model simulations

Since the effect of the 4 scenario runs (Table 5-5) is only limited, three extra model simulations are performed to study the changes near the Gat van Ossenisse - Middelgat in more detail. An attempt is made to investigate whether longer term evolutions in this area did cause larger changes than the ones observed in the previous paragraph.

For these extra simulations, the bathymetry for 1970-1971 is used everywhere in the Scheldt estuary except for the area at the Gat van Ossenisse - Middelgat. For this part of the river the bathymetry for 1977-1978 is used. Therefore, comparison of the results of this simulation and model run for 1970-1971 shows the total effect of all morphological changes that happened at the Gat van Ossenisse - Middelgat from 1970 to 1978 (not only the direct effect of the evolutions, but also the mid-long effect).

This extra model simulation for the year 1978 has very similar results to run 44 (Table A-32 and Figures 87 - 91). Therefore, it can be concluded that the changes at the Gat van Ossenisse - Middelgat resulted only in a very small increase of high waters, low waters decreased a little or did not change.

A second extra model simulation was carried out with the bathymetry for the year 1955 - before the change of the navigation channel from Middelgat to Gat van Ossenisse took place - for the part of the Scheldt estuary near the Gat van Osseniss - Middelgat (Figure 92). For the rest of the estuary the bathymetry for 1970 – 1971 is used. This simulation shows the effect of all morphological changes that happened near the Gat van Ossenisse - Middelgat from 1955 to 1971. Since the natural morphological evolution is a slow process, the analysis of the changes during a longer period could give more information about the effect of the relocation of the ebb and flood channels.

The results of this model run are presented in Table A-33 and Figures 94 - 98. The changes that happened at the Gat van Ossenisse - Middelgat have only a very small effect on the magnitude and phase of the water levels in the Scheldt estuary.

As a result of natural changes the high waters in 1955 were a little lower than in 1970, while the low waters were a little higher (only in the upstream part of the estuary the low waters were lower in 1955). The differences in the magnitude do not exceed 1 to 2 cm for most stations. The largest difference in low waters is observed at Hansweert, where the low waters in 1955 were 3 cm higher than in 1970.

The changes in the phase of the high waters are negligible. The low waters were observed 1 to 3 min later in 1955 than in 1970 (5 min at Hansweert).

For the third extra simulation the bathymetry for 2007 is used for the Rug van Baarland and the Molenplaat (i.e. the shallow intertidal area near the Gat van Ossenisse and Middelgat). For the rest of the estuary the bathymetry for 1970 - 1971 is used (as in the reference run). The morphology of the Western Scheldt is characterized by an ebb-flood channel system. The connecting shortcut channels intersect the intertidal areas between the two channels and form a link between the main ebb and flood channel. These connecting channels result in water exchange between two main channels and redistribute the tidal flow in the channel system (*Swinkels et al.,* 2007). In 2007 there was only one shortcut channel left connecting the flood and ebb channels (Figure 93). Therefore, the water exchange between two main channels was limited. The effect of this change in bathymetry on the water levels is studied in the model.

The results of the model run with the bathymetry for 2007 for the Rug van Baarland and the Molenplaat are presented in Table A-33 and Figures 94 - 98. The change of the bathymetry of the shallow intertidal area near the Gat van Ossenisse and Middelgat does not have a strong effect on the model results. As a result of a limited water exchange between two main channels in 2007 the high waters increased a little in comparison to 1970 and the low waters decreased a little at most stations. The changes are very small (smaller than 1 cm at most stations and 1 cm at Hansweert). The changes in the phase are negligible.

5.4.7 Conclusion

The analysis of the results shows that the changes that happened at the Gat van Ossenisse – Middelgat in 1970th did not have a significant effect on the water levels in the estuary. Four different scenarios with the changes in bathymetry are analyzed. The water levels change in these scenarios by less than 1 cm. These results are in agreement with the results of (*Witteveen and Bos*, 1999).

5.5 Sand mining scenarios

5.5.1 Introduction

The sand mining has been performed in the Western Scheldt for more than 50 years. The last years about 2.6 Mm³ per year is extracted from the estuary: around 2.0 Mm³ in the Western Scheldt and 1.0 Mm³ in the Sea Scheldt. However, for most years the volumes of sand mining were smaller (*Schelde Informatie Centrum*, 2009).

(*Vroon et al*., 1997) analyzed the effect of the sand mining in the Western Scheldt. Until the beginning of 1990s the sand was mostly mined from the western part of the Western Scheldt (downstream Terneuzen). 100 Mm³ of sand in total was extracted from the estuary since 1955. Because of the sediment import from the mouth area, the total volume of the estuary was enlarged by only 15 to 20 Mm³. If this volume was distributed over the entire Western Scheldt, the mean increase in depth would be only 6 cm. Therefore, the observed effects of the sand mining on the estuarium system are limited. Since a lot of sediment is imported in the western part of the estuary, where the sand mining takes place, the effects of sand mining are very small in this area. However, it can not be concluded that sand mining is unimportant factor. If practiced during a long period, sand mining can play an important role in the morphological changes in the estuary. The estuary becomes larger because of sand mining. This happens if the volumes of sand mining are larger than the sediment import.

It is attempted not to extract more sand than the volume that can be naturally imported in the estuary. The sand mining locations are chosen so that they can stimulate maintenance of the navigation channel and necessary changes in the channel and on the intertidal areas. Therefore, the effect of sand mining on the short term is comparable with the effect of dredging. However, on a longer term sand mining has a significant impact on a sand balance of the estuary (*Pieters et al*., 1991).

5.5.2 Model results

It is very difficult – not to say impossible – to study the effect of sand mining in a model. The annual effect of sand mining is probably not important, however it is the long term effect which can have some effect on the tidal penetration in the estuary. Moreover, the net effect of sand mining is closely related to the imported (or exported) quantities of sediment into the estuary. In fact there is need for a large scale long term morphological model to study the effect of sand mining, but since the reliability of such models is not yet very high, in this study no such model is being used. The effect of sand mining on a medium term has been investigated with a hydrodynamic model. In order to do so, the effect of the sand mining intervention is translated into an adaptation of the local bathymetry. On short term, it can be expected that the effect of sand mining remains on a local level, however on a longer term sand mining will induce morphological changes which will not be limited to local adaptations of the bathymetry.

With these critical thoughts, the effect of sand mining was studied in a hydrodynamic model.

In our study the effect of sand mining for a period of 10 years was analyzed. The bathymetry for this scenario was made by the adaptation of the bathymetry for the reference situation (the most recent bathymetry for the Scheldt estuary). Sand mining was implemented in the model by change of the depth of the sand mining locations. Based on the information about the sand mining volumes in 2005 and the area of the sand mining locations, the values that had to be added to the reference depth were calculated for each location (Table 34). The adapted bathymetry is presented on Figure 99.

The hydrodynamic model with immobile bed was used for the analysis. Therefore, the change of the bathymetry of the sand mining locations with time could not be implemented in the model. However, in reality the sediment on every location of the river bed can be transported by the water flow. The depth of the sand mining locations changes with time due to the sedimentation and erosion processes. The sand mining affects the river bed evolution process. In the hydrodynamic model only the initial effect of sand mining can be studied. In reality the sand mining with analyzed volumes is carried out during a period of 10 years. In our model it was implemented instantaneously.

The results of the comparison of the water levels for the scenario with sand mining to the reference scenario are presented in Table 35 and on Figures 100 - 104. The model results show that sand mining during a period of 10 years has a very small effect on the water levels. The high waters increase a little, the low waters decrease. This effect is similar to the effect of the enlargement without sediment disposal but the changes in the water levels are smaller in the scenario with sand mining. The changes in the water levels magnitude are smaller than 1 cm. Both high and low waters are observed a little earlier as a result of the sand mining. However, the differences in the phase are very small (1 to 2 min).

6 Conclusions

The natural changes and human activities affected the tidal regime of the Scheldt estuary during the last centuries. The effect of the different changes was studied in this report by numerical modeling. However this was done in a schematic way since only a hydrodynamic model was used. As a consequence the effect of the morphologic evolutions due to a certain change could not be taken into account. The analysis of the model results was based on comparison of the magnitude and phase of the high and low waters calculated for the reference situation and for a certain scenario.

The following scenarios (each of them trying to investigate a specific change) were modeled:

- The effect of sea level rise;
- The depoldering of low lying areas;
- The enlargement of the navigation channel (with and without disposal of the capital dredging material);
- The changes at the ebb-flood channel system Gat van Ossenisse – Middelgat;
- The effect of sand mining.

The analysis of the results showed that sea level rise has a strong impact on the water levels in the estuary. Sea level rise results in increase of both high and low waters: since high water levels increase more than low water levels, tidal amplitude increases as well. The effect of sea level rise is not uniform along the estuary. It is strongest in the Western Scheldt and it decreases upstream. However, at Wetteren and Melle the effect of sea level rise becomes stronger again. From schematic simulations it was concluded that sea level rise resulted in increase of high waters by 22 to 27 cm and increase of low waters by 14 to 25 cm since the last century (i.e. sea level rise of about 25 cm). When taking into account the effect of the amplification of the tidal amplitude in the North Sea, the difference in tidal amplitude along the estuary becomes even more pronounced.

The poldering of the low lying areas had a second strongest impact on the water levels in the estuary. However, it affected mainly the high water levels and had a smaller effect on the low waters. Polders were created by building dikes, which protected the low lying areas from the inundation during the flood periods. This resulted in a decrease of the storage volume and increase of the high waters in the estuary. The largest changes in the high waters due to the land reclamation were observed at the stations located close to the poldered areas.

In this report polders Braakman, New – Westland, Tielrodebroek and Groot Schoor of St-Amands were studied. To study the effect of the polders, these areas were depoldered in the model. In order to be able to compare the effect of the different polders, adaptations were made to Tielrodebroek and Groot Schoor of St-Amands in order for the intertidal volume of all polders to be equal to approximately 5% of the local flood volume. The depoldering resulted in a decrease of the high waters and increase of the low waters. As a consequence it can be concluded that in reality since the low lying areas were poldered an opposite effect on the water levels was observed. The poldering of these areas during the last centuries resulted in increase of the high waters and a smaller decrease of the low waters. The combined effect of the 4 polders together resulted in a maximal increase of the high waters around Temse. The strongest effect of the polders on the low waters is observed in the Upper Sea Scheldt.

The capital enlargement of the navigation channel in 1997-1998 and the changes at the Gat van Ossenisse – Middelgat had only a very small effect on the water levels in the estuary. The enlargement without disposal of the capital dredging material resulted in an increase of the high waters and a decrease of the low waters. The changes of the water levels did not exceed 2 cm, which is within the accuracy range of the numerical model. The effect of the enlargement with disposal was even smaller. The differences in the water levels were smaller than 1 cm. At some stations there was no effect at all. The largest changes were observed in the Lower Sea Scheldt. Both high and low waters decreased there as a result of the enlargement with disposal.

The natural changes at the Gat van Ossenisse – Middelgat had a very small effect on the water levels in the Scheldt. The changes of the water levels did not exceed several millimeters.

The effect of sand mining over a period of 10 years was analyzed. The results of the model simulation showed that sand mining during this period has only a small effect on the water levels in the estuary.

The conclusions of this report do result from hydrodynamic simulations. In a schematized way, single well-distinguished changes in the estuary were studied by adaptation of the bathymetry. However it is sure that besides this direct effect on the bathymetry of a certain change there will also be an indirect change of the bathymetry. As an example the poldering of a certain area is taken. Due to the poldering of this area (which is the direct adaptation of the bathymetry) the hydrodynamic conditions in the estuary will change slightly. These changes will cause morphological changes of the estuary, which will in turn influence the hydrodynamics. However, with a hydrodynamic numerical model these changes can not be taken into account. Due to limitations in the equations describing the sediment transport and the morphological evolutions, these effects can also not be modeled with a morphological model in a reliable way. So the reader has to bear in mind these limitations when interpreting the results of this study.

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Tables

Table A-1. Calculated ebb and flood volumes for spring and neap tide (reference run)

Station	spring tide			neap tide		
	V_{flood} (m^3)	V_{ebb} (m^3)	Ratio V_{flood}/V_{ebb}	V_{flood} (m^3)	V_{ebb} (m^3)	Ratio V_{flood}/V_{ebb}
Western Scheldt						
Vlissingen	1.15E+09	-1.15E+09	1.00	8.63E+08	-9.84E+08	0.88
Hoofdplaat	1.02E+09	-1.02E+09	1.00	7.66E+08	-8.73E+08	0.88
Borssele	9.03E+08	-9.04E+08	1.00	6.76E+08	-7.72E+08	0.88
Terneuzen	7.96E+08	-7.97E+08	1.00	5.95E+08	-6.80E+08	0.87
Hansweert	4.87E+08	-4.83E+08	1.01	3.59E+08	-4.14E+08	0.87
Walsoorden	4.31E+08	-4.26E+08	1.01	3.15E+08	-3.65E+08	0.86
Baalhoek	3.42E+08	-3.38E+08	1.01	2.50E+08	-2.91E+08	0.86
Schaar van de Noord	2.78E+08	-2.74E+08	1.02	2.06E+08	-2.40E+08	0.86
Bath	2.12E+08	-2.10E+08	1.01	1.63E+08	-1.90E+08	0.85
Lower Sea Scheldt						
Prosperpolder	1.85E+08	-1.83E+08	1.01	1.41E+08	-1.67E+08	0.85
Zandvliet	1.78E+08	-1.76E+08	1.01	1.36E+08	-1.61E+08	0.85
Liefkenshoek	1.36E+08	-1.35E+08	1.01	1.03E+08	-1.24E+08	0.83
Boudewijnsluis	1.26E+08	-1.25E+08	1.01	9.54E+07	-1.16E+08	0.82
Kallo	1.19E+08	-1.19E+08	1.00	8.99E+07	-1.10E+08	0.82
Boerenschans	1.05E+08	-1.05E+08	1.01	7.84E+07	-9.70E+07	0.81
Oosterweel	9.61E+07	-9.57E+07	1.00	7.07E+07	-8.86E+07	0.80
Antwerp	8.98E+07	-8.93E+07	1.01	6.56E+07	-8.28E+07	0.79
Galgenweel	8.39E+07	-8.36E+07	1.00	6.09E+07	-7.76E+07	0.78
Hoboken	7.48E+07	-7.46E+07	1.00	5.36E+07	-6.94E+07	0.77
Hemiksem	6.47E+07	-6.46E+07	1.00	4.55E+07	-6.05E+07	0.75
Schelle	6.27E+07	-6.26E+07	1.00	4.40E+07	-5.87E+07	0.75
Steendorp	3.83E+07	-3.78E+07	1.01	2.68E+07	-3.58E+07	0.75
Durme						
Durme Bunt	1.56E+06	-1.53E+06	1.01	9.93E+05	-1.18E+06	0.84
Durme Mirabrug	1.00E+06	-9.85E+05	1.02	5.96E+05	-7.25E+05	0.82
Hamme	9.35E+05	-9.21E+05	1.01	5.54E+05	-6.79E+05	0.82
Waasmunster	3.03E+04	-2.99E+04	1.01	1.84E+04	-2.04E+04	0.90
Upper Sea Scheldt						
Temse	3.12E+07	-3.06E+07	1.02	2.13E+07	-2.95E+07	0.72
Tielrode	2.68E+07	-2.63E+07	1.02	1.80E+07	-2.58E+07	0.70
Sint-Amands	1.55E+07	-1.54E+07	1.00	9.96E+06	-1.65E+07	0.60
Dendermonde	8.73E+06	-8.93E+06	0.98	5.11E+06	-1.07E+07	0.48
Schoonaarde	4.96E+06	-5.23E+06	0.95	2.59E+06	-6.72E+06	0.39
Wetteren	2.59E+06	-3.10E+06	0.84	8.15E+05	-4.50E+06	0.18
Melle	1.75E+06	-2.40E+06	0.73	3.24E+05	-3.85E+06	0.08

Station	spring tide			neap tide		
	V_{flood} (m³)	V_{ebb} (m³)	Ratio V_{flood}/V_{ebb}	V_{flood} (m³)	V_{ebb} (m³)	Ratio V_{flood}/V_{ebb}
Rupel						
Boom	1.10E+07	-1.18E+07	0.93	6.93E+06	-1.13E+07	0.61
Walem	3.44E+06	-3.50E+06	0.98	2.17E+06	-3.48E+06	0.62
Zenne						
Hombeek	1.55E+05	-3.83E+05	0.40	4.98E+04	-5.11E+05	0.10
Dijle						
Mechelen	2.41E+05	-9.70E+05	0.25	0.00E+00	-1.85E+06	0
Rijmenam	1.90E+04	-7.68E+05	0.02	0.00E+00	-1.75E+06	0
Beneden, Grote and Kleine Nete						
Duffel	2.07E+06	-2.19E+06	0.95	1.15E+06	-2.29E+06	0.50
Lier Molbrug	9.12E+05	-1.13E+06	0.80	4.00E+05	-1.38E+06	0.29
Emblem	2.00E+05	-3.39E+05	0.59	4.40E+04	-5.10E+05	0.09
Kessel	1.71E+05	-2.81E+05	0.61	2.98E+04	-4.47E+05	0.07

Table A-2. Comparison of ebb volumes and fresh water discharge volumes during the ebb period for some upstream locations along the Scheldt estuary (reference run)

Station	spring tide			neap tide		
	$V_{fresh\ water}$ (m³)	V_{ebb} (m³)	Ratio V_{fresh}/V_{ebb}	$V_{fresh\ water}$ (m³)	V_{ebb} (m³)	Ratio V_{fresh}/V_{ebb}
Dendermonde	6.25E+05	8.93E+06	0.07	2.42E+06	1.07E+07	0.23
Schoonaarde	5.79E+05	5.23E+06	0.11	1.77E+06	6.72E+06	0.26
Wetteren	6.44E+05	3.10E+06	0.21	2.11E+06	4.50E+06	0.47
Melle	6.48E+05	2.40E+06	0.27	2.42E+06	3.85E+06	0.63
Hombeek	1.62E+05	3.83E+05	0.42	4.25E+05	5.11E+05	0.83
Kessel	9.11E+04	2.81E+05	0.32	3.02E+05	4.47E+05	0.68
Emblem	1.19E+05	3.39E+05	0.35	3.69E+05	5.10E+05	0.72

Table A-3. Comparison of the magnitude of high and low waters for the scenarios with sea level change to the reference run
(NV = water level could not be determined based on the used algorithm)

Station	**Difference (run - reference run)**											
	high water (cm)				**low water (cm)**				**tidal amplitude (cm)**			
	2050 increase 25 cm	*2100 increase 60 cm*	*1900 decrease 25cm*	*2100 increase amplitude 5%+50cm*	*2050 increase 25 cm*	*2100 increase 60 cm*	*1900 decrease 25cm*	*2100 increase amplitude 5%+50cm*	*2050 increase 25 cm*	*2100 increase 60 cm*	*1900 decrease 25cm*	*2100 increase amplitude 5%+50cm*
Western Scheldt												
Vlissingen	25	61	-25	61	25	60	-25	42	0	1	0	19
Terneuzen	25	61	-26	61	24	59	-24	41	1	3	-1	20
Hansweert	26	61	-26	60	24	58	-24	40	2	3	-2	20
Baalhoek	25	60	-26	59	24	58	-24	40	1	2	-2	19
Schaar van de Noord	25	58	-25	58	24	57	-24	39	1	1	-1	18
Bath	25	59	-25	58	24	57	-24	39	1	2	-2	19
Lower Sea Scheldt												
Liefkenshoek	25	58	-25	58	24	57	-23	39	1	1	-2	18
Antwerp	24	57	-24	56	23	56	-23	39	0	0	-1	17
Hemiksem	24	57	-24	56	23	56	-23	39	1	1	-1	17
Upper Sea Scheldt												
Temse	24	57	-24	56	23	55	-23	39	1	1	-2	17
Dendermonde	22	51	-24	49	17	41	-16	33	5	10	-8	16
Schoonaarde	23	53	-24	51	15	38	-15	32	8	15	-9	19
Wetteren	24	58	-25	54	15	38	-15	32	9	20	-10	22
Melle	27	64	-27	59	16	39	-15	33	11	24	-12	26
Durme												
Waasmunster	22	52	-23	52	NV	NV	NV	NV	NV	NV	NV	NV

Station	Difference (run - reference run)											
	high water (cm)				low water (cm)				tidal amplitude (cm)			
	2050 increase 25 cm	*2100 increase 60 cm*	*1900 decrease 25cm*	*2100 increase amplitude 5%+50cm*	*2050 increase 25 cm*	*2100 increase 60 cm*	*1900 decrease 25cm*	*2100 increase amplitude 5%+50cm*	*2050 increase 25 cm*	*2100 increase 60 cm*	*1900 decrease 25cm*	*2100 increase amplitude 5%+50cm*
Rupel												
Boom	24	56	-24	56	22	53	-21	38	2	3	-3	18
Walem	24	56	-24	55	18	46	-18	33	5	10	-7	22
Mechelen	23	54	-23	54	NV	NV	NV	NV	NV	NV	NV	NV
Hombeek	23	53	-24	53	NV	NV	NV	NV	NV	NV	NV	NV
Nete												
Duffel	23	54	-23	53	15	35	-14	30	8	18	-9	23
Kessel	23	56	-22	52	NV	NV	NV	NV	NV	NV	NV	NV
Emblem	22	53	-22	51	NV	NV	NV	NV	NV	NV	NV	NV

Table A-4. Comparison of the phase of high and low waters for the scenarios with sea level change to the reference run (NV = water level could not be determined based on the used algorithm)

Station	**Difference (run - reference run)**							
	phase of high water (min)				**phase of low water (min)**			
	2050 increase 25 cm	*2100 increase 60 cm*	*1900 decrease 25cm*	*2100 increase amplitude 5%+50cm*	*2050 increase 25 cm*	*2100 increase 60 cm*	*1900 decrease 25cm*	*2100 increase amplitude 5%+50cm*
Western Scheldt								
Vlissingen	0	0	0	0	0	0	1	0
Terneuzen	-1	-2	-1	-2	-1	-3	2	-1
Hansweert	-1	-3	1	-2	-1	-2	2	-2
Baalhoek	-1	-2	1	-1	-1	-3	2	-2
Schaar van de Noord	-1	-1	1	-1	-1	-4	1	-1
Bath	0	-1	1	-1	-3	-6	1	-2
Lower Sea Scheldt								
Liefkenshoek	-1	-2	3	-2	-3	-6	2	-2
Antwerp	0	-2	1	-1	-2	-6	3	-1
Hemiksem	0	-1	1	0	-3	-6	3	-3
Upper Sea Scheldt								
Temse	-1	-1	2	0	-3	-7	4	-3
Dendermonde	-2	-2	1	1	-5	-12	5	-6
Schoonaarde	0	0	1	3	-5	-13	7	-7
Wetteren	1	5	0	7	-10	-20	9	-13
Melle	0	1	1	3	-9	-25	10	-16
Durme								
Waasmunster	-3	-5	4	-4	NV	NV	NV	NV
Rupel								
Boom	-1	-1	1	-1	-4	-9	3	-4
Walem	-1	-1	1	0	-4	-12	5	-5
Mechelen	-2	-3	1	-1	NV	NV	NV	NV
Hombeek	-2	-7	2	-5	NV	NV	NV	NV
Nete								
Duffel	-1	-2	1	0	-7	-15	7	-9
Kessel	-2	-5	1	-4	NV	NV	NV	NV
Emblem	-1	-3	3	-1	NV	NV	NV	NV

Table A-5. Flood volumes (spring tide) for the scenarios with sea level change

Station	**reference run**	**2050 (increase 25 cm)**	**2100 (increase 60 cm)**	**1900 (decrease 25 cm)**	**2100 (increase 50 cm, increase tidal amplitude 5%)**
	V_{flood} (m³)				
Hoofdplaat	1.02E+09	1.04E+09	1.08E+09	9.95E+08	1.11E+09
Terneuzen	7.96E+08	8.16E+08	8.45E+08	7.75E+08	8.69E+08
Gat van Ossenisse	6.01E+08	6.19E+08	6.44E+08	5.83E+0.8	6.60E+08
Bath	2.12E+08	2.15E+08	2.20E+08	2.08E+08	2.26E+08
Antwerp	8.98E+07	9.21E+07	9.58E+07	8.71E+07	9.78E+07
Temse	3.12E+07	3.23E+07	3.42E+07	2.99E+07	3.48E+07
Dendermonde	8.73E+06	9.30E+06	1.02E+07	8.15E+06	1.02E+07
Wetteren	2.59E+06	2.81E+06	3.03E+06	2.37E+06	3.05E+06

Table A-6. Mean values of the average and maximal velocity (cm/s) for the scenarios with sea level change and reference run (the level between intertidal area and river channel is the same as in the reference run)

Location		1900 (decrease 25 cm)				reference run				2050 (increase 25 cm)				2100 (increase 60 cm)				2100 (increase amplitude 5%, +50cm)			
		spring flood		spring ebb		spring flood		spring ebb		spring flood		spring ebb		spring flood		spring ebb		spring flood		spring ebb	
		VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX
Bath - Hemiksem	CH	71	99	67	82	71	99	68	82	71	99	68	83	72	99	69	85	74	103	71	86
	IT	10	27	06	14	12	30	07	17	13	32	08	20	15	35	10	23	15	35	10	24
Hemiksem – St-Amands	CH	85	122	87	96	86	123	88	98	87	124	90	100	87	125	92	102	89	128	93	104
	IT	19	46	10	24	21	48	12	26	23	51	13	29	25	55	16	34	25	56	16	34
St-Amands - Schoonaarde	CH	83	115	84	93	84	116	86	96	86	116	89	99	87	116	94	103	89	118	94	103
	IT	17	37	04	12	20	42	06	14	23	45	07	17	27	51	09	21	27	52	09	21
Schoonaarde-Melle	CH	83	102	63	71	86	103	65	73	87	102	68	76	88	101	71	79	90	103	71	79
	IT	11	21	03	09	14	26	04	11	18	30	05	15	24	37	07	21	23	36	07	21

CH: channel area (underneath the low water level); IT: intertidal area (above the low water level)

VEL AVER: average velocity; VEL MAX: maximum velocity

Table A-7. Mean values of the average and maximal velocity (cm/s) for the scenarios with sea level change and reference run (the level between intertidal area and river channel is different from the reference run)

Location		1900 (decrease 25 cm)				reference run				2050 (increase 25 cm)				2100 (increase 60 cm)				2100 (increase amplitude 5%, +50cm)			
		spring flood		spring ebb		spring flood		spring ebb		spring flood		spring ebb		spring flood		spring ebb		spring flood		spring ebb	
		VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX
Bath - Hemiksem	CH	71	100	67	82	71	99	68	82	71	99	68	83	71	98	68	83	73	102	70	85
	IT	13	31	07	17	12	30	07	17	11	28	06	16	09	23	05	14	09	24	05	14
Hemiksem – St-Amands	CH	85	123	88	97	86	123	88	98	86	123	89	99	86	124	91	101	89	127	92	103
	IT	21	50	13	27	21	48	12	26	20	48	11	26	20	47	11	26	20	49	12	27
St-Amands - Schoonaarde	CH	84	116	84	93	84	116	86	96	85	116	89	98	86	115	92	102	88	118	92	102
	IT	21	43	06	15	20	42	06	14	20	41	06	14	22	45	06	15	23	46	06	15
Schoonaarde-Melle	CH	83	102	63	71	86	103	65	73	87	102	68	76	87	101	70	79	89	103	71	78
	IT	15	28	04	12	14	26	04	11	15	25	04	12	16	27	04	13	16	27	04	14

CH: channel area (underneath the low water level); IT: intertidal area (above the low water level)

VEL AVER: average velocity; VEL MAX: maximum velocity

Table A-8. Comparison of the magnitude of high and low waters for the scenarios with polders to the reference run
(NV = water level could not be determined based on the used algorithm)

Station	**Difference (run - reference run)**											
	high water (cm)						**low water (cm)**					
	Braakman polder	New - Westland polder	Braakman + New - Westland polders	Tielrodebroek	Groot Schoor of St-Amands	4 polders together	Braakman polder	New - Westland polder	Braakman + New - Westland polders	Tielrodebroek	Groot Schoor of St-Amands	4 polders together
Western Scheldt												
Vlissingen	-3	0	-3	0	0	-3	0	0	0	0	0	0
Terneuzen	-4	0	-4	0	0	-4	0	0	0	0	0	1
Hansweert	-2	-3	-6	0	0	-6	0	0	0	0	0	1
Baalhoek	-3	-5	-7	0	0	-7	0	0	0	0	0	1
Schaar van de Noord	-4	-4	-7	0	0	-7	0	0	0	0	0	1
Bath	-4	-3	-6	0	0	-7	0	0	0	0	0	1
Lower Sea Scheldt												
Liefkenshoek	-4	-3	-7	0	0	-7	0	0	0	0	1	1
Antwerp	-4	-2	-6	-1	-1	-8	0	0	0	0	1	2
Hemiksem	-3	-2	-5	-5	-2	-11	0	1	0	0	1	2
Upper Sea Scheldt												
Temse	-3	-2	-6	-3	-3	-11	0	1	1	1	1	3
Dendermonde	-2	-1	-4	-2	-2	-7	1	1	2	1	2	5
Schoonaarde	-1	-1	-2	-1	-2	-5	2	1	3	1	1	5
Wetteren	0	0	0	0	-2	-2	2	1	3	1	1	5
Melle	1	1	2	1	-2	1	1	1	2	1	1	4
Durme												
Waasmunster	-4	-3	-7	-3	-3	-13	NV	NV	NV	NV	NV	NV
Rupel												

Station	Difference (run - reference run)											
	high water (cm)						low water (cm)					
	Braakman polder	New - Westland polder	Braakman + New - Westland polders	Tielrodebroek	Groot Schoor of St-Amands	4 polders together	Braakman polder	New - Westland polder	Braakman + New - Westland polders	Tielrodebroek	Groot Schoor of St-Amands	4 polders together
Boom	-3	-2	-5	-5	-2	-11	0	1	1	0	1	3
Walem	-3	-3	-6	-5	-2	-12	0	1	1	0	1	2
Mechelen	-3	-5	-7	-4	-2	-13	NV	NV	NV	NV	NV	NV
Hombeek	-4	-4	-7	-6	-2	-15	NV	NV	NV	NV	NV	NV
Nete												
Duffel	-3	-3	-6	-5	-2	-12	1	1	2	0	0	2
Kessel	0	0	-1	-2	-1	-3	NV	NV	NV	NV	NV	NV
Emblem	-1	-1	-2	-3	-2	-6	NV	NV	NV	NV	NV	NV

Table A-9. Comparison of the tidal amplitude for the scenarios with polders to the reference run (NV = water level could not be determined based on the used algorithm)

Station	**Difference (run - reference run)**					
	tidal amplitude (cm)					
	Braakman polder	New - Westland polder	Braakman + New - Westland polders	Tielrodebroek	Groot Schoor of St-Amands	4 polders together
Western Scheldt						
Vlissingen	-3	0	-3	0	0	-3
Terneuzen	-4	0	-5	0	0	-5
Hansweert	-2	-3	-6	0	0	-6
Baalhoek	-3	-5	-7	-1	0	-8
Schaar van de Noord	-4	-4	-7	0	0	-8
Bath	-4	-3	-7	0	0	-7
Lower Sea Scheldt						
Liefkenshoek	-4	-3	-7	0	-1	-8
Antwerp	-4	-3	-6	-1	-2	-10
Hemiksem	-3	-2	-5	-5	-3	-13
Upper Sea Scheldt						
Temse	-3	-3	-6	-4	-4	-14
Dendermonde	-4	-2	-6	-3	-3	-13
Schoonaarde	-3	-2	-5	-3	-3	-10
Wetteren	-2	-1	-3	-2	-3	-7
Melle	0	0	-1	0	-3	-4
Durme						
Waasmunster	NV	NV	NV	NV	NV	NV
Rupel						
Boom	-3	-3	-7	-5	-3	-14
Walem	-4	-4	-7	-5	-3	-14
Mechelen	NV	NV	NV	NV	NV	NV
Hombeek	NV	NV	NV	NV	NV	NV
Nete						
Duffel	-4	-3	-8	-5	-2	-14
Kessel	NV	NV	NV	NV	NV	NV
Emblem	NV	NV	NV	NV	NV	NV

Table A-10. Comparison of the phase of high and low waters for the scenarios with polders to the reference run (NV = water level could not be determined based on the used algorithm)

Station	**Difference (run - reference run)**											
	phase of high water (min)						**phase of low water (min)**					
	Braakman polder	New - Westland polder	Braakman + New - Westland polders	Tielrodebroek	Groot Schoor of St-Amands	4 polders together	Braakman polder	New - Westland polder	Braakman + New - Westland polders	Tielrodebroek	Groot Schoor of St-Amands	4 polders together
Western Scheldt												
Vlissingen	0	1	-1	1	0	0	1	0	0	0	0	0
Terneuzen	4	-1	5	0	-1	4	1	0	1	0	0	2
Hansweert	5	-2	3	0	1	3	0	0	1	0	0	1
Baalhoek	5	2	7	0	1	8	1	1	1	1	0	1
Schaar van de Noord	4	4	7	0	0	7	0	1	1	1	0	1
Bath	3	3	7	0	0	8	0	0	1	0	0	1
Lower Sea Scheldt												
Liefkenshoek	3	4	7	0	1	7	0	0	1	0	0	1
Antwerp	2	4	7	-1	0	5	1	1	1	0	0	2
Hemiksem	2	3	7	1	1	9	1	1	2	0	0	3
Upper Sea Scheldt												
Temse	3	3	6	4	1	10	1	1	2	0	1	4
Dendermonde	1	2	4	1	2	10	1	1	1	0	0	3
Schoonaarde	2	2	5	2	2	11	1	1	2	0	1	3
Wetteren	4	4	6	4	3	12	0	1	1	0	0	3
Melle	3	2	5	4	3	11	1	1	1	1	2	4
Durme												
Waasmunster	1	3	4	NV	NV	NV	NV	NV	NV	NV	NV	NV
Rupel												

Station	Difference (run - reference run)											
	phase of high water (min)						phase of low water (min)					
	Braakman polder	New - Westland polder	Braakman + New - Westland polders	Tielrodebroek	Groot Schoor of St-Amands	4 polders together	Braakman polder	New - Westland polder	Braakman + New - Westland polders	Tielrodebroek	Groot Schoor of St-Amands	4 polders together
Boom	1	2	5	1	-1	7	1	1	1	0	0	2
Walem	1	2	6	1	0	8	1	2	2	0	1	3
Mechelen	2	3	5	NV	NV	NV	NV	NV	NV	NV	NV	NV
Hombeek	1	1	2	NV	NV	NV	NV	NV	NV	NV	NV	NV
Nete												
Duffel	1	3	6	1	0	7	1	1	1	0	0	2
Kessel	3	3	5	NV	NV	NV	NV	NV	NV	NV	NV	NV
Emblem	3	3	6	NV	NV	NV	NV	NV	NV	NV	NV	NV

Table A-11. Flood and ebb volumes (spring tide) for the scenarios with Braakman respectively New-Westland polder

Station	**reference run**		**Braakman polder**		**New - Westland polder**	
	spring flood V (m³)	*spring ebb V (m³)*	*spring flood V (m³)*	*spring ebb V (m³)*	*spring flood V (m³)*	*spring ebb V (m³)*
Hoofdplaat	1.02E+09	1.02E+09	1.06E+09	1.06E+09	1.02E+09	1.02E+09
Terneuzen	7.96E+08	7.97E+08	7.91E+08	7.93E+08	7.97E+08	7.98E+08
Gat van Ossenisse	6.01E+08	5.98E+08	5.95E+08	5.94E+08	6.05E+08	6.03E+08
Overloop Valkenisse	2.99E+08	2.95E+08	2.96E+08	2.93E+08	3.10E+08	3.06E+08
Bath	2.12E+08	2.10E+08	2.10E+08	2.09E+08	2.15E+08	2.14E+08
Zandvliet	1.78E+08	1.76E+08	1.76E+08	1.75E+08	1.77E+08	1.75E+08
Antwerp	8.98E+07	8.93E+07	8.87E+07	8.88E+07	8.90E+07	8.90E+07
Temse	3.12E+07	3.06E+07	3.07E+07	3.03E+07	3.09E+07	3.04E+07
Dendermonde	8.73E+06	8.93E+06	8.64E+06	8.91E+06	8.68E+06	8.90E+06
Wetteren	2.59E+06	3.10E+06	2.57E+06	3.10E+06	2.58E+06	3.10E+06

Table A-12. Difference in flood and ebb volumes for the scenarios with Braakman respectively New-Westland polder compared to reference run

Station	**Difference in volumes (run - reference run) (m³)**				**Difference in volumes (% of the reference volume)**			
	Braakman polder		**New – Westland polder**		**Braakman polder**		**New - Westland polder**	
	spring flood	*spring ebb*	*spring flood*	*spring ebb*	*spring flood*	*spring ebb*	*spring flood*	*spring ebb*
Hoofdplaat	3.96E+07	4.13E+07	-1.26E+05	-6.06E+05	3.88	4.05	-0.01	-0.06
Terneuzen	-5.49E+06	-4.00E+06	9.69E+05	1.40E+06	-0.69	-0.50	0.12	0.18
Gat van Ossenisse	-5.34E+06	-3.92E+06	3.97E+06	5.35E+06	-0.89	-0.66	0.66	0.90
Overloop Valkenisse	-3.22E+06	-2.20E+06	1.12E+07	1.07E+07	-1.08	-0.75	3.74	3.62
Bath	-2.01E+06	-1.32E+06	2.97E+06	3.88E+06	-0.95	-0.63	1.40	1.85
Zandvliet	-1.54E+06	-9.74E+05	-1.12E+06	-7.00E+05	-0.86	-0.55	-0.63	-0.40
Antwerp	-1.09E+06	-4.82E+05	-7.31E+05	-2.86E+05	-1.21	-0.54	-0.81	-0.32
Temse	-5.34E+05	-2.98E+05	-3.39E+05	-2.09E+05	-1.71	-0.98	-1.09	-0.68
Dendermonde	-9.37E+04	-1.79E+04	-5.16E+04	-2.62E+04	-1.07	-0.20	-0.59	-0.29
Wetteren	-2.83E+04	-6.50E+02	-1.56E+04	2.68E+03	-1.09	-0.02	-0.60	0.09

Table A-13. Flood and ebb volumes (spring tide) for the scenarios
with Tielrodebroek respectively Groot Schoor of Sint-Amands

Station	**reference run**		**Tielrodebroek**		**Groot Schoor of Sint- Amands**	
	spring flood V (m³)	*spring ebb V (m³)*	*spring flood V (m³)*	*spring ebb V (m³)*	*spring flood V (m³)*	*spring ebb V (m³)*
Gat van Ossenisse	6.01E+08	5.98E+08	6.00E+08	5.97E+08	6.00E+08	5.97E+08
Overloop Valkenisse	2.99E+08	2.95E+08	2.99E+08	2.95E+08	2.98E+08	2.95E+08
Bath	2.12E+08	2.10E+08	2.11E+08	2.10E+08	2.12E+08	2.09E+08
Zandvliet	1.78E+08	1.76E+08	1.78E+08	1.76E+08	1.78E+08	1.76E+08
Antwerp	8.98E+07	8.93E+07	9.06E+07	9.00E+07	9.01E+07	8.94E+07
Schelle	6.27E+07	6.26E+07	6.39E+07	6.38E+07	6.32E+07	6.31E+07
Temse	3.12E+07	3.06E+07	3.26E+07	3.21E+07	3.20E+07	3.14E+07
Tielrode	2.68E+07	2.63E+07	2.82E+07	2.62E+07	2.77E+07	2.72E+07
Sint-Amands	1.55E+07	1.54E+07	1.53E+07	1.53E+07	1.65E+07	1.64E+07
Dendermonde	8.73E+06	8.93E+06	8.65E+06	8.87E+06	8.62E+06	8.81E+06
Wetteren	2.59E+06	3.10E+06	2.57E+06	3.09E+06	2.56E+06	3.08E+06

Table A-14. Difference in flood and ebb volumes for the scenarios with Tielrodebroek respectively Groot Schoor compared with reference run

Station	**Difference in volumes (run - reference run) (m^3)**				**Difference in volumes (% of the reference volume)**			
	Tielrodebroek		**Groot Schoor of Sint- Amands**		**Tielrodebroek**		**Groot Schoor of Sint-Amands**	
	spring flood	*spring ebb*	*spring flood*	*spring ebb*	*spring flood*	*spring ebb*	*spring flood*	*spring ebb*
Gat van Ossenisse	-9.47E+05	-8.09E+05	-1.06E+06	-9.14E+05	-0.16	-0.14	-0.18	-0.15
Overloop Valkenisse	-1.81E+05	-4.05E+05	-4.24E+05	-7.10E+05	-0.06	-0.14	-0.14	-0.24
Bath	-4.33E+05	-3.54E+05	-2.60E+05	-4.76E+05	-0.20	-0.17	-0.12	-0.23
Zandvliet	-9.43E+04	-1.81E+05	-1.26E+05	-2.91E+05	-0.05	-0.10	-0.07	-0.17
Antwerp	8.34E+05	7.22E+05	3.59E+05	1.45E+05	0.93	0.81	0.40	0.16
Schelle	1.17E+06	1.16E+06	5.40E+05	5.24E+05	1.86	1.85	0.86	0.84
Temse	1.45E+06	1.48E+06	7.75E+05	8.36E+05	4.63	4.83	2.49	2.73
Tielrode	1.42E+06	-8.07E+04	9.54E+05	9.07E+05	5.30	-0.31	3.56	3.45
Sint-Amands	-1.72E+05	-1.15E+05	1.06E+06	9.73E+05	-1.11	-0.75	6.86	6.31
Dendermonde	-7.66E+04	-5.58E+04	-1.13E+05	-1.20E+05	-0.88	-0.63	-1.29	-1.34
Wetteren	-2.42E+04	-1.06E+04	-3.00E+04	-2.20E+04	-0.93	-0.34	-1.16	-0.71

Table A-15. The influence area of the different polders

Distance from the polder (km)		Effect of the polder on the water level							
		high water (cm)				low water (cm)			
		Braakman polder	New - Westland polder	Tielrodebroek	Groot Schoor of St-Amands	Braakman polder	New - Westland polder	Tielrodebroek	Groot Schoor of St-Amands
Distnace downstream the polder	-100			0	0			0	0
	-90			0	0			0	0
	-80			0	0			0	0
	-70			0	0			0	0
	-60			0	0			0	0
	-50		0	0	-3		0	0	1
	-40		0	0	1		0	0	1
	-30		-1	0	-1		0	0	1
	-20		-2	-1	-2		0	0	1
	-10	-3	-5	-5	-2	0	0	1	1
polder	0	-4	-3	-3	-2	0	0	1	1
Distance upstream the polder	10	-3	-3	-3	-3	0	0	1	2
	20	-2	-3	-2	-2	0	0	1	1
	30	-4	-2	-1	-2	0	1	1	1
	40	-4	-2	-1	-2	0	1	1	1
	50	-4	-2	1		0	1	1	
	60	-4	-2			0	1		
	70	-4	-1			0	1		
	80	-3	-1			0	1		
	90	-3	0			1	1		
	100	-2	1			1	1		
	110	-2				1			
	120	-1				2			
	130	1				2			

Table A-16.Volumes and areas in the Scheldt estuary of disposed material (July 1997 - July 1998)

Disposal location	**Disposed V from report (*Dam and Van Prooijen*, 2006) (m³)**	**Percentage of total disposed V (%)**	**Calculated disposed V (m³)**	**Area (m²)**	**Intensity of disposed material (m³/m²)**
Schaar van Spijkerplaat	2.39E+06	11.7	1.87E+06	1.39E+06	1.35
Vloedschaar Everingen	1.92E+06	9.4	1.50E+06	1.70E+06	0.88
Ellewoutsdijk	6.34E+06	30.9	4.95E+06	9.26E+05	5.34
Ebschaar Everingen	2.09E+05	1.0	1.63E+05	1.02E+06	0.16
G.v.Ossenisse afw B31	1.24E+06	6.1	9.68E+05	5.62E+05	1.72
G.v.Ossenisse afw B39	1.55E+06	7.6	1.21E+06	1.03E+06	1.18
Biezelingsche Ham	2.67E+06	13.0	2.08E+06	6.92E+05	3.01
Plaat van Ossenisse	3.81E+05	1.9	2.97E+05	6.53E+05	0.46
Schaar van Waarde	7.99E+05	3.9	6.24E+05	4.11E+06	0.15
Schaar Ouden Doel	2.96E+06	14.4	2.31E+06	9.57E+05	2.41
Plaat van Boomke	3.59E+04	0.2	2.80E+04		
TOTAL	2.05E+07	100	1.60E+07		

Table A-17.Volumes of dredged material (July 1997 - July 1998)

Dredging location	**Depth before deepening campaign**	**Target depth in 1998 (m GLLWS)**	**Dredged V (m³)**
Drempel van Vlissingen	-15.5	-16.80	1.25E+05
Drempel van Borssele	-14.8	-16.30	1.85E+06
Pas van Terneuzen	-14.8	-16.30	1.51E+06
Put van Terneuzen	-14.8	-16.30	9.08E+05
Plaat van Ossenisse	-14.6	-15.90	1.34E+06
Overloop van Hansweert	-14.4	-15.90	6.11E+05
Drempel van Hansweert	-14.4	-15.90	2.89E+06
Plaat van Walsoorden	-14.4	-15.90	
Drempel van Valkenisse	-14.4	-16.00	1.89E+06
Plaat van Valkenisse	-14.4	-16.00	
Overloop van Valkenisse	-14.4	-16.00	
Drempel van Bath	-14.4	-16.00	1.15E+06
Drempel Zandvliet - Europaterminal	-14.4	-16.10	1.22E+06
Drempel Frederick	-14.4	-15.80	2.08E+06
TOTAL			1.56E+07

Table A-18. Comparison of water levels for the scenarios with enlargement of navigation channel to the reference run
(NV = water level could not be determined based on the used algorithm)

Station	**Difference (run – reference run)**									
	high water (cm)		**low water (cm)**		**tidal amplitude (cm)**		**phase of high water (min)**		**phase of low water (min)**	
	without disposal	*with disposal*	*without disposal*	*with disposal*	*without disposal*	*with disposal*	*without disposal*	*with disposal*	*without disposal*	*with disposal*
Western Scheldt										
Vlissingen	-0.2	-0.1	-0.1	0.1	-0.1	-0.2	0	-1	0	0
Terneuzen	0.0	-0.9	-0.2	0.4	0.2	-1.3	1	1	0	1
Hansweert	0.5	-0.5	-0.5	0.3	1.1	-0.8	0	1	-1	1
Baalhoek	0.7	-0.5	-0.8	0.0	1.5	-0.5	-1	0	-1	1
Schaar van de Noord	0.8	-0.4	-1.2	-0.3	2.0	-0.1	-1	1	-1	1
Bath	0.9	-0.4	-1.5	-0.5	2.3	0.1	1	0	0	0
Lower Sea Scheldt										
Liefkenshoek	2.0	-0.5	-2.1	-1.0	4.1	0.5	0	0	-2	0
Antwerp	1.2	-0.6	-1.9	-1.0	3.2	0.4	-2	-1	-2	0
Hemiksem	1.1	-0.6	-1.8	-1.0	2.9	0.4	-1	0	-1	0
Upper Sea Scheldt										
Temse	1.1	-0.5	-1.6	-0.9	2.7	0.3	-1	-1	-2	0
Dendermonde	1.1	-0.6	-0.1	-0.3	1.2	-0.3	-1	0	-1	0
Schoonaarde	1.0	-0.5	0.1	-0.3	0.9	-0.2	-1	0	-1	0
Wetteren	1.0	-0.4	0.2	-0.2	0.8	-0.2	-1	0	-2	-1
Melle	1.0	-0.5	0.3	-0.2	0.6	-0.3	-1	0	-2	0
Durme										
Waasmunster	1.0	-0.7	NV	NV	NV	NV	0	0	NV	NV
Rupel										
Boom	1.0	-0.6	-1.6	-0.9	2.6	0.3	-2	0	-1	0
Walem	1.2	-0.5	-1.1	-0.7	2.2	0.2	0	0	-1	0
Mechelen	1.3	-0.5	NV	NV	NV	NV	-1	-1	NV	NV
Hombeek	0.9	-0.5	NV	NV	NV	NV	-1	-1	NV	NV
Nete										
Duffel	1.1	-0.5	0.0	-0.3	1.1	-0.3	-1	-1	-1	0
Kessel	1.4	-0.2	NV	NV	NV	NV	-1	1	NV	NV
Emblem	0.9	-0.4	NV	NV	NV	NV	0	0	NV	NV

Table A-19. Flood and ebb volumes (spring tide) for the scenarios with enlargement of navigation channel

Station	**reference run with bathymetry for 1990, 1995**		**enlargement without disposal**		**enlargement with disposal**	
	V_{flood} (m³)	V_{ebb} (m³)	V_{flood} (m³)	V_{ebb} (m³)	V_{flood} (m³)	V_{ebb} (m³)
Hoofdplaat	9.84E+08	9.82E+08	9.88E+08	9.87E+08	9.82E+08	9.81E+08
Terneuzen	7.67E+08	7.63E+08	7.71E+08	7.68E+08	7.66E+08	7.63E+08
Gat van Ossenisse	5.76E+08	5.71E+08	5.80E+08	5.75E+08	5.76E+08	5.71E+08
Bath	2.05E+08	2.03E+08	2.07E+08	2.04E+08	2.05E+08	2.03E+08
Antwerp	8.93E+07	8.84E+07	8.99E+07	8.89E+07	8.92E+07	8.84E+07
Temse	3.02E+07	2.94E+07	3.03E+07	2.95E+07	3.02E+07	2.94E+07
Dendermonde	8.56E+06	8.66E+06	8.57E+06	8.71E+06	8.57E+06	8.65E+06
Wetteren	2.51E+06	3.00E+06	2.52E+06	3.02E+06	2.51E+06	3.01E+06

Table A-20. Flood volumes through the ebb and flood channel for the scenarios with enlargement of the navigation channel

Cross section	Station	reference run with bathymetry before enlargement (1990-1995)			enlargement without disposal			enlargement with disposal		
		spring flood V (m³)		% of total V through cross section	spring flood V (m³)		% of total V through cross section	spring flood V (m³)		% of total V through cross section
1	Honte	8.60E+08	9.87E+08	87.1	8.63E+08	9.91E+08	87.2	8.57E+08	9.85E+08	87.1
	Vaarwater Hoofdplaat	1.27E+08		12.9	1.27E+08		12.8	1.27E+08		12.9
2	Everingen	4.94E+08	7.69E+08	64.3	4.95E+08	7.72E+08	64.1	4.83E+08	7.68E+08	62.9
	Terneuzen	2.75E+08		35.7	2.78E+08		35.9	2.85E+08		37.1
3	Middelgat	2.36E+08	5.77E+08	40.8	2.34E+08	5.81E+08	40.4	2.34E+08	5.77E+08	40.5
	Gat van Ossenisse	3.42E+08		59.2	3.46E+08		59.6	3.43E+08		59.5
4	Schaar van Waarde	1.85E+08	3.89E+08	47.5	1.84E+08	3.91E+08	47.0	1.83E+08	3.88E+08	47.0
	Zuidergat	2.04E+08		52.5	2.07E+08		53.0	2.06E+08		53.0

Table A-21. Ebb volumes through the ebb and flood channel for the scenarios with enlargement of the navigation channel

Cross section	Station	reference run with bathymetry for 1990, 1995			enlargement without disposal			enlargement with disposal		
		spring ebb V (m³)		% of total V through cross section	spring ebb V (m³)		% of total V through cross section	spring ebb V (m³)		% of total V through cross section
1	Honte	8.71E+08	9.86E+08	88.4	8.76E+08	9.91E+08	88.4	8.69E+08	9.84E+08	88.3
	Vaarwater Hoofdplaat	1.15E+08		11.6	1.15E+08		11.6	1.15E+08		11.7
2	Everingen	4.27E+08	7.65E+08	55.8	4.27E+08	7.69E+08	55.5	4.19E+08	7.64E+08	54.8
	Terneuzen	3.38E+08		44.2	3.42E+08		44.5	3.46E+08		45.2
3	Middelgat	2.59E+08	5.72E+08	45.2	2.58E+08	5.76E+08	44.8	2.56E+08	5.72E+08	44.7
	Gat van Ossenisse	3.14E+08		54.8	3.18E+08		55.2	3.16E+08		55.3
4	Schaar van Waarde	1.41E+08	3.81E+08	37.0	1.41E+08	3.84E+08	36.8	1.40E+08	3.81E+08	36.8
	Zuidergat	2.40E+08		63.0	2.42E+08		63.2	2.41E+08		63.2

Table A-22. Mean values of the average and maximal velocity (cm/s) for the scenarios with enlargement and reference scenario.

Area		**1995 (reference for scenarios with enlargement)**				**enlargement without disposal**				**enlargement with disposal**			
		spring flood		**spring ebb**		**spring flood**		**spring ebb**		**spring flood**		**spring ebb**	
		VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX	VEL AVER	VEL MAX
Bath - Hemiksem	CH	73	104	68	83	72	103	68	82	73	104	67	82
	IT	13	32	07	17	13	32	07	17	13	32	07	17
Hemiksem – St-Amands	CH	84	120	83	91	84	120	83	92	84	120	83	91
	IT	20	47	13	27	20	47	13	27	19	47	13	27
St-Amands - Schoonaarde	CH	84	115	83	91	84	115	83	92	84	114	83	91
	IT	18	39	06	14	19	39	06	14	18	39	06	14
Schoonaarde-Melle	CH	84	102	64	71	85	102	64	72	84	102	64	71
	IT	13	23	04	11	13	24	04	11	13	23	04	11

CH: channel area (underneath the low water level); IT: intertidal area (above the low water level)

VEL AVER: average velocity; VEL MAX: maximum velocity

Table A-23. Comparison of the water levels for the years 2006, 1999 and 1995
(NV = water level could not be determined based on the used algorithm)

Station	**Difference (run - run for the year 1995)**									
	high water (cm)		**low water (cm)**		**tidal amplitude (cm)**		**phase of high water (min)**		**phase of low water (min)**	
	year 2006	*year 1999*	*year 2006*	*year 1999*	*year 2006*	*year 1999*	*year 2006*	*year 1999*	*year 2006*	*year 1999*
Western Scheldt										
Vlissingen	0	0	0	0	0	0	-2	-1	0	0
Terneuzen	0	0	-1	0	1	0	1	0	2	1
Hansweert	4	1	-3	-1	7	2	2	2	3	1
Baalhoek	4	2	-8	-4	12	6	-1	-1	0	-1
Schaar van de Noord	5	2	-9	-5	14	7	-2	0	-4	-2
Bath	6	3	-10	-5	16	8	-2	0	-4	-3
Lower Sea Scheldt										
Liefkenshoek	9	6	-12	-7	21	13	-6	-2	-8	-6
Antwerp	9	5	-14	-5	23	10	-9	-5	-11	-13
Hemiksem	9	4	-15	-9	23	13	-9	-4	-13	-10
Upper Sea Scheldt										
Temse	9	5	-14	-9	23	14	-8	-4	-14	-11
Dendermonde	8	5	-2	0	10	5	-9	-5	-12	-9
Schoonaarde	8	5	2	2	7	3	-6	-3	-12	-9
Wetteren	8	5	3	3	5	3	-7	-3	-11	-8
Melle	8	6	3	3	5	3	-7	-3	-11	-8
Durme										
Waasmunster	9	4	NV	NV	NV	NV	-8	-4	NV	NV
Rupel										
Boom	9	5	-13	-8	22	13	-8	-6	-12	-9
Walem	9	5	-9	-6	19	11	-8	-5	-11	-8
Mechelen	9	5	NV	NV	NV	NV	-7	-3	NV	NV
Hombeek	9	4	NV	NV	NV	NV	-10	-7	NV	NV
Nete										
Duffel	9	5	1	1	8	4	-9	-6	-9	-7
Kessel	8	5	NV	NV	NV	NV	-8	-5	NV	NV
Emblem	8	5	NV	NV	NV	NV	-9	-4	NV	NV

Table A-24. Comparison of the changes per year in magnitude of water levels for the years 2006, 1999 and 1995
(NV = water level could not be determined based on the used algorithm)

Station	Difference (run - run for the year 1995) per 1 year								
	high water (cm)			low water (cm)			tidal amplitude (cm)		
	year 2006	year 1999	effect of enlargement with disposal	year 2006	year 1999	effect of enlargement with disposal	year 2006	year 1999	effect of enlargement with disposal
Western Scheldt									
Vlissingen	0.0	0.0	-0.1	0.0	0.0	0.1	0.0	0.0	-0.2
Terneuzen	0.0	-0.1	-0.9	-0.1	0.0	0.4	0.1	-0.1	-1.3
Hansweert	0.3	0.3	-0.5	-0.3	-0.2	0.3	0.6	0.5	-0.8
Baalhoek	0.4	0.5	-0.5	-0.7	-1.0	0.0	1.1	1.6	-0.5
Schaar van de Noord	0.5	0.5	-0.4	-0.8	-1.2	-0.3	1.3	1.7	-0.1
Bath	0.5	0.8	-0.4	-0.9	-1.3	-0.5	1.4	2.1	0.1
Lower Sea Scheldt									
Liefkenshoek	0.8	1.4	-0.5	-1.1	-1.8	-1.0	1.9	3.2	0.5
Antwerp	0.8	1.4	-0.6	-1.3	-1.3	-1.0	2.1	2.6	0.4
Hemiksem	0.8	1.0	-0.6	-1.3	-2.3	-1.0	2.1	3.3	0.4
Upper Sea Scheldt									
Temse	0.8	1.2	-0.5	-1.3	-2.2	-0.9	2.1	3.4	0.3
Dendermonde	0.8	1.2	-0.6	0.2	0.0	-0.3	0.9	1.2	-0.3
Schoonaarde	0.8	1.3	-0.5	0.2	0.5	-0.3	0.6	0.8	-0.2
Wetteren	0.7	1.4	-0.4	0.2	0.7	-0.2	0.5	0.7	-0.2
Melle	0.7	1.5	-0.5	0.3	0.7	-0.2	0.5	0.8	-0.3
Durme									
Waasmunster	0.8	1.1	-0.7	NV	NV	NV	NV	NV	NV
Rupel									
Boom	0.8	1.2	-0.6	-1.2	-2.1	-0.9	2.0	3.3	0.3
Walem	0.8	1.3	-0.5	-0.8	-1.5	-0.7	1.7	2.7	0.2
Mechelen	0.8	1.3	-0.5	NV	NV	NV	NV	NV	NV
Hombeek	0.8	0.9	-0.5	NV	NV	NV	NV	NV	NV
Nete									

Station	Difference (run - run for the year 1995) per 1 year								
	high water (cm)			low water (cm)			tidal amplitude (cm)		
	year 2006	year 1999	effect of enlargement with disposal	year 2006	year 1999	effect of enlargement with disposal	year 2006	year 1999	effect of enlargement with disposal
Duffel	0.8	1.2	-0.5	0.1	0.3	-0.3	0.8	0.9	-0.3
Kessel	0.7	1.3	-0.2	NV	NV	NV	NV	NV	NV
Emblem	0.7	1.2	-0.4	NV	NV	NV	NV	NV	NV

Table A-25. Comparison of the changes per year in phase of water levels for the years 2006, 1999 and 1995 (NV = water level could not be determined based on the used algorithm)

Station	**Difference (run - run for the year 1995) per 1 year**					
	phase of high water (min)			**phase of low water (min)**		
	year 2006	year 1999	effect of only enlargement with disposal	year 2006	year 1999	effect of only enlargement with disposal
Western Scheldt						
Vlissingen	0	0	-1	0	0	0
Terneuzen	0	0	1	0	0	1
Hansweert	0	1	1	0	0	1
Baalhoek	0	0	0	0	0	1
Schaar van de Noord	0	0	1	0	-1	1
Bath	0	0	0	0	-1	0
Lower Sea Scheldt						
Liefkenshoek	-1	-1	0	-1	-2	0
Antwerp	-1	-1	-1	-1	-3	0
Hemiksem	-1	-1	0	-1	-3	0
Upper Sea Scheldt						
Temse	-1	-1	-1	-1	-3	0
Dendermonde	-1	-1	0	-1	-2	0
Schoonaarde	-1	-1	0	-1	-2	0
Wetteren	-1	-1	0	-1	-2	-1
Melle	-1	-1	0	-1	-2	0
Durme						
Waasmunster	-1	-1	0	NV	NV	NV
Rupel						
Boom	-1	-1	0	-1	-2	0
Walem	-1	-1	0	-1	-2	0
Mechelen	-1	-1	-1	NV	NV	NV
Hombeek	-1	-2	-1	NV	NV	NV
Nete						
Duffel	-1	-1	-1	-1	-2	0
Kessel	-1	-1	1	NV	NV	NV
Emblem	-1	-1	0	NV	NV	NV

Table A-26. Volumes of dredged and disposed material for the scenarios with changes at the Gat van Ossenisse - Middelgat

Scenario	**Dredged V (m^3)**	**Disposed V (m^3)**
1	1.23E+06	1.24E+06
2	7.93E+06	8.00E+06
3	3.90E+06	3.95E+06
4	3.90E+06	0.00E+00

Table A-27. Comparison of the low and high waters for the scenarios with changes at the Gat van Ossenisse - Middelgat to the reference run (NV = water level could not be determined based on the used algorithm)

Station	Difference (run - reference run)											
	high water (cm)				**low water (cm)**				**tidal amplitude (cm)**			
	scenario 1	*scenario 2*	*scenario 3*	*scenario 4*	*scenario 1*	*scenario 2*	*scenario 3*	*scenario 4*	*scenario 1*	*scenario 2*	*scenario 3*	*scenario 4*
Western Scheldt												
Vlissingen	0.0	0.0	0.1	-0.1	0.0	0.1	0.1	0.0	0.0	-0.1	0.0	-0.1
Terneuzen	0.0	-0.1	-0.1	0.0	0.1	0.4	0.7	-0.1	-0.1	-0.5	-0.8	0.1
Hansweert	-0.2	-0.6	-0.8	0.2	0.1	0.4	0.7	-0.5	-0.3	-1.0	-1.5	0.7
Schaar van de Noord	-0.2	-0.6	-0.7	0.2	0.0	0.3	0.6	-0.4	-0.2	-0.9	-1.2	0.6
Bath	-0.2	-0.6	-0.6	0.3	0.0	0.3	0.5	-0.3	-0.2	-0.9	-1.1	0.6
Lower Sea Scheldt												
Liefkenshoek	-0.1	-0.5	-0.6	0.3	0.0	0.3	0.5	-0.3	-0.2	-0.7	-1.0	0.6
Antwerp	-0.2	-0.5	-0.5	0.3	0.0	0.3	0.5	-0.3	-0.2	-0.8	-1.0	0.6
Hemiksem	-0.1	-0.4	-0.6	0.2	0.1	0.2	0.4	-0.3	-0.2	-0.7	-1.0	0.5
Upper Sea Scheldt												
Temse	-0.1	-0.5	-0.7	0.3	0.0	0.2	0.4	-0.3	-0.2	-0.7	-1.1	0.6
Dendermonde	0.0	-0.4	-0.4	0.3	0.0	0.0	0.0	-0.1	0.0	-0.4	-0.4	0.4
Schoonaarde	0.0	-0.4	-0.5	0.3	0.0	-0.1	-0.2	0.0	0.0	-0.3	-0.3	0.2
Wetteren	-0.1	-0.4	-0.6	0.2	0.0	-0.2	-0.2	0.1	-0.1	-0.2	-0.4	0.1
Melle	0.0	-0.4	-0.5	0.4	0.0	-0.1	-0.2	0.1	0.0	-0.3	-0.3	0.2
Durme												
Waasmunster	-0.3	-0.6	-0.7	0.2	NV	NV	NV	NV	NV	NV	NV	NV
Rupel												
Boom	-0.2	-0.5	-0.6	0.2	0.0	0.2	0.4	-0.3	-0.2	-0.6	-1.0	0.5
Walem	-0.2	-0.6	-0.6	0.2	0.0	0.2	0.3	-0.2	-0.2	-0.7	-0.9	0.4
Mechelen	-0.2	-0.4	-0.5	0.3	NV	NV	NV	NV	NV	NV	NV	NV
Hombeek	-0.2	-0.5	-0.8	0.3	NV	NV	NV	NV	NV	NV	NV	NV
Nete												

Station	**Difference (run - reference run)**											
	high water (cm)				**low water (cm)**				**tidal amplitude (cm)**			
	scenario 1	*scenario 2*	*scenario 3*	*scenario 4*	*scenario 1*	*scenario 2*	*scenario 3*	*scenario 4*	*scenario 1*	*scenario 2*	*scenario 3*	*scenario 4*
Duffel	-0.2	-0.5	-0.7	0.2	0.0	-0.1	-0.1	0.0	-0.1	-0.4	-0.6	0.2
Kessel	0.1	-0.4	-0.3	0.0	NV	NV	NV	NV	NV	NV	NV	NV
Emblem	-0.1	-0.4	-0.4	0.2	NV	NV	NV	NV	NV	NV	NV	NV

Table A-28. Comparison of the phase of low and high waters for the scenarios with changes at the Gat van Ossenisse - Middelgat to the reference run (NV = water level could not be determined based on the used algorithm)

Station	**Difference (run - reference run)**							
	phase of high water (min)				**phase of low water (min)**			
	scenario 1	*scenario 2*	*scenario 3*	*scenario 4*	*scenario 1*	*scenario 2*	*scenario 3*	*scenario 4*
Western Scheldt								
Vlissingen	0	1	0	0	0	0	0	0
Terneuzen	1	0	0	1	0	1	0	0
Hansweert	0	0	0	0	0	1	1	-1
Schaar van de Noord	0	0	0	0	0	0	1	0
Bath	0	1	0	-1	0	0	1	0
Lower Sea Scheldt								
Liefkenshoek	0	0	1	-1	0	0	0	0
Antwerp	0	0	1	0	0	0	0	0
Hemiksem	0	0	0	0	0	0	0	0
Upper Sea Scheldt								
Temse	1	1	2	0	0	1	1	0
Dendermonde	-1	1	0	-1	0	1	0	0
Schoonaarde	1	1	1	0	0	1	1	0
Wetteren	0	0	0	-1	0	0	0	0
Melle	0	0	0	-1	0	1	1	0
Durme								
Waasmunster	0	-1	0	-1	NV	NV	NV	NV
Rupel								
Boom	0	0	1	0	0	0	0	-1
Walem	0	0	1	0	0	0	0	-1
Mechelen	-1	0	-1	0	NV	NV	NV	NV
Hombeek	1	1	1	1	NV	NV	NV	NV
Nete								
Duffel	0	0	0	0	0	0	0	0
Kessel	1	1	0	1	NV	NV	NV	NV
Emblem	0	0	0	1	NV	NV	NV	NV

Table A-29. Flood and ebb volumes (spring tide) for the scenarios with changes at the Gat van Ossenisse - Middelgat

Station	reference run (bathymetry for 1970 - 1971)		scenario 1		scenario 2		scenario 3		scenario 4	
	V_{flood} (m^3)	V_{ebb} (m^3)	V_{flood} (m^3)	V_{ebb} (m^3)	V_{flood} (m^3)	V_{ebb} (m^3)	V_{flood} (m^3)	V_{ebb} (m^3)	V_{flood} (m^3)	V_{ebb} (m^3)
Hoofdplaat	9.87E+08	9.80E+08	9.86E+08	9.80E+08	9.84E+08	9.78E+08	9.84E+08	9.77E+08	9.88E+08	9.82E+08
Terneuzen	7.68E+08	7.61E+08	7.68E+08	7.60E+08	7.66E+08	7.59E+08	7.66E+08	7.58E+08	7.69E+08	7.62E+08
Gat van Ossenisse	5.80E+08	5.72E+08	5.80E+08	5.72E+08	5.80E+08	5.71E+08	5.79E+08	5.70E+08	5.81E+08	5.73E+08
Bath	1.98E+08	1.94E+08	1.98E+08	1.94E+08	1.98E+08	1.94E+08	1.98E+08	1.94E+08	1.99E+08	1.94E+08
Antwerp	8.51E+07	8.38E+07	8.49E+07	8.38E+07	8.48E+07	8.36E+07	8.47E+07	8.36E+07	8.49E+07	8.39E+07
Temse	2.99E+07	2.90E+07	2.98E+07	2.90E+07	2.98E+07	2.90E+07	2.97E+07	2.89E+07	3.00E+07	2.90E+07
Dendermonde	8.47E+06	8.58E+06	8.47E+06	8.58E+06	8.48E+06	8.56E+06	8.45E+06	8.56E+06	8.48E+06	8.59E+06
Wetteren	2.48E+06	2.97E+06	2.48E+06	2.96E+06	2.47E+06	2.97E+06	2.48E+06	2.97E+06	2.48E+06	2.97E+06

Table A-30. Flood volumes through the ebb and flood channel for the scenarios with the changes at the Gat van Ossenisse - Middelgat

Cross section	**Station**	**reference run (bathymetry for 1970 - 1971)**			**scenario 1**			**scenario 2**			**scenario 3**			**scenario 4**		
		spring flood V (m³)		*% of total V through cross section*	*spring flood V (m³)*		*% of total V through cross section*	*spring flood V (m³)*		*% of total V through cross section*	*spring flood V (m³)*		*% of total V through cross section*	*spring flood V (m³)*		*% of total V through cross section*
1	Honte	8.48E+08	9.88E+08	85.8	8.48E+08	9.88E+08	85.8	8.46E+08	9.86E+08	85.8	8.46E+08	9.86E+08	85.8	8.50E+08	9.90E+08	85.8
	Vaarwater Hoofdplaat	1.40E+08		14.2	1.40E+08		14.2	1.40E+08		14.2	1.40E+08		14.2	1.40E+08		14.2
2	Everingen	4.63E+08	7.70E+08	60.1	4.63E+08	7.70E+08	60.1	4.62E+08	7.69E+08	60.1	4.62E+08	7.69E+08	60.1	4.64E+08	7.71E+08	60.1
	Terneuzen	3.07E+08		39.9	3.07E+08		39.9	3.07E+08		39.9	3.06E+08		39.9	3.08E+08		39.9
3	Middelgat	2.64E+08	5.82E+08	45.4	2.61E+08	5.82E+08	44.8	2.63E+08	5.81E+08	45.2	2.53E+08	5.81E+08	43.6	2.61E+08	5.83E+08	44.8
	Gat van Ossenisse	3.18E+08		54.6	3.21E+08		55.2	3.18E+08		54.8	3.28E+08		56.4	3.22E+08		55.2
4	Schaar van Waarde	2.24E+08	3.88E+08	57.8	2.24E+08	3.88E+08	57.7	2.21E+08	3.87E+08	57.0	2.23E+08	3.87E+08	57.8	2.25E+08	3.88E+08	57.8
	Zuidergat	1.64E+08		42.2	1.64E+08		42.3	1.66E+08		43.0	1.63E+08		42.2	1.64^{E}+08		42.2

Table A-31. Ebb volumes through the ebb and flood channel for the scenarios with the changes at the Gat van Ossenisse - Middelgat

Cross section	**Station**	**reference run (bathymetry for 1970 - 1971)**			**scenario 1**			**scenario 2**			**scenario 3**			**scenario 4**		
		spring ebb V (m³)		*% of total V through cross section*	*spring ebb V (m³)*		*% of total V through cross section*	*spring ebb V (m³)*		*% of total V through cross section*	*spring ebb V (m³)*		*% of total V through cross section*	*spring ebb V (m³)*		*% of total V through cross section*
1	Honte	8.56E+08	9.82E+08	87.1	8.55E+08	9.82E+08	87.1	8.53E+08	9.80E+08	87.1	8.53E+08	9.79E+08	87.1	8.57E+08	9.84E+08	87.1
	Vaarwater Hoofdplaat	1.27E+08		12.9	1.27E+08		12.9	1.27E+08		12.9	1.27E+08		12.9	1.27E+08		12.9
2	Everingen	3.91E+08	7.62E+08	51.3	3.90E+08	7.62E+08	51.2	3.87E+08	7.60E+08	51.0	3.85E+08	7.60E+08	50.7	3.92E+08	7.64E+08	51.3
	Terneuzen	3.71E+08		48.7	3.72E+08		48.8	3.73E+08		49.0	3.75E+08		49.3	3.72E+08		48.7
3	Middelgat	3.02E+08	5.74E+08	52.7	3.01E+08	5.74E+08	52.5	3.06E+08	5.73E+08	53.5	2.96E+08	5.72E+08	51.8	2.99E+08	5.75E+08	51.9
	Gat van Ossenisse	2.71E+08		47.3	2.73E+08		47.5	2.66E+08		46.5	2.76E+08		48.2	2.76E+08		48.1
4	Schaar van Waarde	1.61E+08	3.79E+08	42.5	1.61E+08	3.79E+08	42.5	1.59E+08	3.78E+08	42.1	1.61E+08	3.78E+08	42.5	1.61E+08	3.79E+08	42.5
	Zuidergat	2.18E+08		57.5	2.18E+08		57.5	2.19E+08		57.9	2.17E+08		57.5	2.18E+08		57.5

Table A-32. Comparison of the water levels before and after the changes at the Gat van Ossenisse – Middelgat
(NV = water level could not be determined based on the used algorithm)

Station	**Difference (run - reference run 1970 - 1971)**									
	high water (cm)		**low water (cm)**		**tidal amplitude (cm)**		**phase of high water (min)**		**phase of low water (min)**	
	scenario 4	*extra scenario for 1978*	*scenario 4*	*extra scenario for 1978*	*scenario 4*	*extra scenario for 1978*	*scenario 4*	*extra scenario for 1978*	*scenario 4*	*extra scenario for 1978*
Western Scheldt										
Vlissingen	-0.1	0.0	0.0	0.1	-0.1	-0.1	0	0	0	0
Terneuzen	0.0	0.2	-0.1	0.1	0.1	0.1	1	2	0	0
Hansweert	0.2	0.4	-0.5	-0.3	0.7	0.7	0	1	-1	0
Schaar van de Noord	0.2	0.2	-0.4	-0.3	0.6	0.5	0	0	0	0
Bath	0.3	0.2	-0.3	-0.3	0.6	0.5	-1	-2	0	0
Lower Sea Scheldt										
Liefkenshoek	0.3	0.2	-0.3	-0.3	0.6	0.5	-1	-1	0	0
Antwerp	0.3	0.2	-0.3	-0.3	0.6	0.5	0	1	0	0
Hemiksem	0.2	0.3	-0.3	-0.3	0.5	0.6	0	0	0	0
Upper Sea Scheldt										
Temse	0.3	0.2	-0.3	-0.3	0.6	0.5	0	0	0	0
Dendermonde	0.3	0.3	-0.1	-0.2	0.4	0.5	-1	-1	0	-1
Schoonaarde	0.3	0.2	0.0	0.0	0.3	0.2	0	0	0	0
Wetteren	0.2	0.2	0.1	0.1	0.1	0.1	-1	-1	0	0
Melle	0.4	0.2	0.1	0.1	0.3	0.1	-1	-1	0	0
Durme										
Waasmunster	0.2	0.1	NV	NV	NV	NV	-1	-1	NV	NV
Rupel										
Boom	0.2	0.3	-0.3	-0.3	0.5	0.6	0	0	-1	0
Walem	0.2	0.2	-0.2	-0.2	0.4	0.4	0	0	-1	0
Mechelen	0.3	0.2	NV	NV	NV	NV	0	-2	NV	NV
Hombeek	0.3	0.3	NV	NV	NV	NV	1	0	NV	NV

Station	**Difference (run - reference run 1970 - 1971)**									
	high water (cm)		**low water (cm)**		**tidal amplitude (cm)**		**phase of high water (min)**		**phase of low water (min)**	
	scenario 4	*extra scenario for 1978*	*scenario 4*	*extra scenario for 1978*	*scenario 4*	*extra scenario for 1978*	*scenario 4*	*extra scenario for 1978*	*scenario 4*	*extra scenario for 1978*
Nete										
Duffel	0.2	0.3	0.0	-0.1	0.2	0.4	0	0	0	0
Kessel	0.0	0.1	NV	NV	NV	NV	1	-2	NV	NV
Emblem	0.2	0.2	NV	NV	NV	NV	1	1	NV	NV

Table A-33. Comparison of the water levels for the scenarios with bathymetry for 2007 and 1955 at the Gat van Ossenisse - Middelgat and reference scenario (NV = water level could not be determined based on the used algorithm)

Station	Difference (run - reference run)									
	high water (cm)		low water (cm)		tidal amplitude (cm)		phase of high water (min)		phase of low water (min)	
	extra scenario for 2007	extra scenario for 1955	extra scenario for 2007	extra scenario for 1955	extra scenario for 2007	extra scenario for 1955	extra scenario for 2007	extra scenario for 1955	extra scenario for 2007	extra scenario for 1955
Western Scheldt										
Vlissingen	-0.2	-0.4	-0.2	0.5	0.0	-0.9	1	0	0	0
Terneuzen	0.0	-0.5	-0.3	1.8	0.3	-2.3	1	1	0	2
Hansweert	0.6	-0.5	-1.2	3.2	1.8	-3.8	-2	0	-1	5
Schaar van de Noord	0.4	-0.5	-0.7	1.8	1.1	-2.3	-1	0	-1	2
Bath	0.5	-0.5	-0.7	1.6	1.2	-2.1	0	0	-1	2
Lower Sea Scheldt										
Liefkenshoek	0.4	-0.5	-0.7	1.5	1.1	-2.0	0	0	-1	2
Antwerp	0.4	-0.6	-0.7	1.4	1.1	-2.0	-1	0	-1	2
Hemiksem	0.4	-0.7	-0.6	1.3	1.0	-2.0	-1	0	-1	3
Upper Sea Scheldt										
Temse	0.5	-0.6	-0.6	1.3	1.1	-1.9	0	1	0	2
Dendermonde	0.6	-0.7	-0.1	-0.6	0.7	0.0	-1	0	-1	2
Schoonaarde	0.6	-1.1	0.1	-1.3	0.4	0.2	0	0	-1	3
Wetteren	0.6	-1.5	0.2	-1.3	0.4	-0.2	-1	1	0	1
Melle	0.7	-1.9	0.3	-1.4	0.4	-0.5	-1	0	0	2
Durme										
Waasmunster	0.2	-0.6	NV	NV	NV	NV	-1	0	NV	NV
Rupel										
Boom	0.4	-0.5	-0.6	1.1	1.0	-1.6	-1	1	-1	2
Walem	0.4	-0.7	-0.4	0.8	0.8	-1.5	0	0	-1	1
Mechelen	0.4	-0.6	NV	NV	NV	NV	-2	0	NV	NV
Hombeek	0.4	-0.6	NV	NV	NV	NV	0	0	NV	NV
Nete										
Duffel	0.4	-0.5	0.0	-0.6	0.4	0.0	0	0	-1	2
Kessel	0.5	-1.1	NV	NV	NV	NV	-1	0	NV	NV
Emblem	0.5	-1.1	NV	NV	NV	NV	-1	0	NV	NV

Table A-34. Sand mining volumes

Sand mining location	Volume (m^3)	Area (m^2)	m per year	m per 10 years
IIa	100 000	158 253	0.63	6.32
IIb	100 000	165 167	0.61	6.05
IV	399 700	583 460	0.69	6.85
Va	180 000	179 014	1.01	10.06
Vb	140 000	230 477	0.61	6.07
Vc	180 000	342 350	0.53	5.26
VIIIa	64 200	205 761	0.31	3.12
VIIIb	64 200	147 205	0.44	4.36
VIIIc	192 600	193 080	1.00	9.98
VIIId	64 200	189 516	0.34	3.39
VIIIe	64 200	236 143	0.27	2.72
VIIIf	64 200	148 357	0.43	4.33
VIIIg	256 800	136 504	1.88	18.81
VIIIh	129 600	178 935	0.72	7.24
IX	0	145 716	0.00	0.00
TOTAL Volume	**2.00E+06**			
Total Volume in 10 years	**2.00E+07**			

Table A-35. Comparison of the water levels for the scenario with sand mining for a period of 10 years and reference run (NV = water level could not be determined based on the used algorithm)

Station	**Difference (run - reference run)**				
	high water (cm)	**low water (cm)**	**tidal amplitude (cm)**	**phase of high water (min)**	**phase of low water (min)**
Western Scheldt					
Vlissingen	0.1	-0.1	0.1	0	0
Terneuzen	0.0	-0.2	0.1	0	0
Hansweert	0.8	-0.4	1.2	1	0
Baalhoek	0.1	-0.2	0.3	-1	0
Schaar van de Noord	0.4	-0.4	0.8	-1	-1
Bath	0.3	-0.4	0.7	0	-1
Lower Sea Scheldt					
Liefkenshoek	0.3	-0.4	0.7	-1	-2
Antwerp	0.3	-0.4	0.7	-1	-1
Hemiksem	0.3	-0.4	0.7	-1	-2
Upper Sea Scheldt					
Temse	0.3	-0.3	0.6	-1	-2
Dendermonde	0.3	0.1	0.2	0	-1
Schoonaarde	0.3	0.0	0.2	-2	-1
Wetteren	0.2	0.0	0.2	0	-2
Melle	0.4	0.2	0.3	0	-1
Durme					
Waasmunster	0.5	NV	NV	0	NV
Rupel					
Boom	0.2	-0.2	0.4	-1	-1
Walem	0.3	0.0	0.4	0	-1
Mechelen	0.4	NV	NV	-2	NV
Hombeek	0.1	NV	NV	0	NV
Nete					
Duffel	0.3	0.0	0.2	0	-1
Kessel	0.3	NV	NV	0	NV
Emblem	0.3	NV	NV	0	NV

Figures

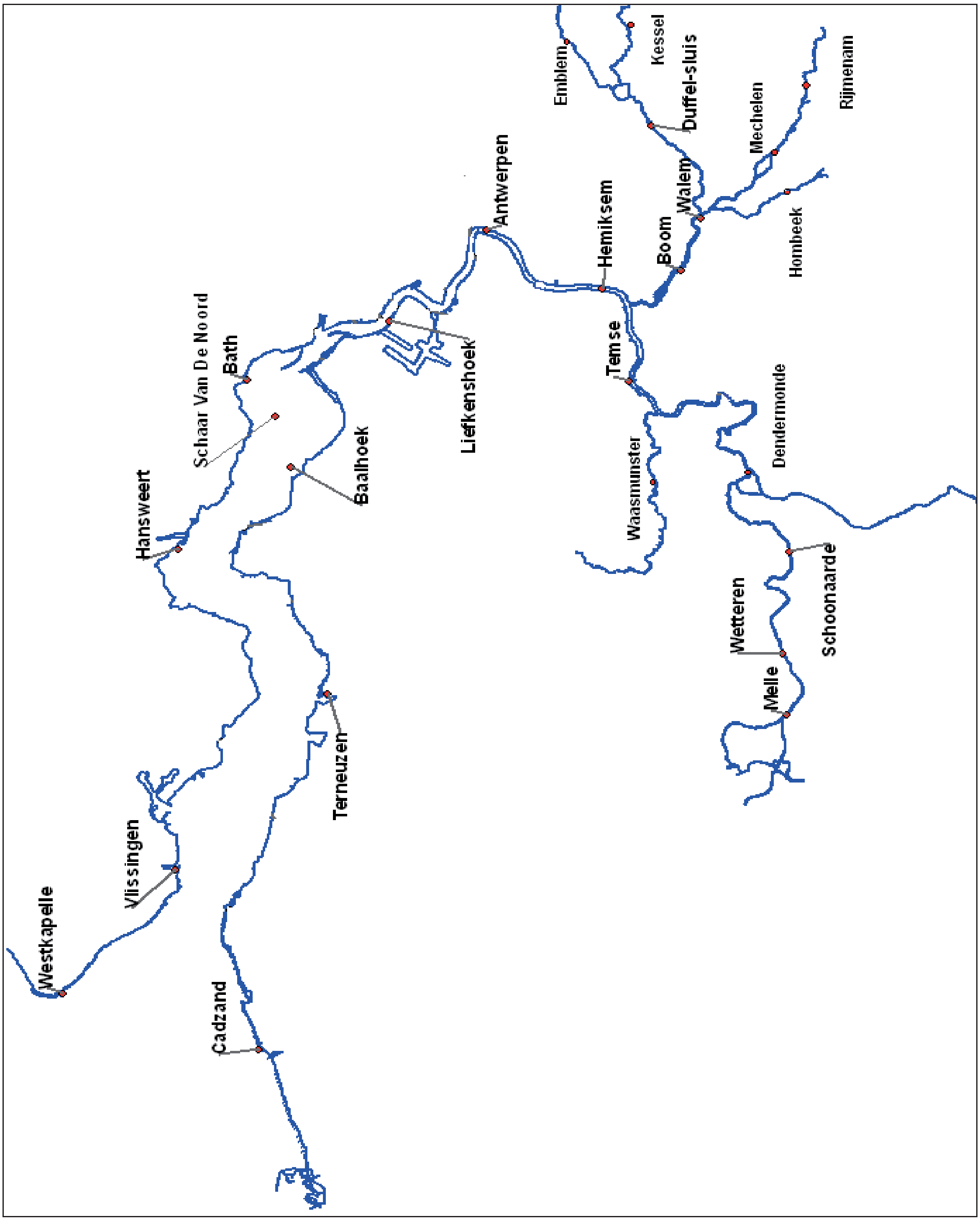


Figure 1 - The Scheldt estuary with different water level stations

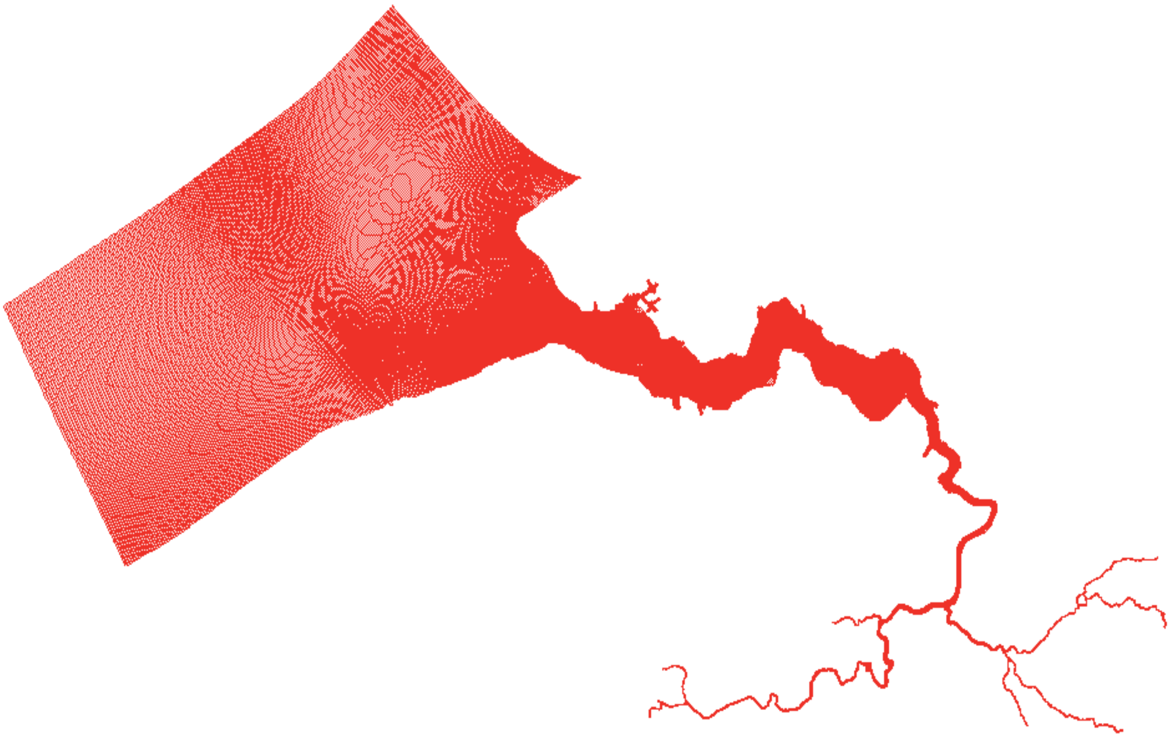


Figure 2 - Grid of the NEVLA model. In this study the line Westkapelle-Cadzand was used as seaward boundary (i.e. a large part of the North Sea was not used)

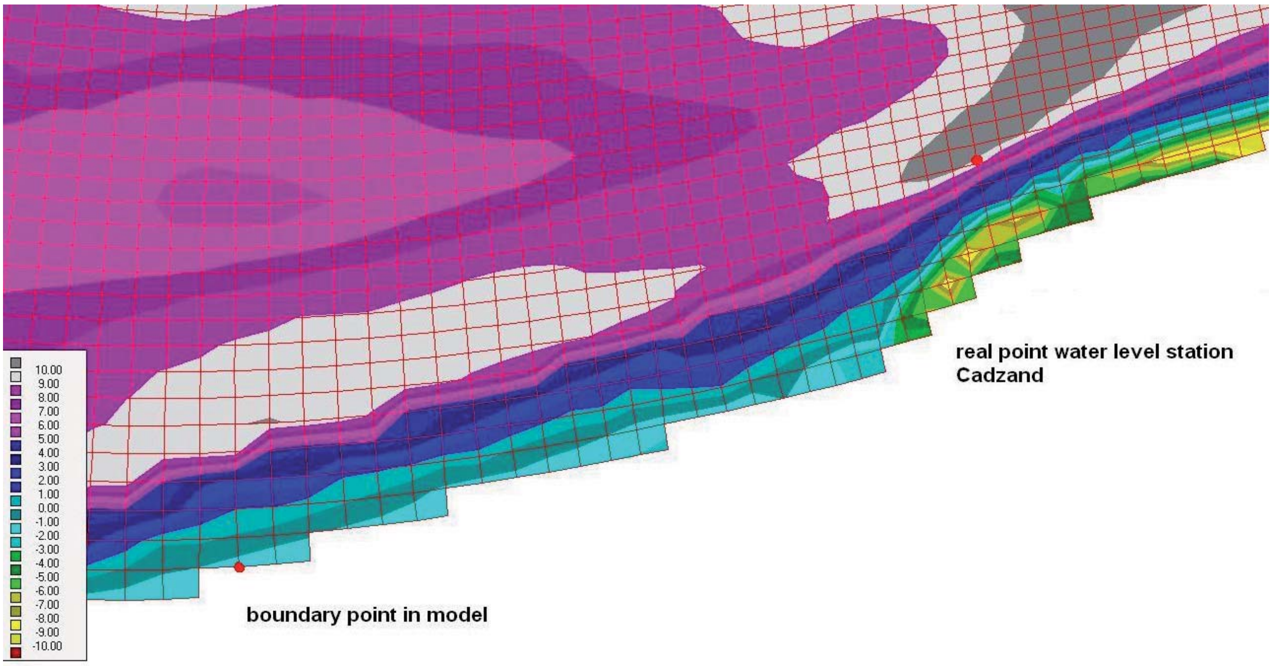


Figure 3 - Location of the boundary point between Zeebrugge and Cadzand in model

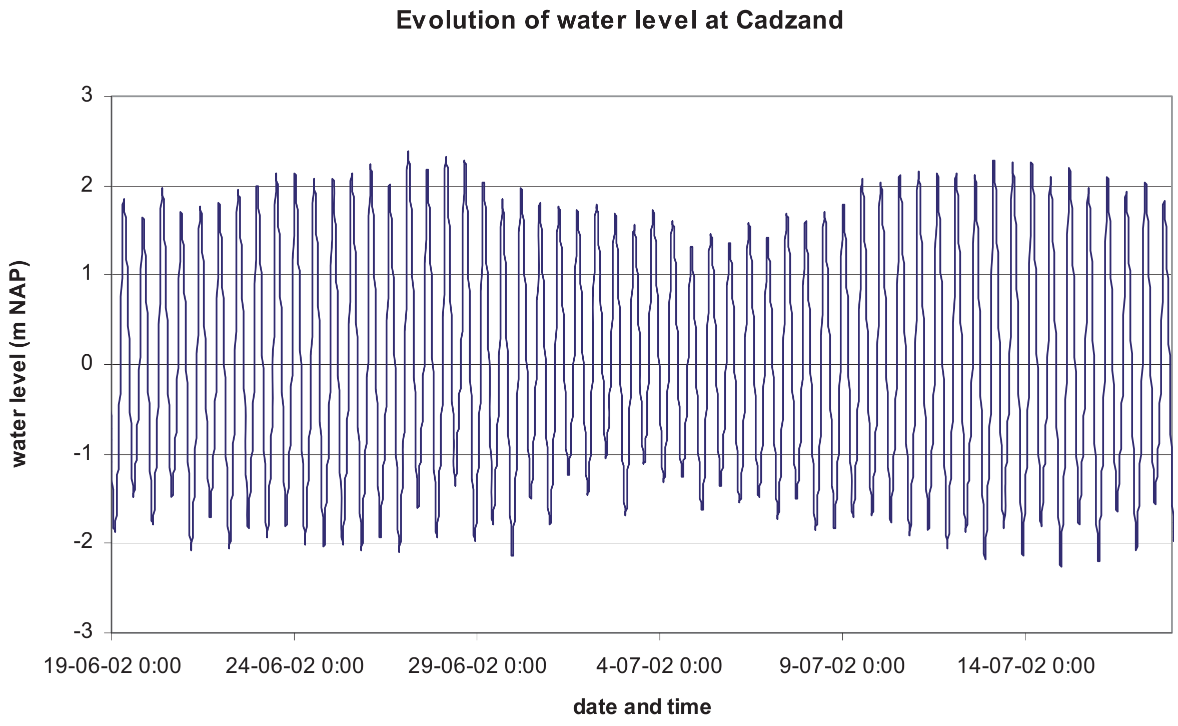


Figure 4 - Evolution of the water level in time at Cadzand for the simulation period

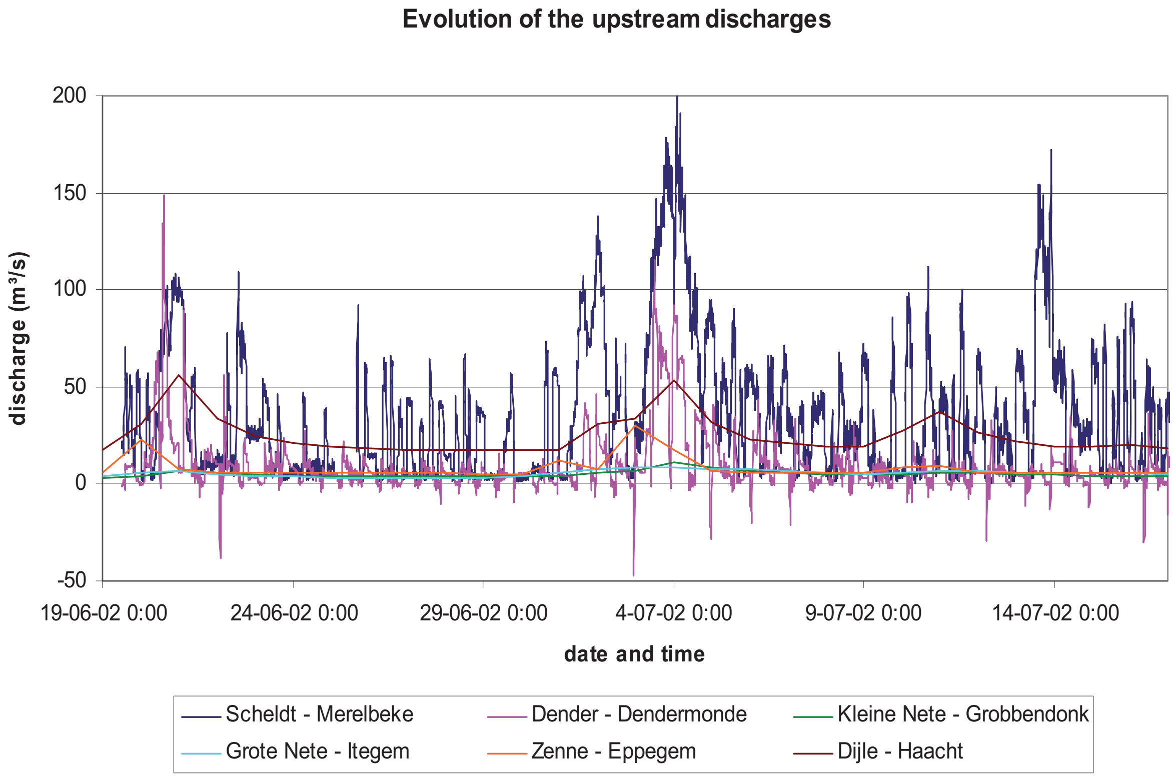
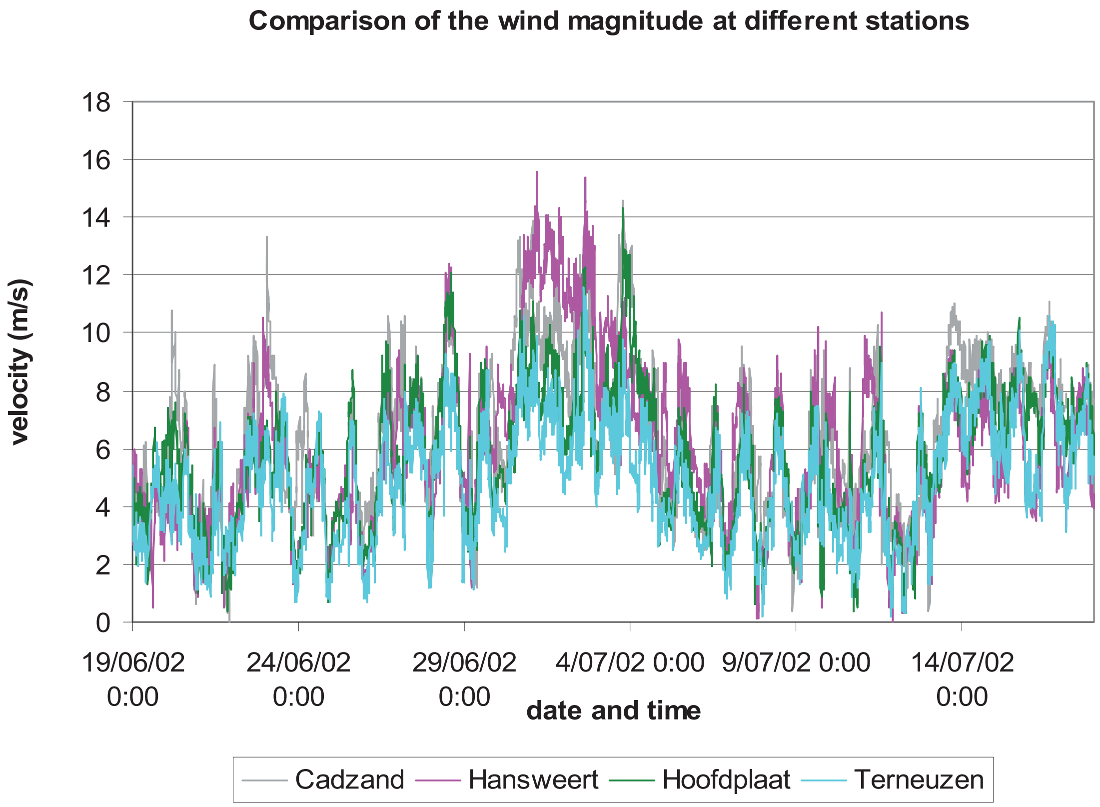


Figure 5 - Evolution of the upstream discharges in time for the simulation period



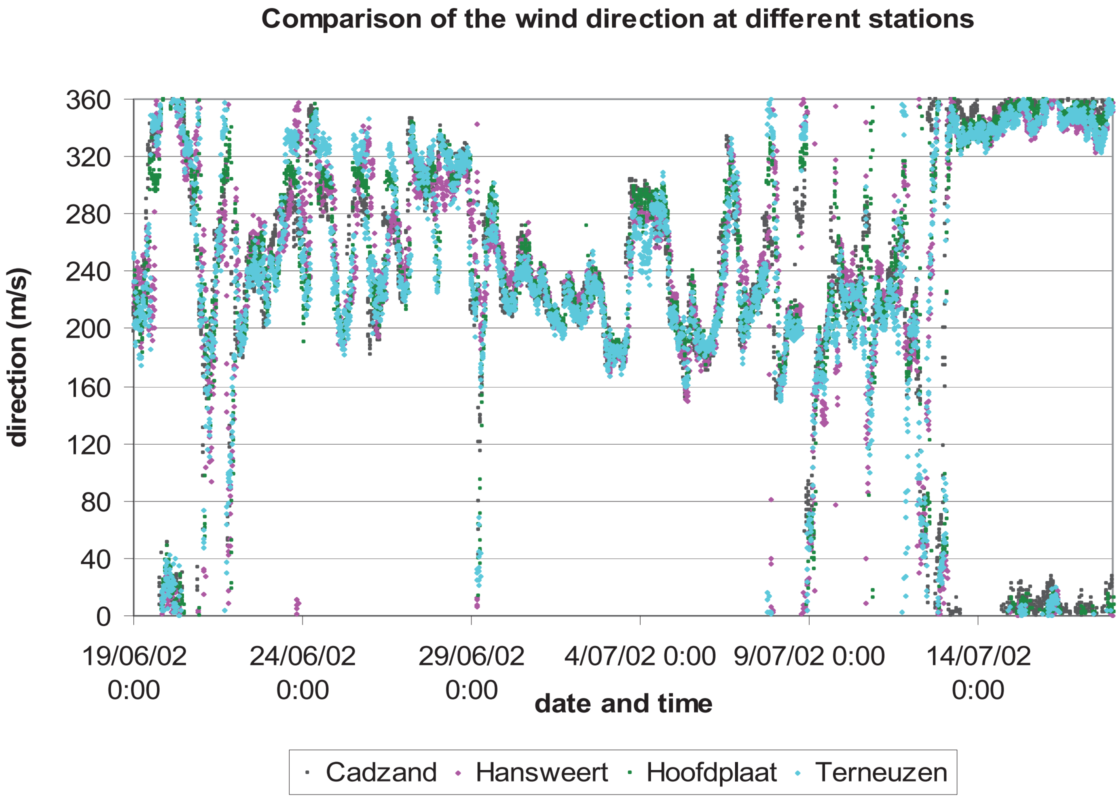
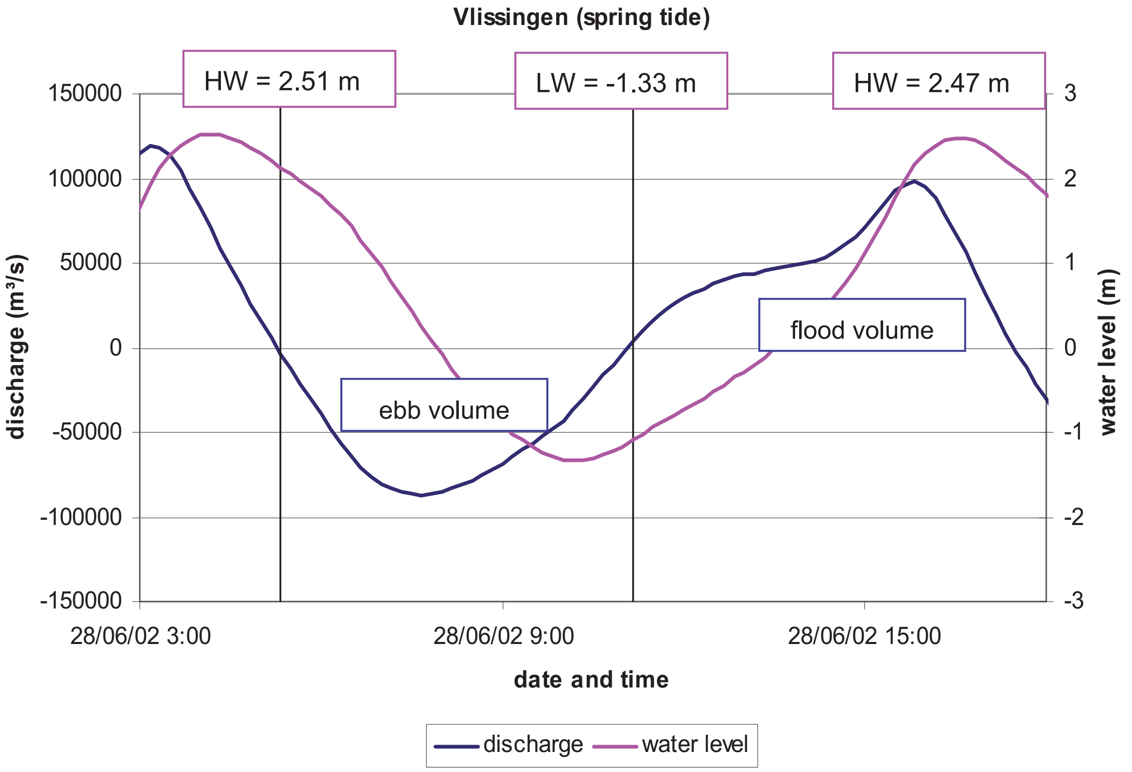


Figure 6 - Comparison of the wind magnitude and direction at different stations for the simulation period



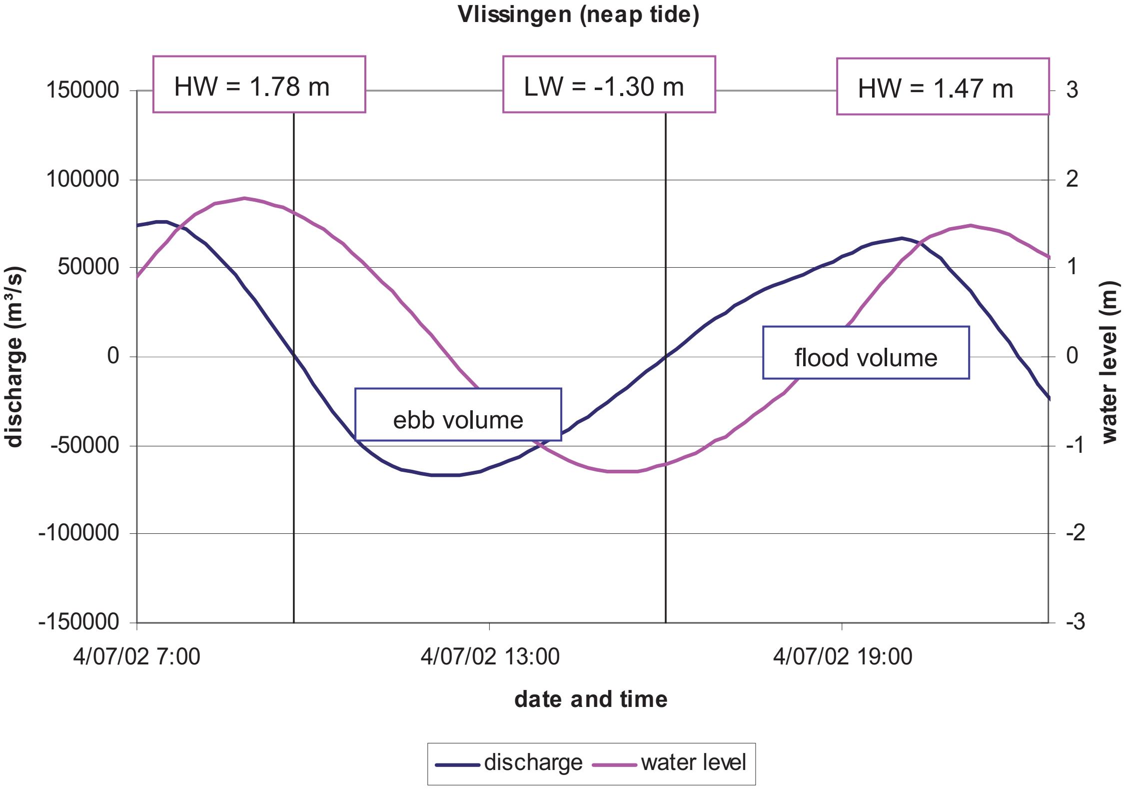


Figure 7 - Discharge and water level at Vlissingen for the analyzed spring and neap tide

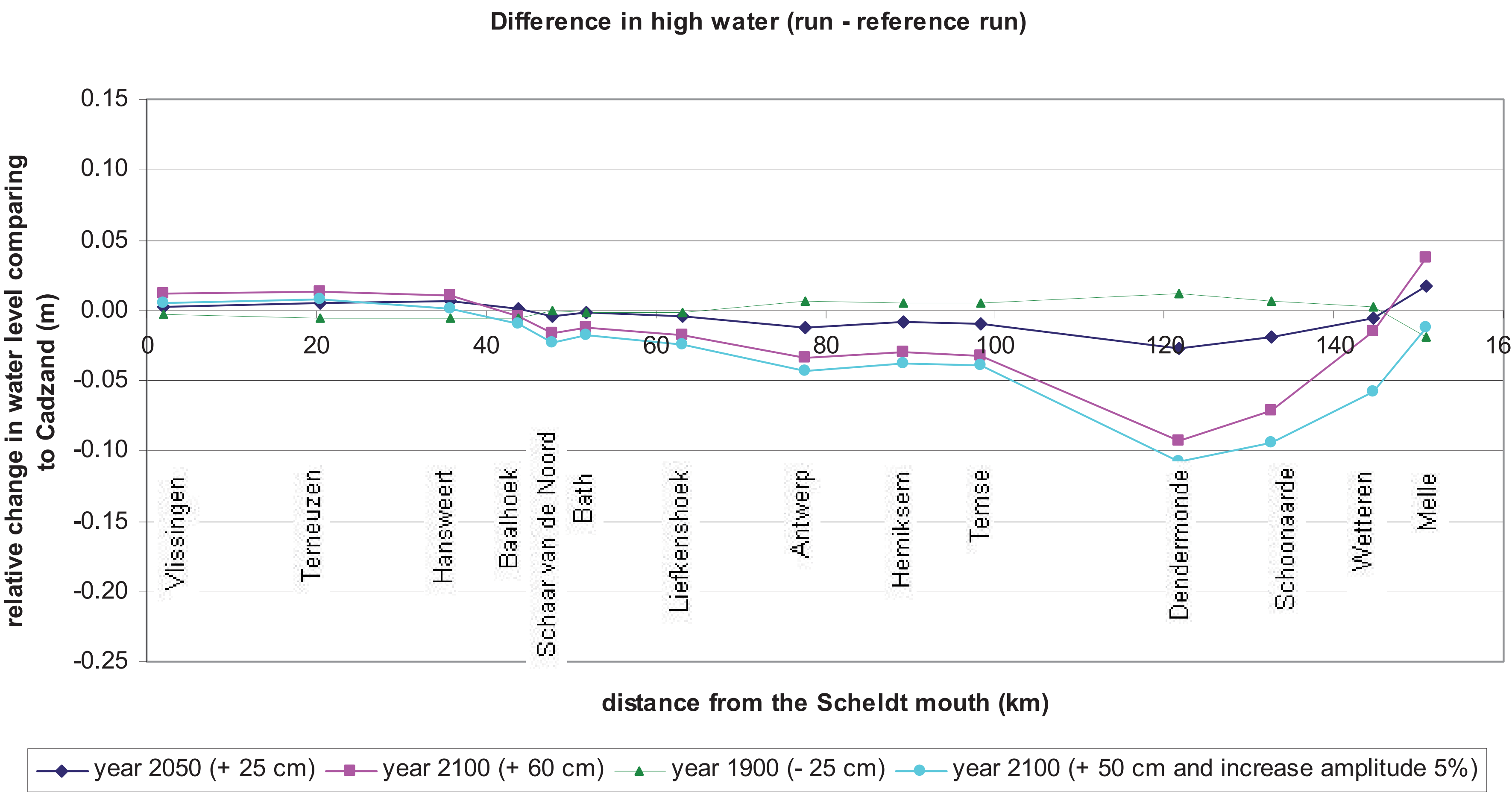


Figure 8 - Relative difference in high water for sea level change scenarios to reference situation (positive value is higher change in high water compared to Cadzand for sea level rise scenarios, and lower change in high water compared to Cadzand for sea level decrease scenarios)

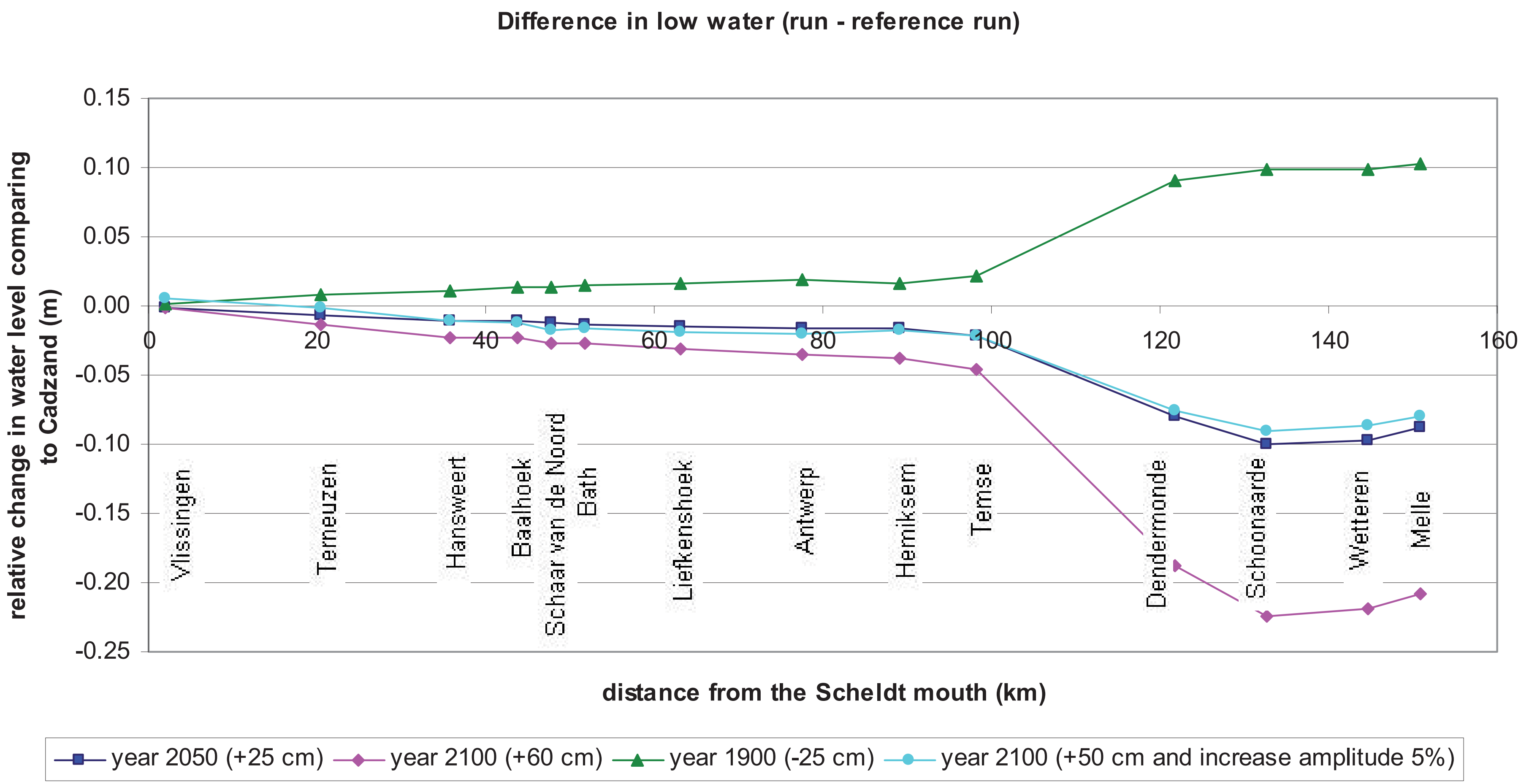


Figure 9 - Relative difference in low water for sea level change scenarios to reference situation (positive value is higher change in low water compared to Cadzand for sea level rise scenarios, and lower change in low water compared to Cadzand for sea level decrease scenarios)

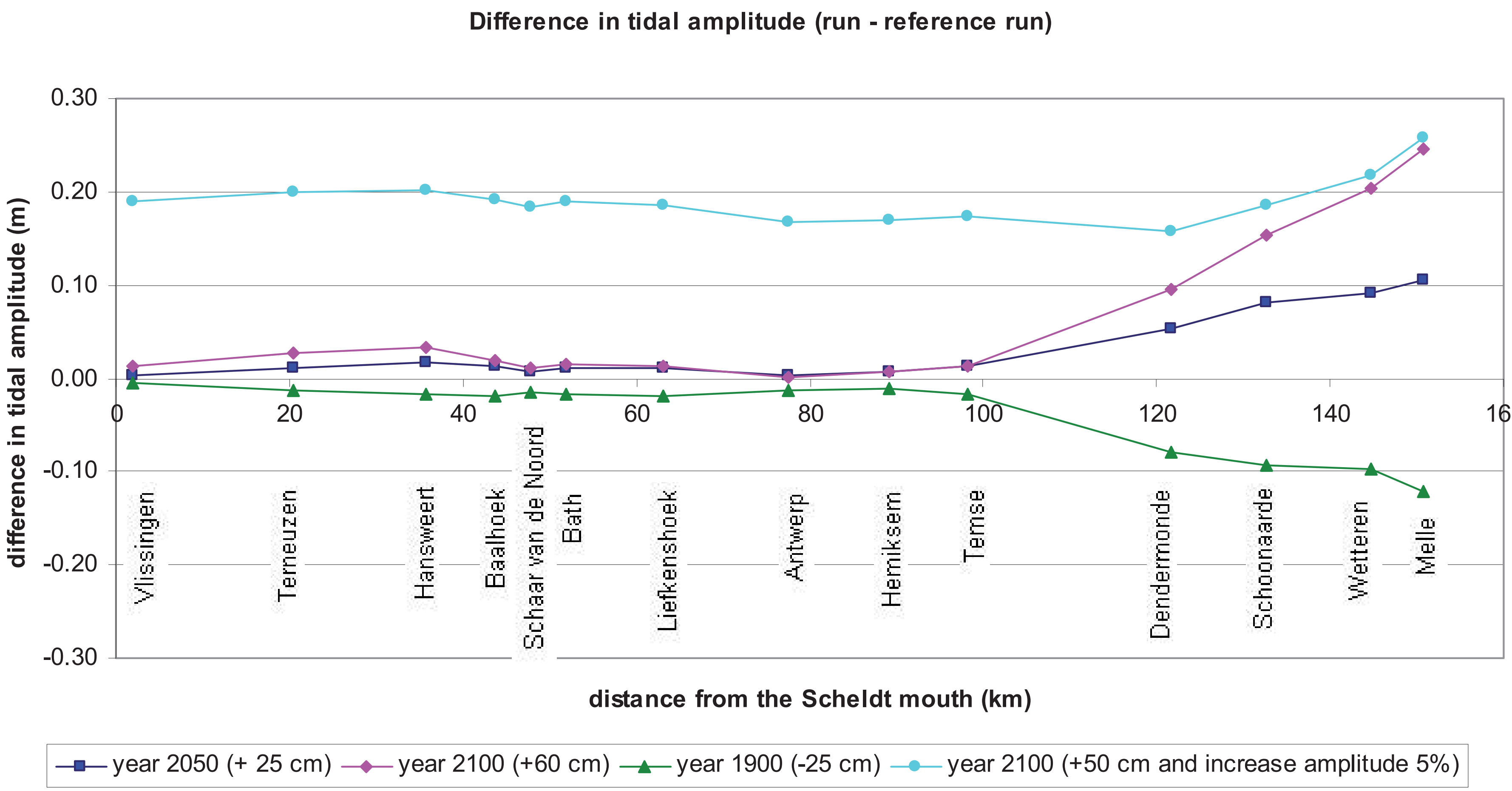


Figure 10 - Difference in tidal amplitude for sea level change scenarios to reference situation
(positive value is higher tidal amplitude compared to the reference scenario)

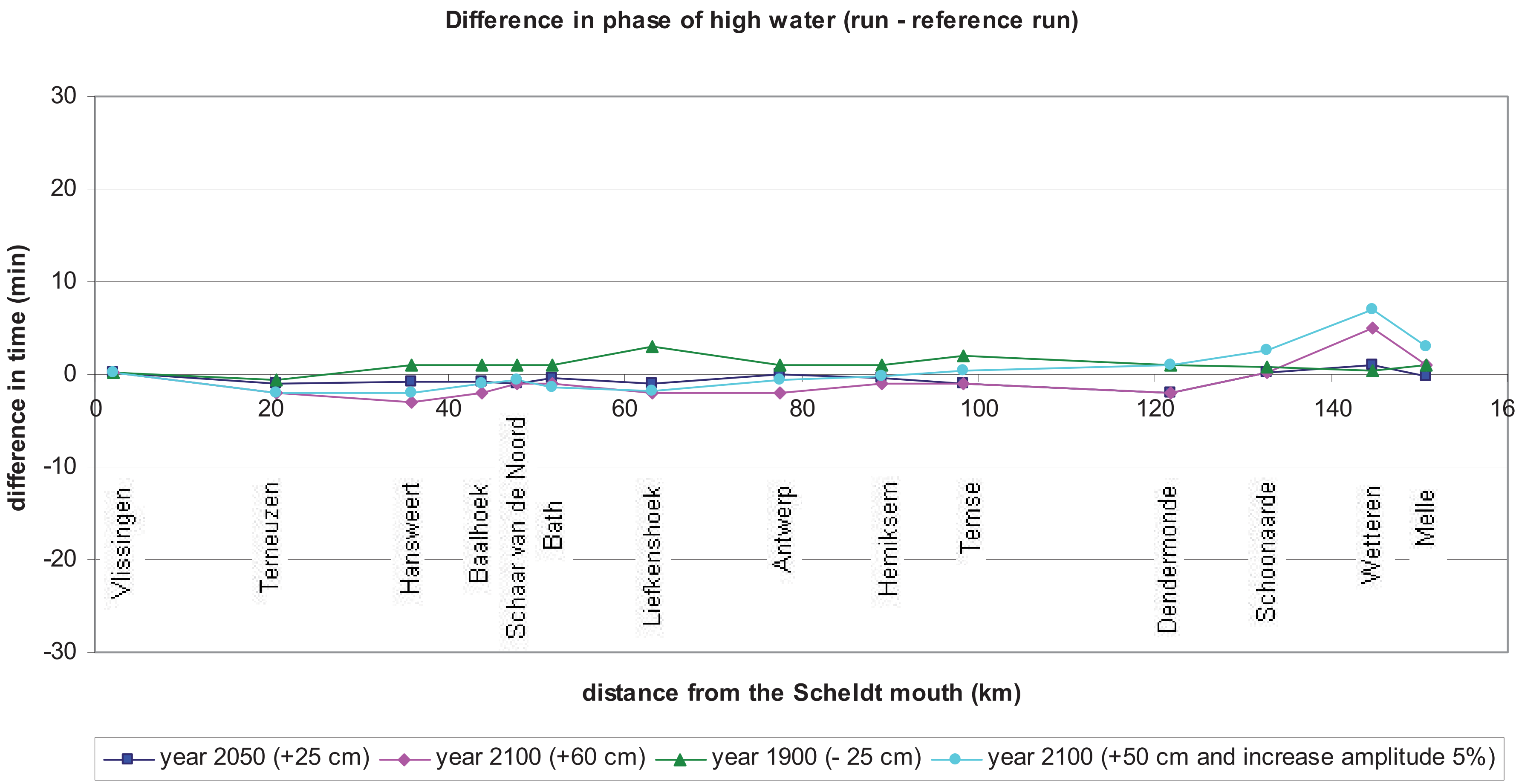


Figure 11 - Difference in phase of high water for sea level change scenarios to reference situation
(positive value is later compared to the reference scenario)

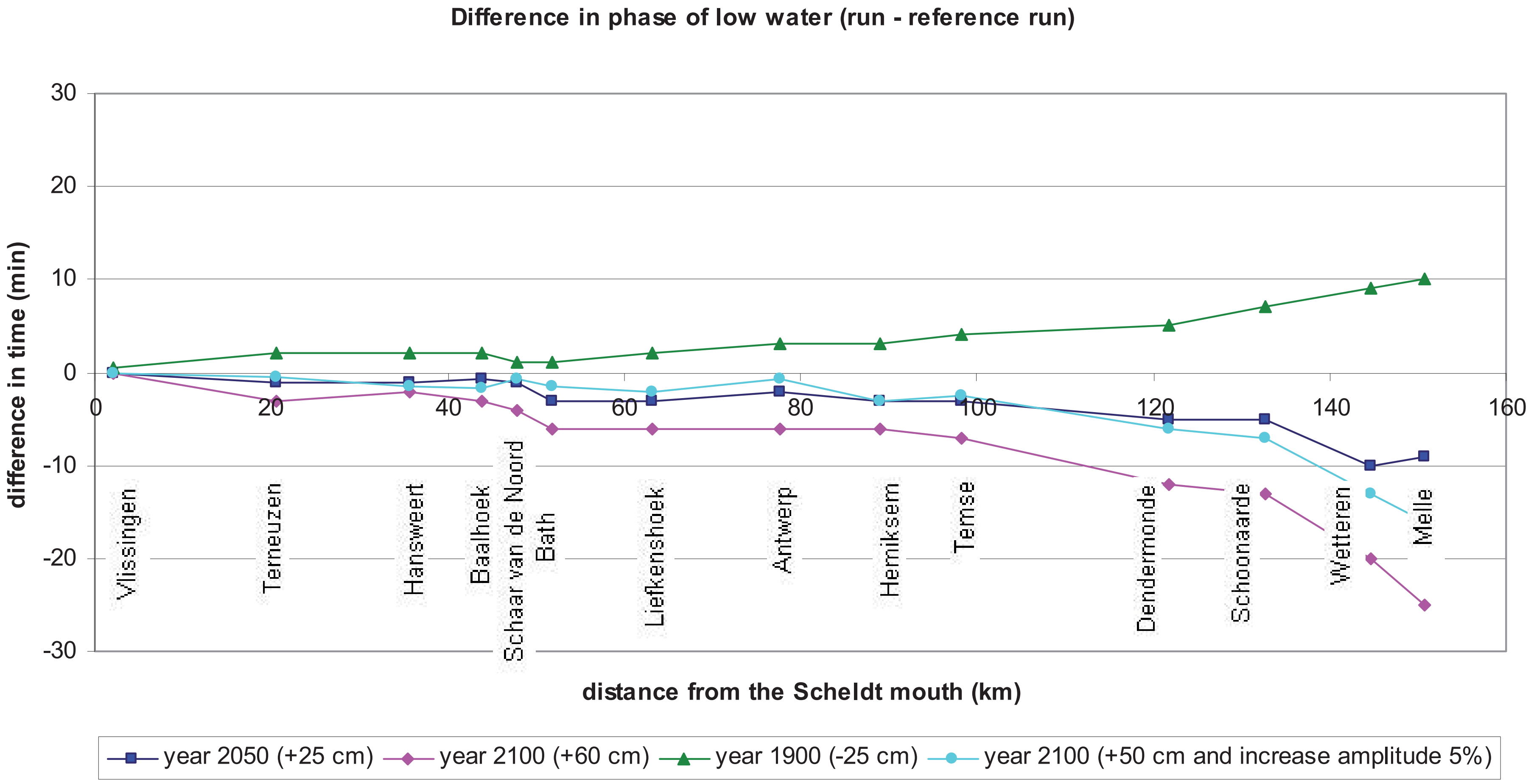


Figure 12 - Difference in phase of low water for sea level change scenarios to reference situation (positive value is later compared to the reference scenario)

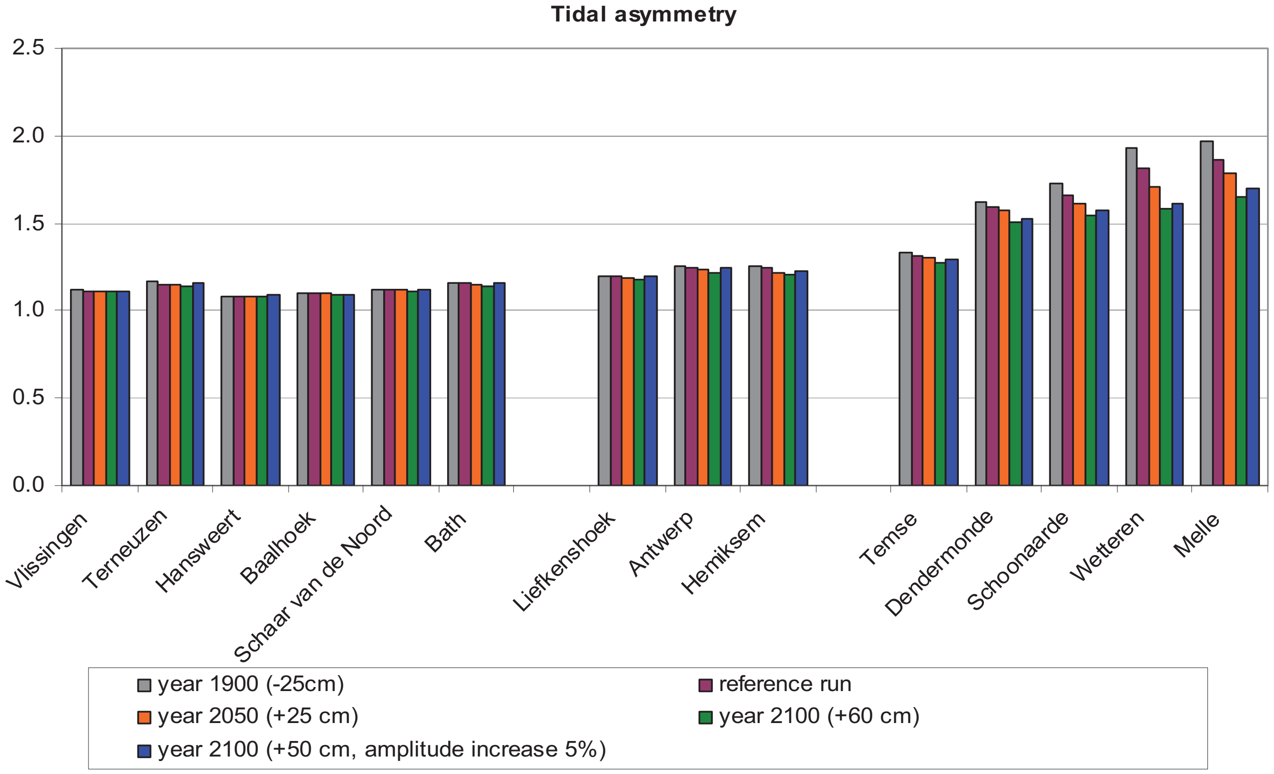


Figure 13 - Change in the tidal asymmetry for the sea level change scenarios

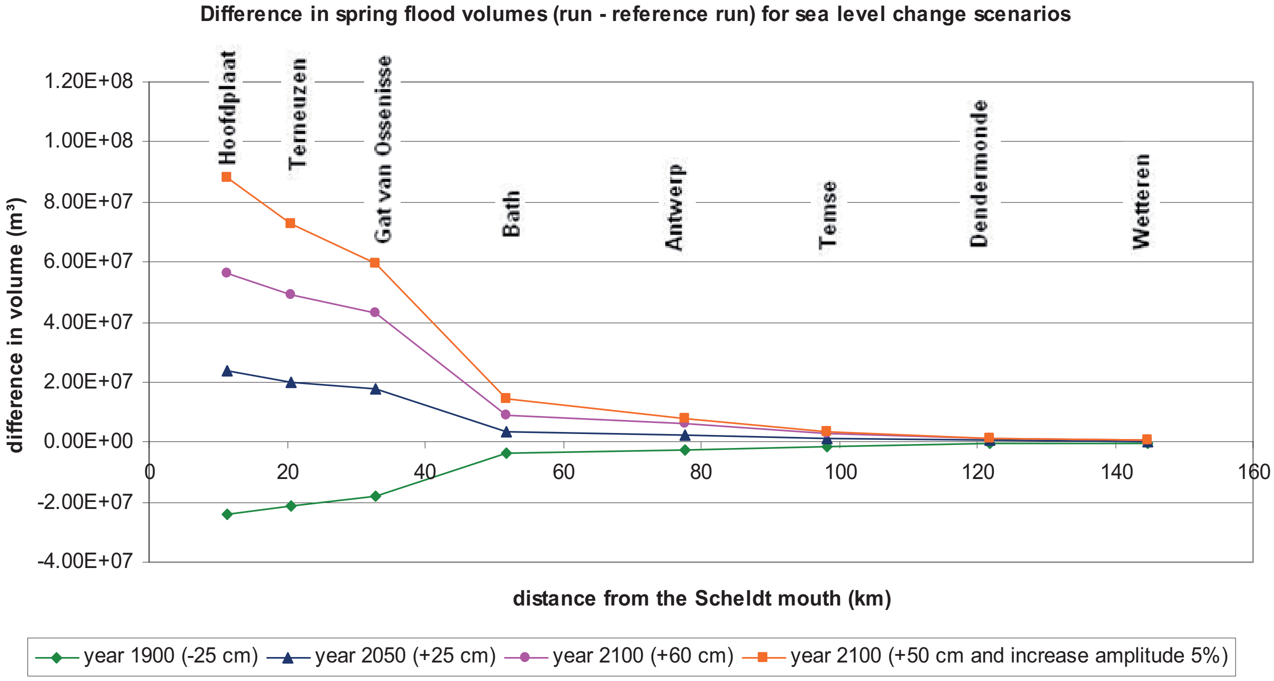


Figure 14 - Difference in the flood volumes for the sea level change scenarios


Average spring flood velocity in the river channel (the level between intertidal area and river channel is the same as in the reference run)

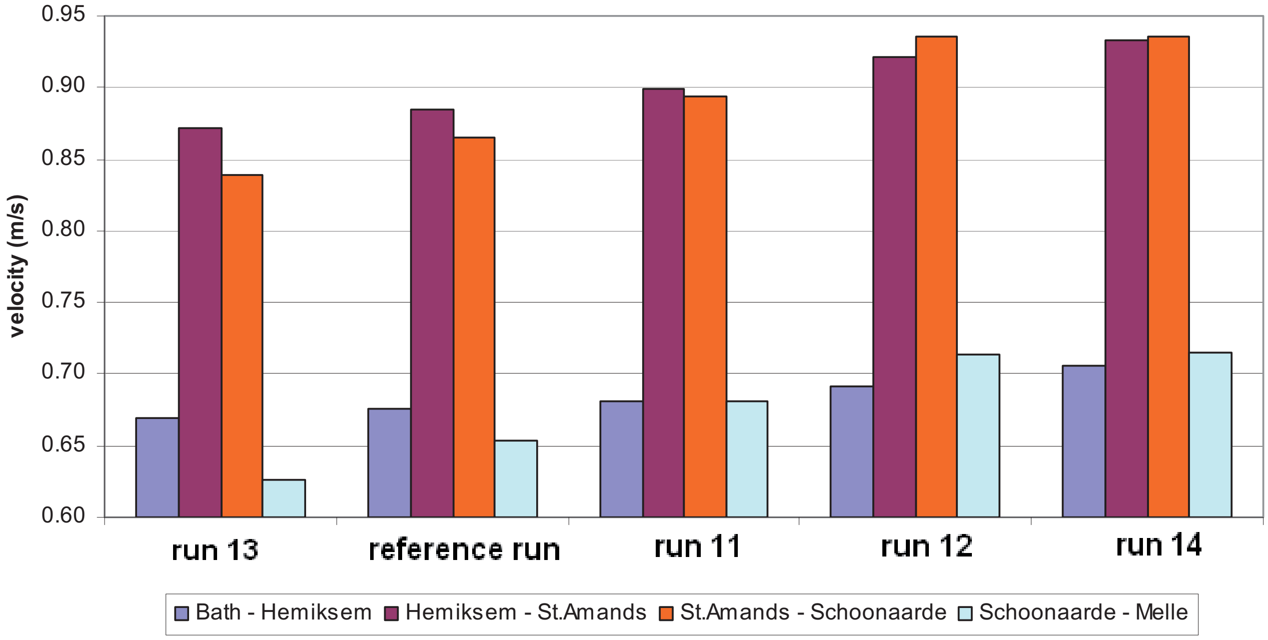
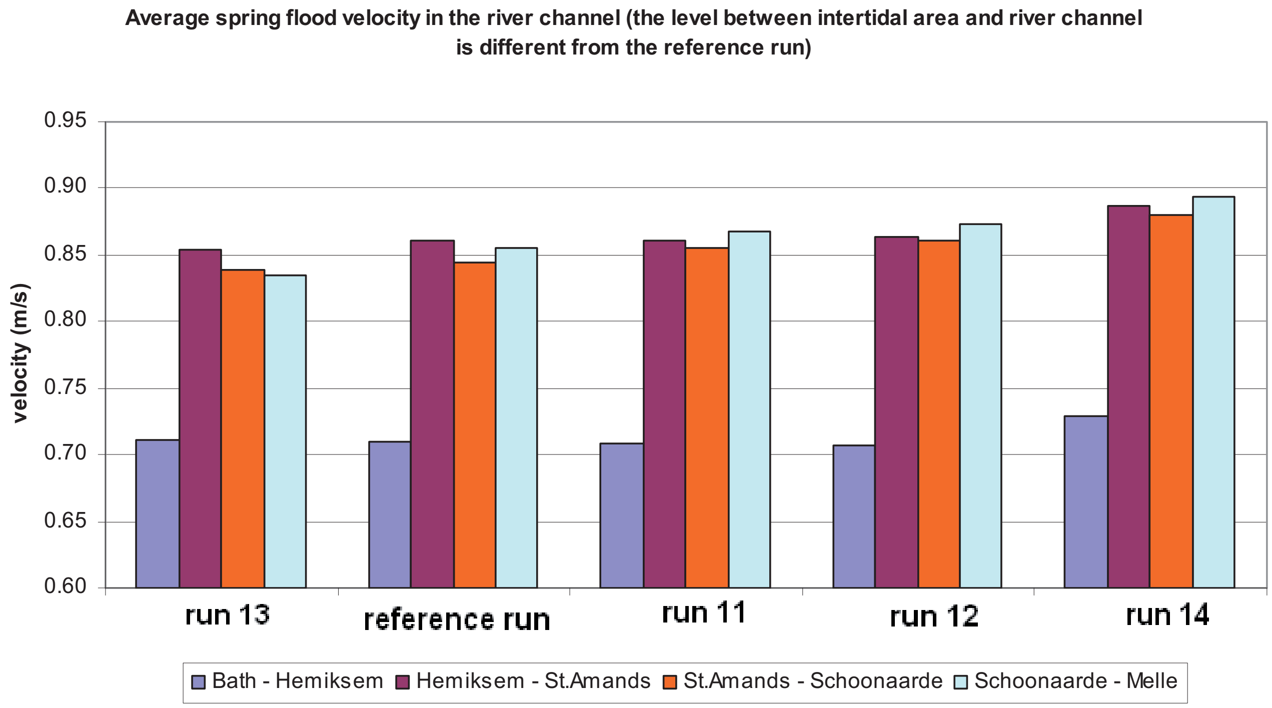

Average spring ebb velocity in the river channel (the level between intertidal area and river channel is the same as in the reference run)

Figure 15 - Average spring flood and ebb velocity in the river channel
(the level between intertidal area and river channel is the same as in the reference run)



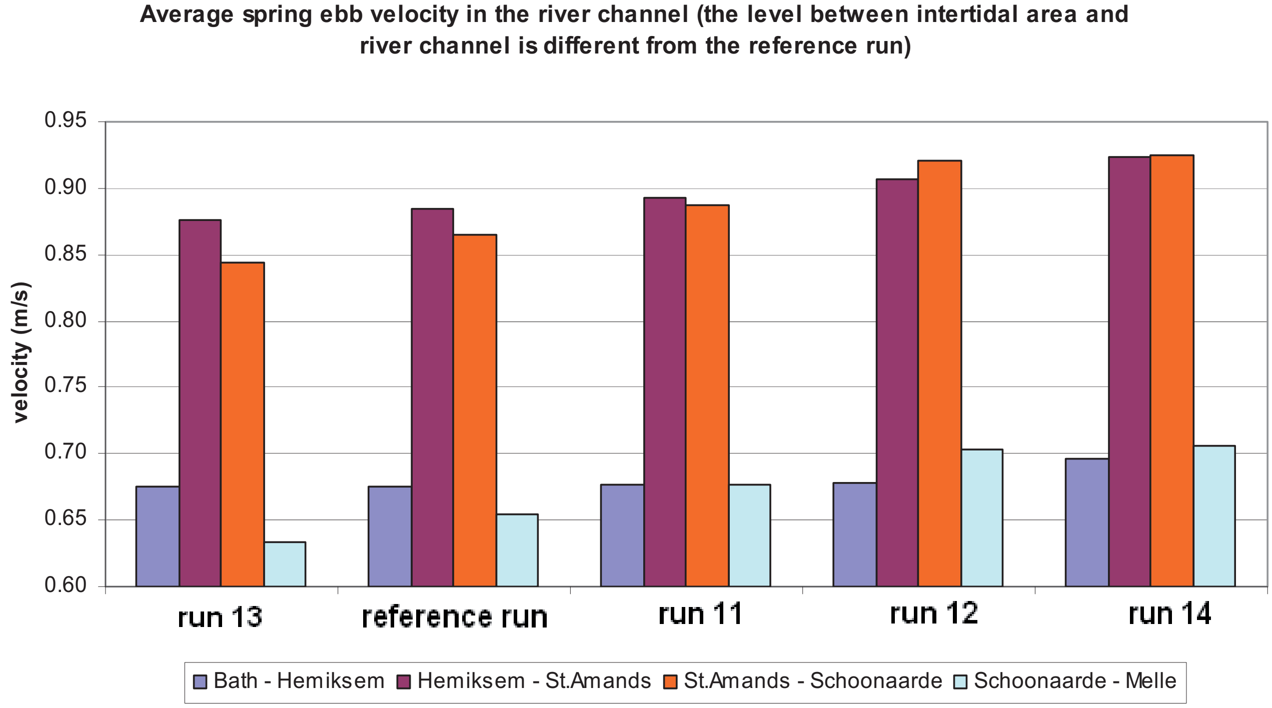


Figure 16 - Average spring flood and ebb velocity in the river channel
(the level between intertidal area and river channel is different from the reference run)

Average spring flood velocity on the intertidal area (the level between intertidal area and river channel is the same as in the reference run)

Average spring ebb velocity on the intertidal area (the level between intertidal area and river channel is the same as in the reference run)

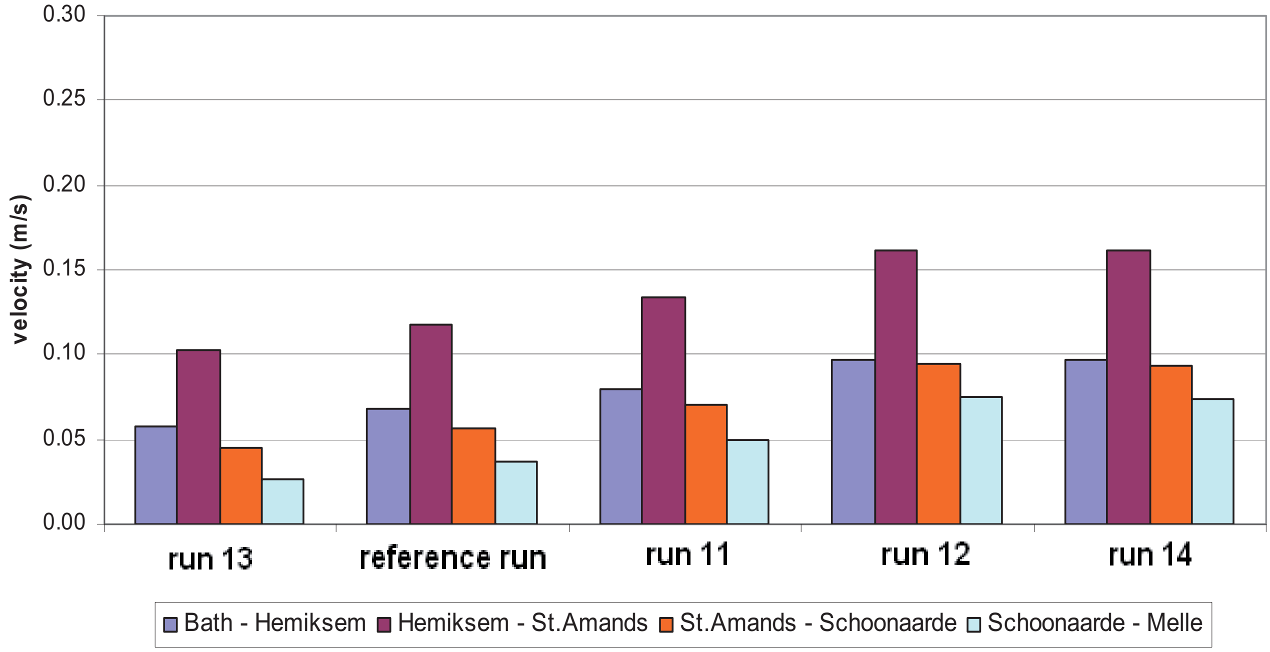
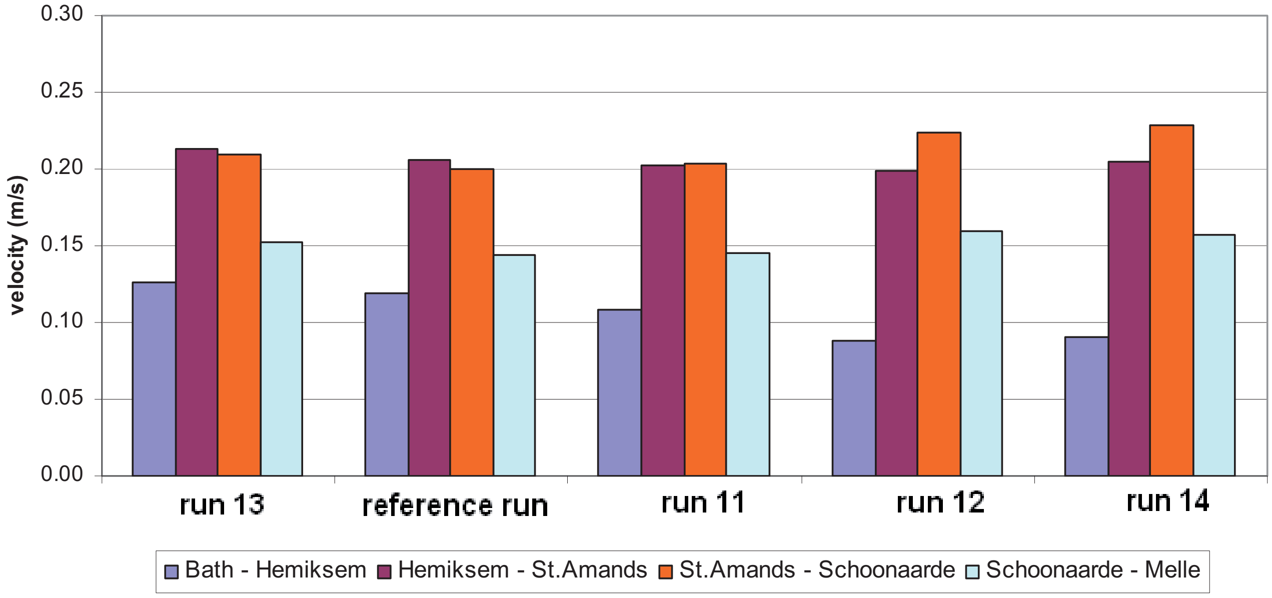


Figure 17 - Average spring flood and ebb velocity on the intertidal area
(the level between intertidal area and river channel is the same as in the reference run)

Average spring flood velocity on the intertidal area (the level between intertidal area and river channel is different from the reference run)



Average spring ebb velocity on the intertidal area (the level between intertidal area and river channel is different from the reference run)

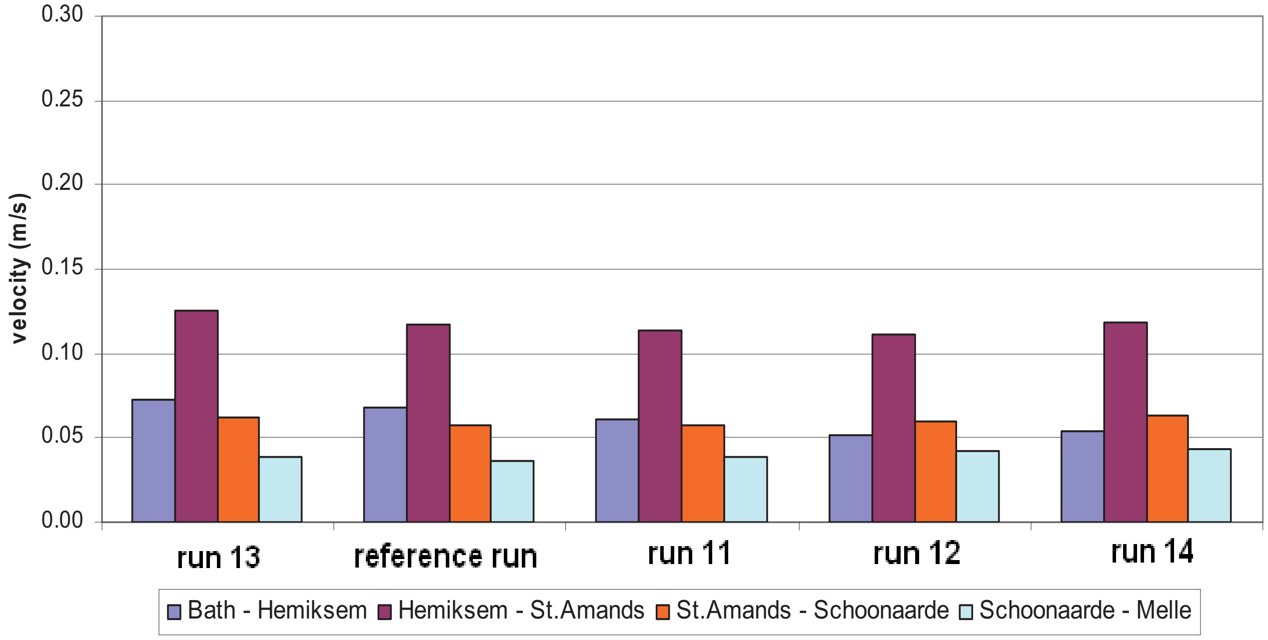


Figure 18 - Average spring flood and ebb velocity on the intertidal area
(the level between intertidal area and river channel is different from the reference run)

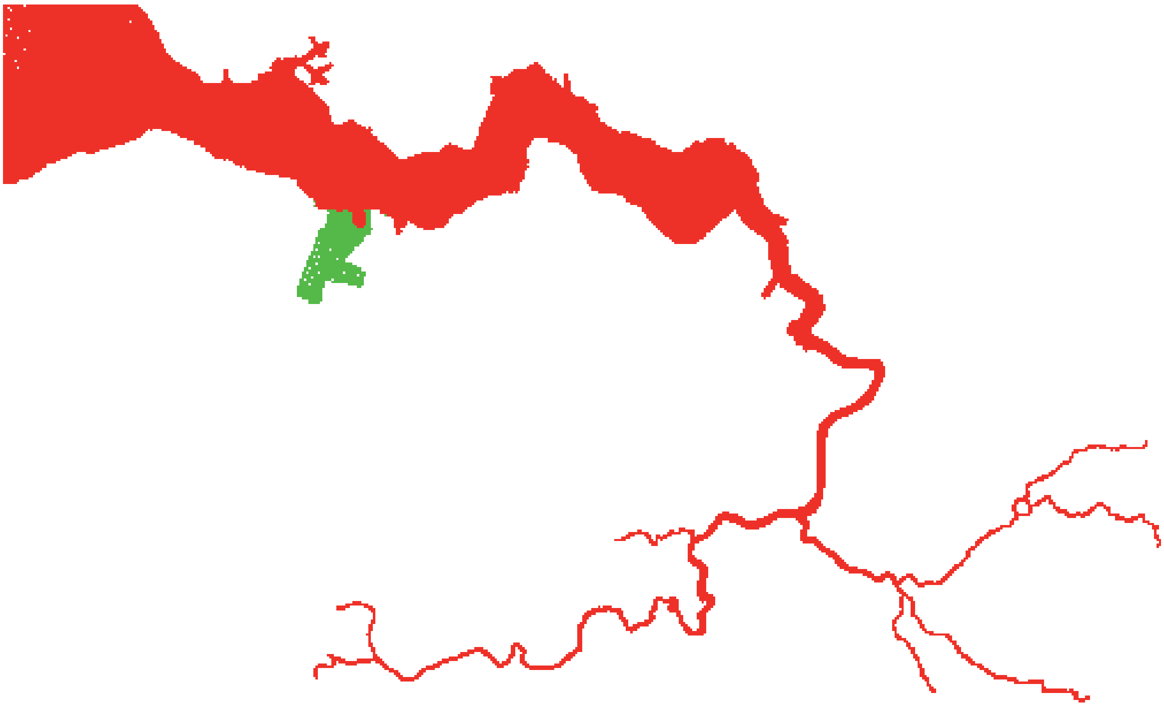


Figure 19 - Model grid (red) including the Braakman polder (green)

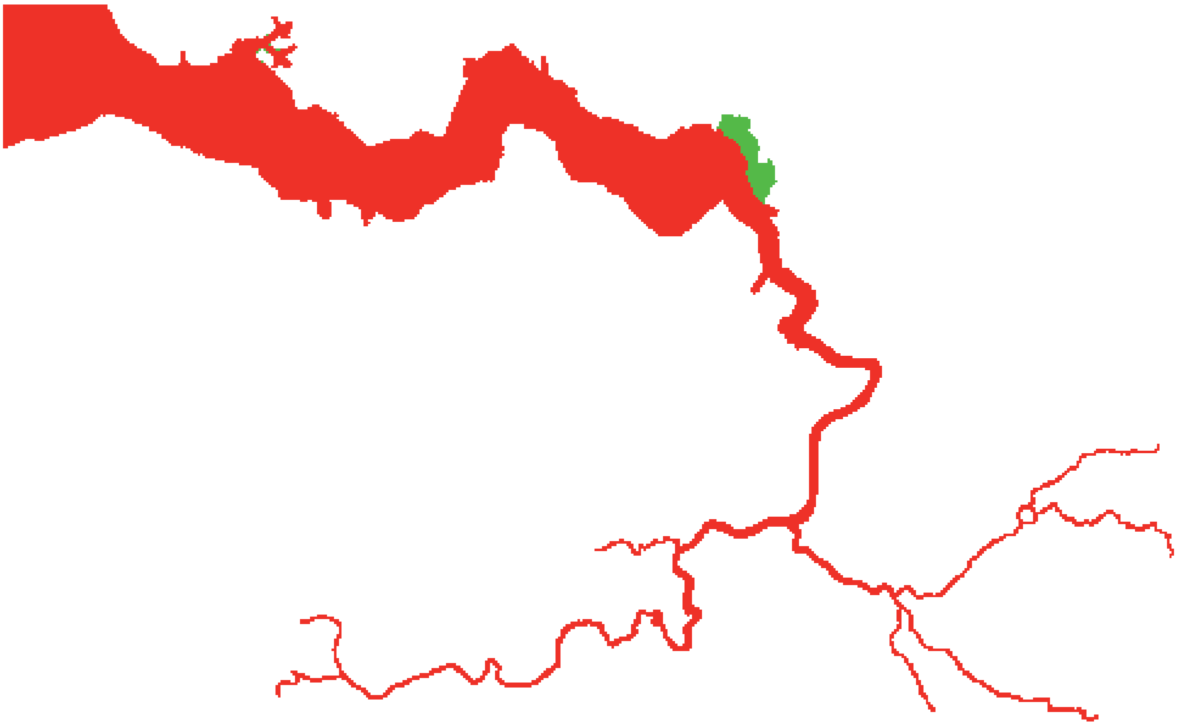


Figure 20 - Model grid (red) including the New – Westland polder (green)

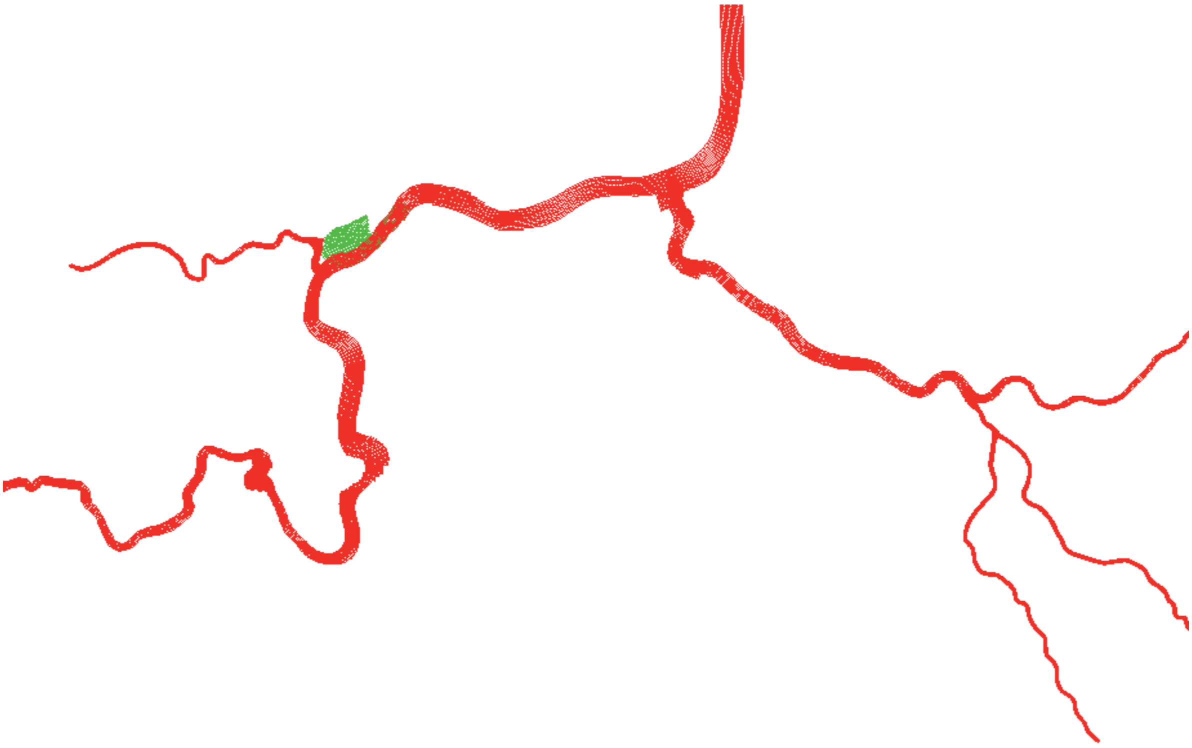


Figure 21 - Model grid (red) including the polder Tielrodebroek (green)

Figure 22 - Model grid (red) including the Groot Schoor of St-Amands (green)

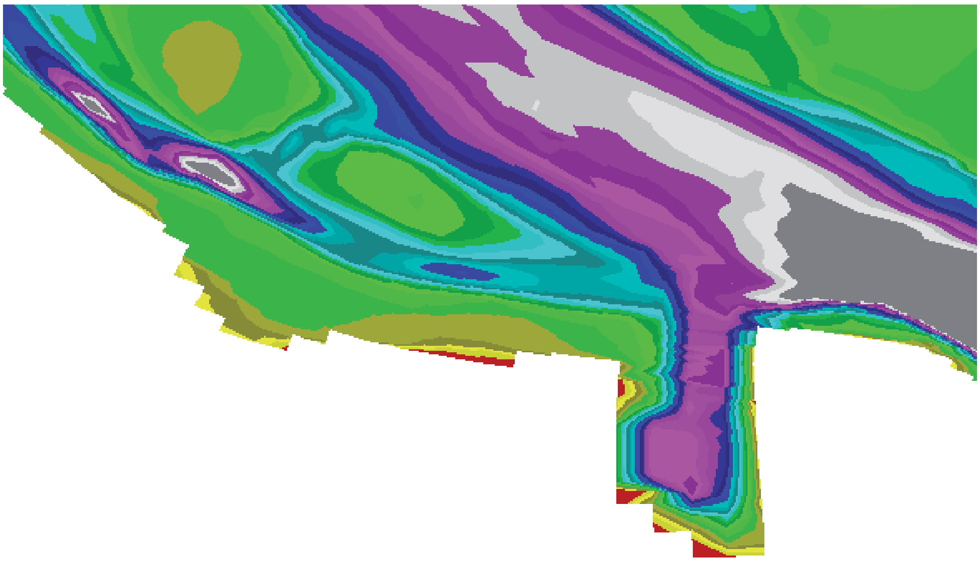


Figure 23 - Bathymetry of the Braakman polder in 2006 (m NAP)

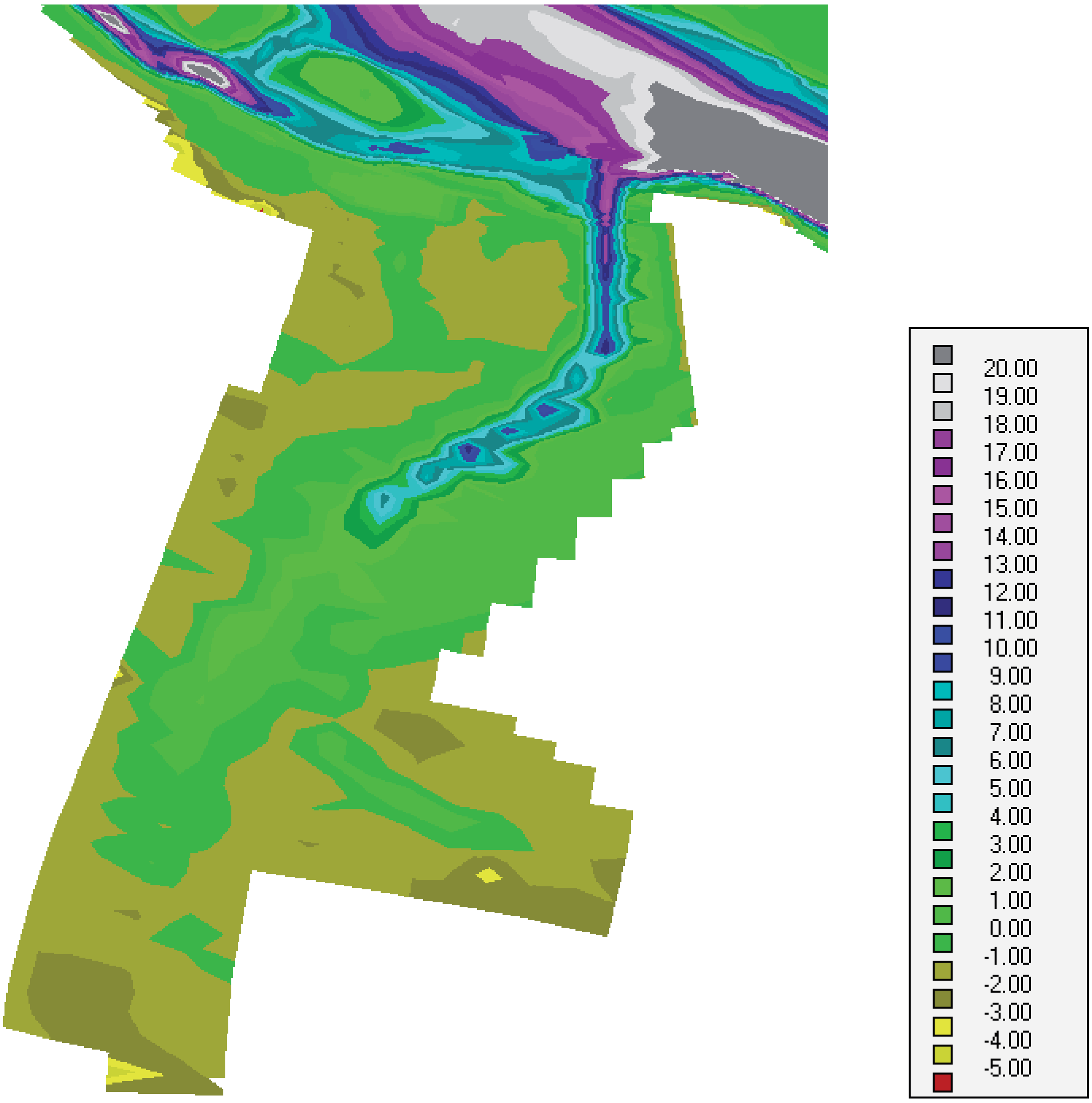


Figure 24 - Bathymetry of the Braakman polder in 1931 (m NAP)

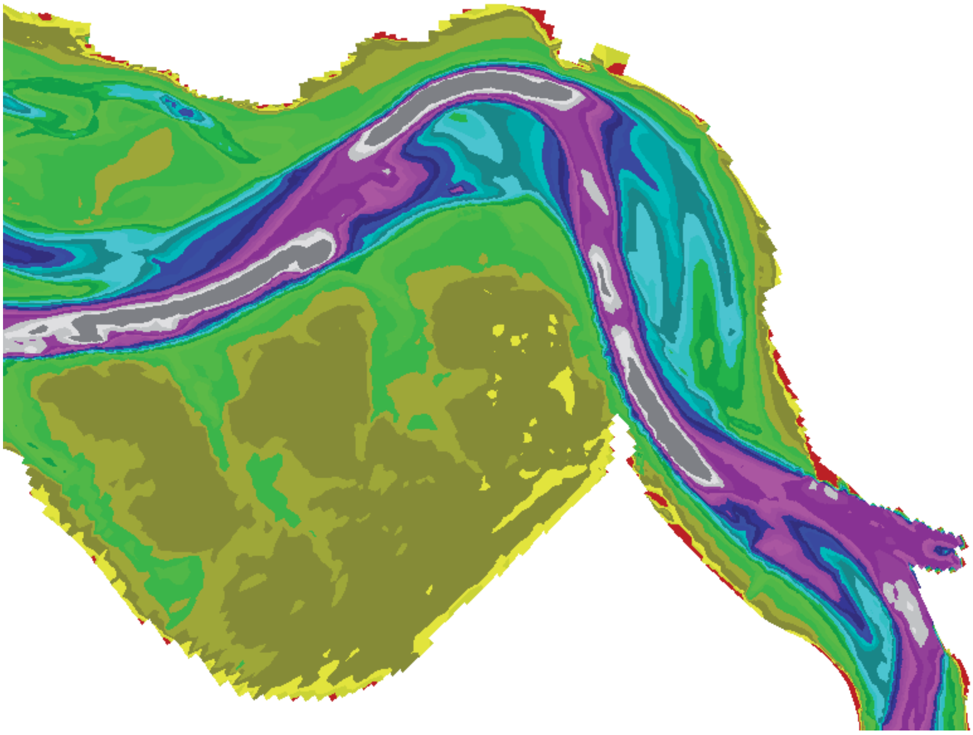


Figure 25 - Bathymetry of the New-Westland polder in 2006 (m NAP)

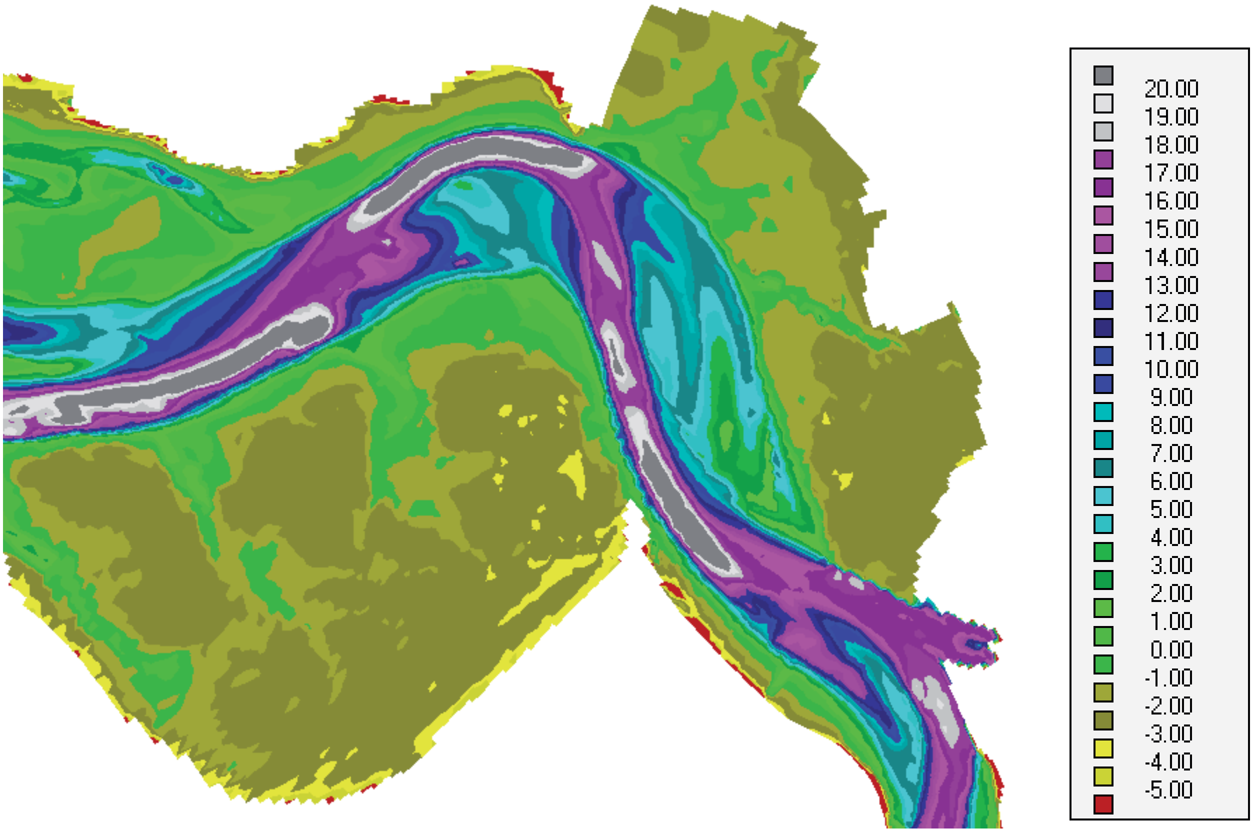


Figure 26 - Bathymetry of the New-Westland polder in 1931 (m NAP)

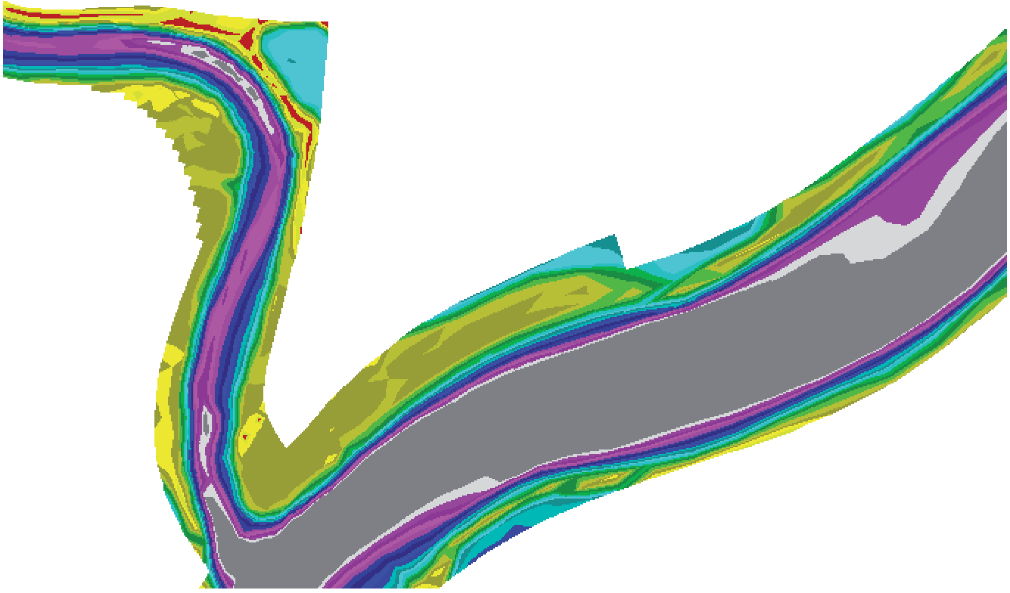


Figure 27 - Bathymetry of the Tielrodebroek in 2006 (m NAP)

Figure 28 - Adapted bathymetry of the Tielrodebroek (m NAP)

Figure 29 - Bathymetry of the Groot Schoor of St-Amands in 2006 (m NAP)

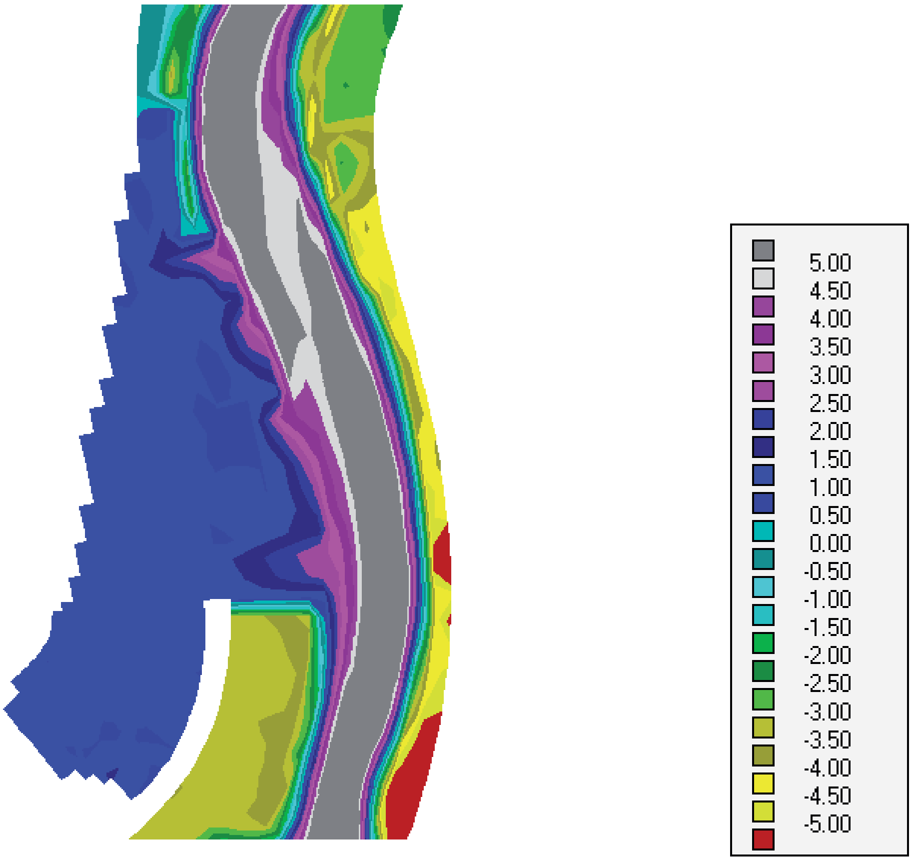


Figure 30 - Adapted bathymetry of the Groot Schoor of St-Amands (m NAP)

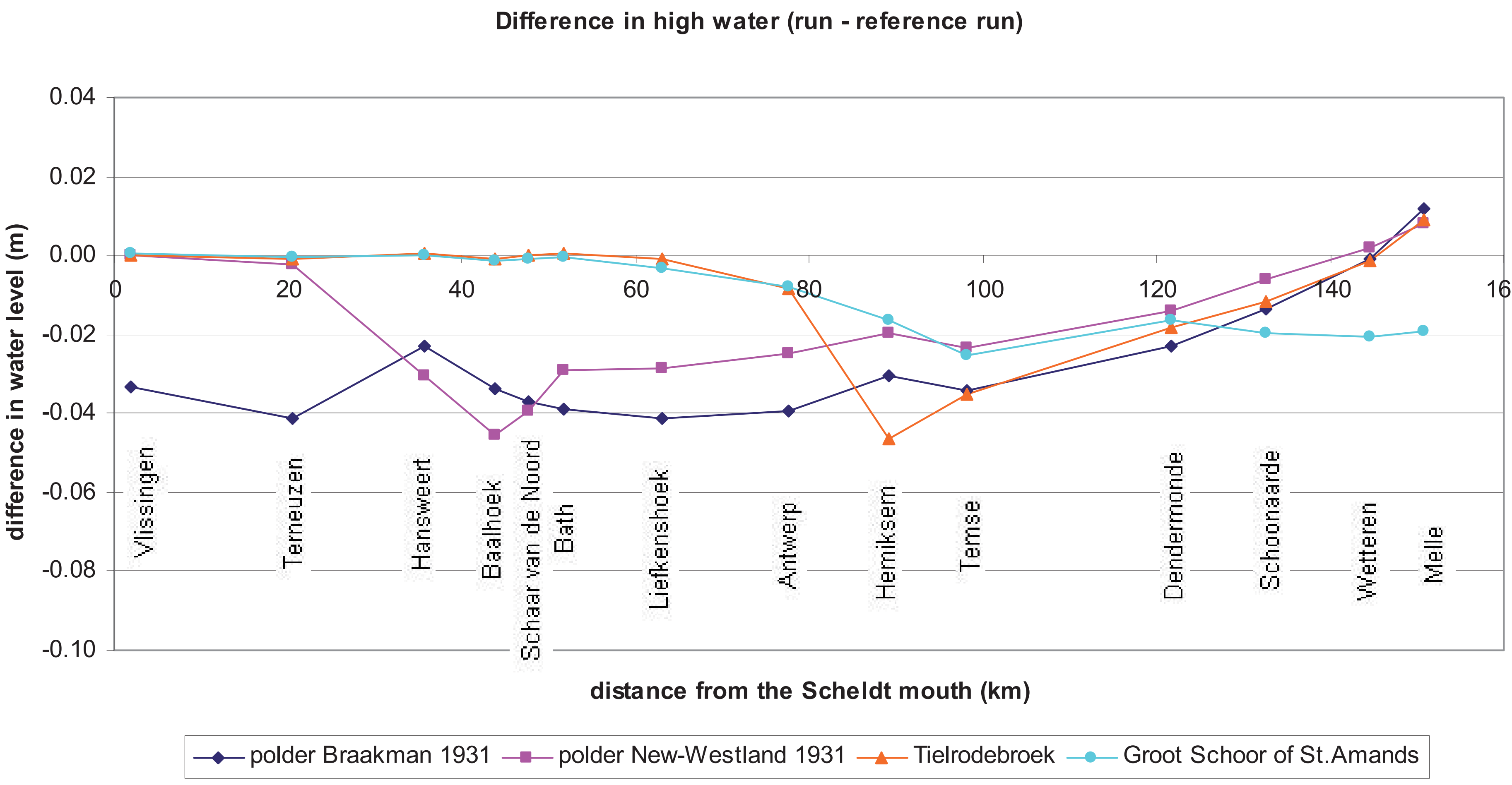


Figure 31 - Difference in high waters for scenarios with polders and reference situation
(positive value is higher high water compared to the reference simulation)

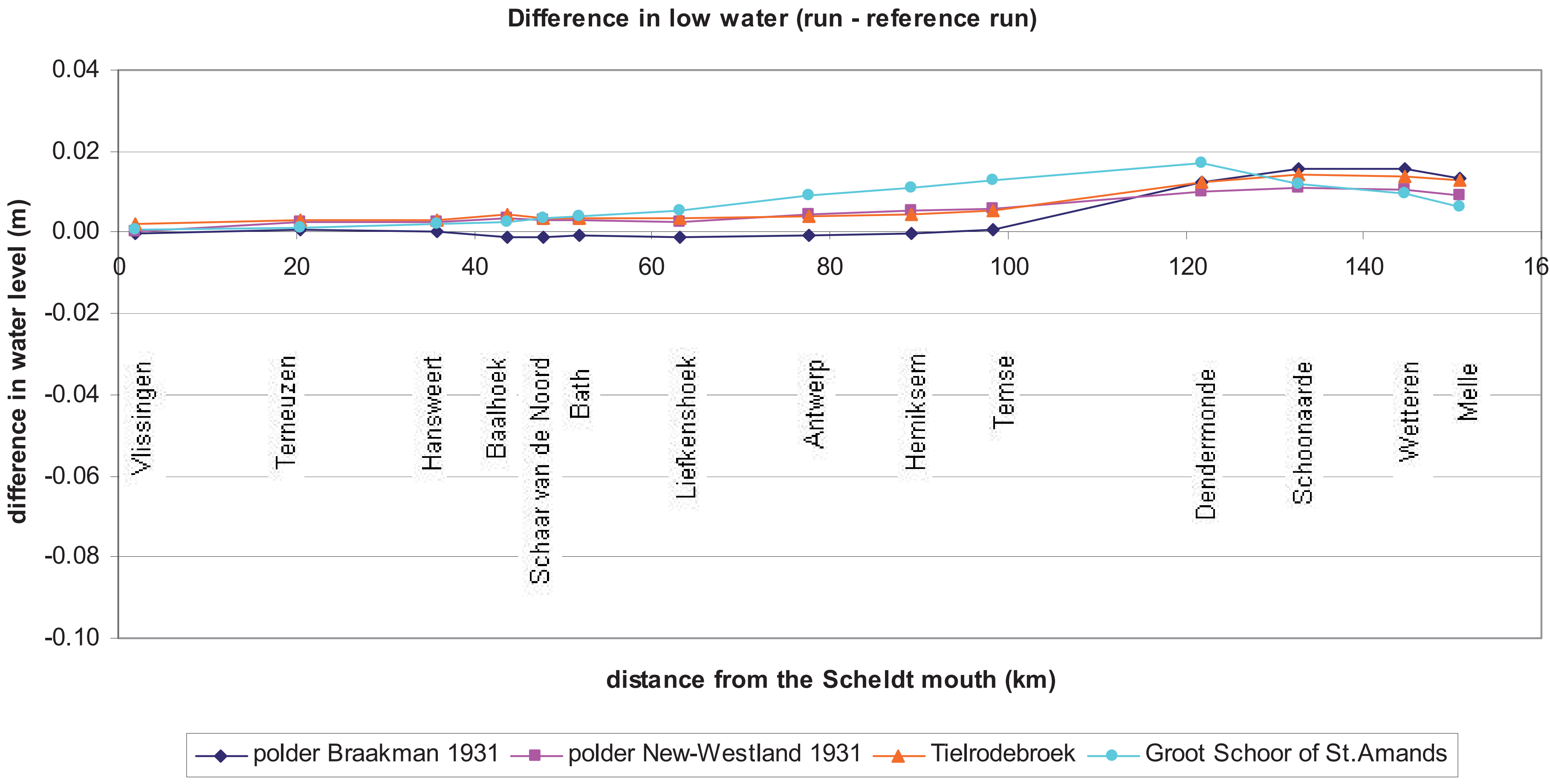


Figure 32 - Difference in low waters for scenarios with polders and reference situation
(positive value is higher low water compared to the reference simulation)

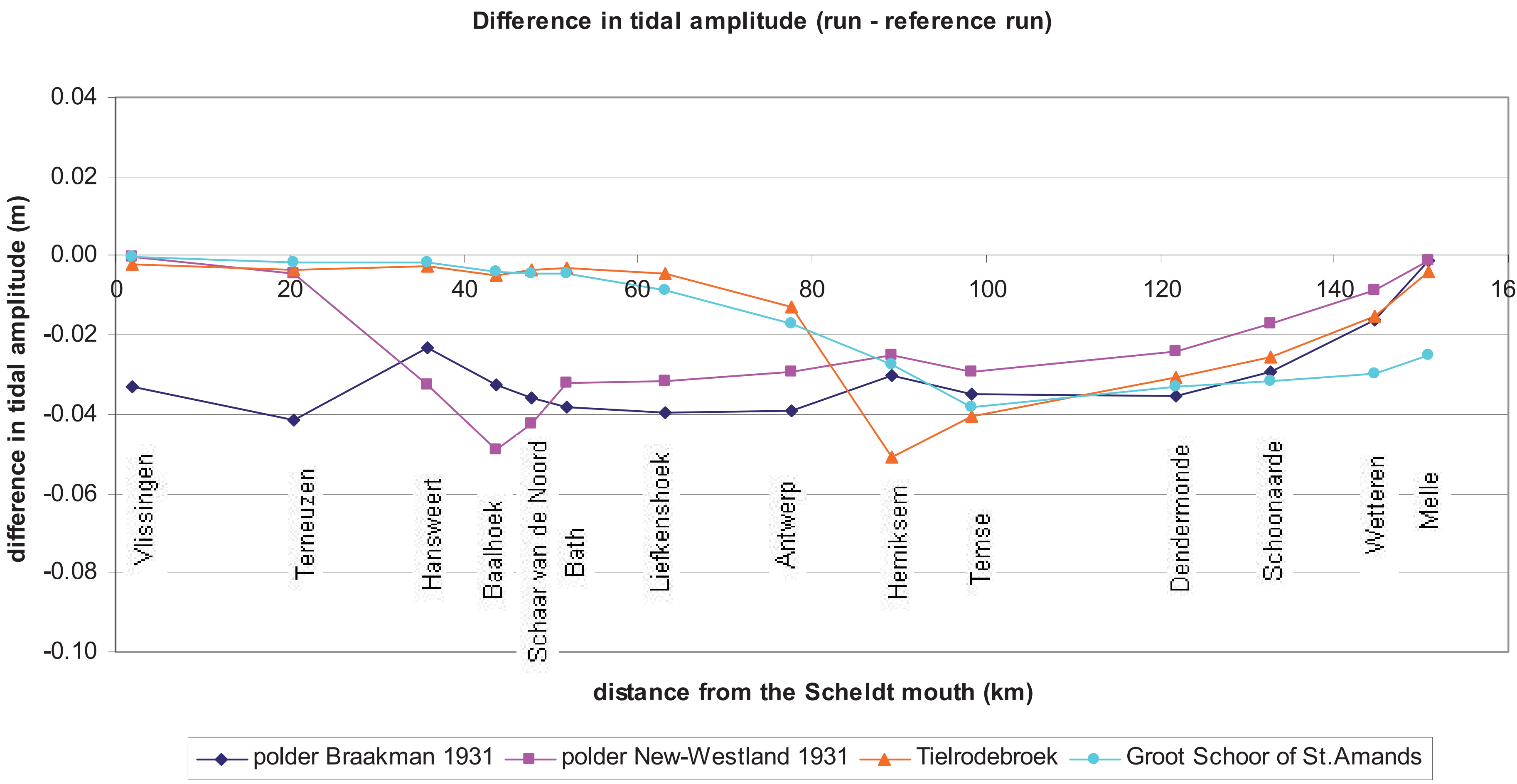


Figure 33 - Difference in tidal amplitude for scenarios with polders and reference situation
(positive value is higher tidal amplitude compared to the reference simulation)

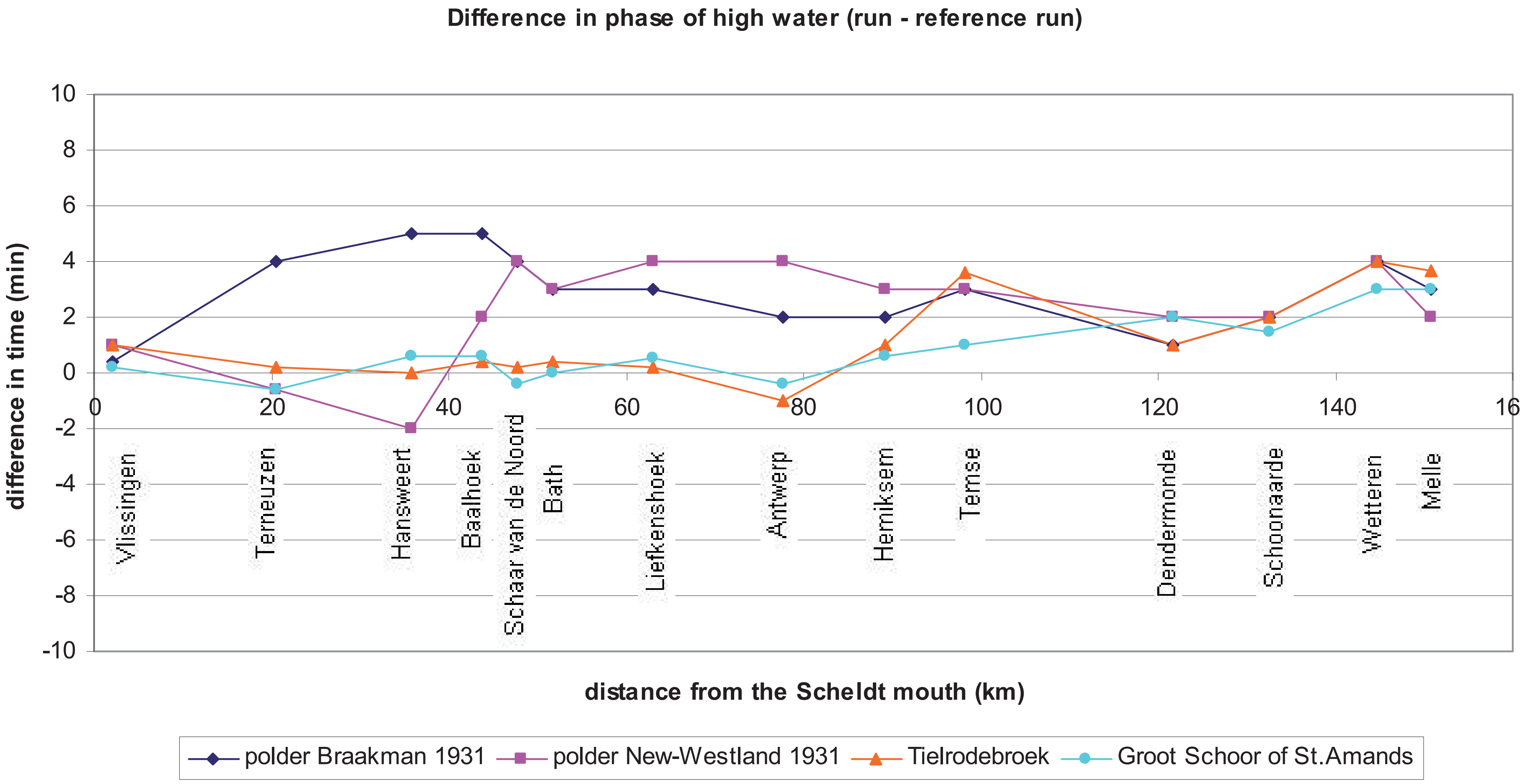


Figure 34 - Difference in phase of high water for scenarios with polders and reference situation
(positive value is later compared to the reference simulation)

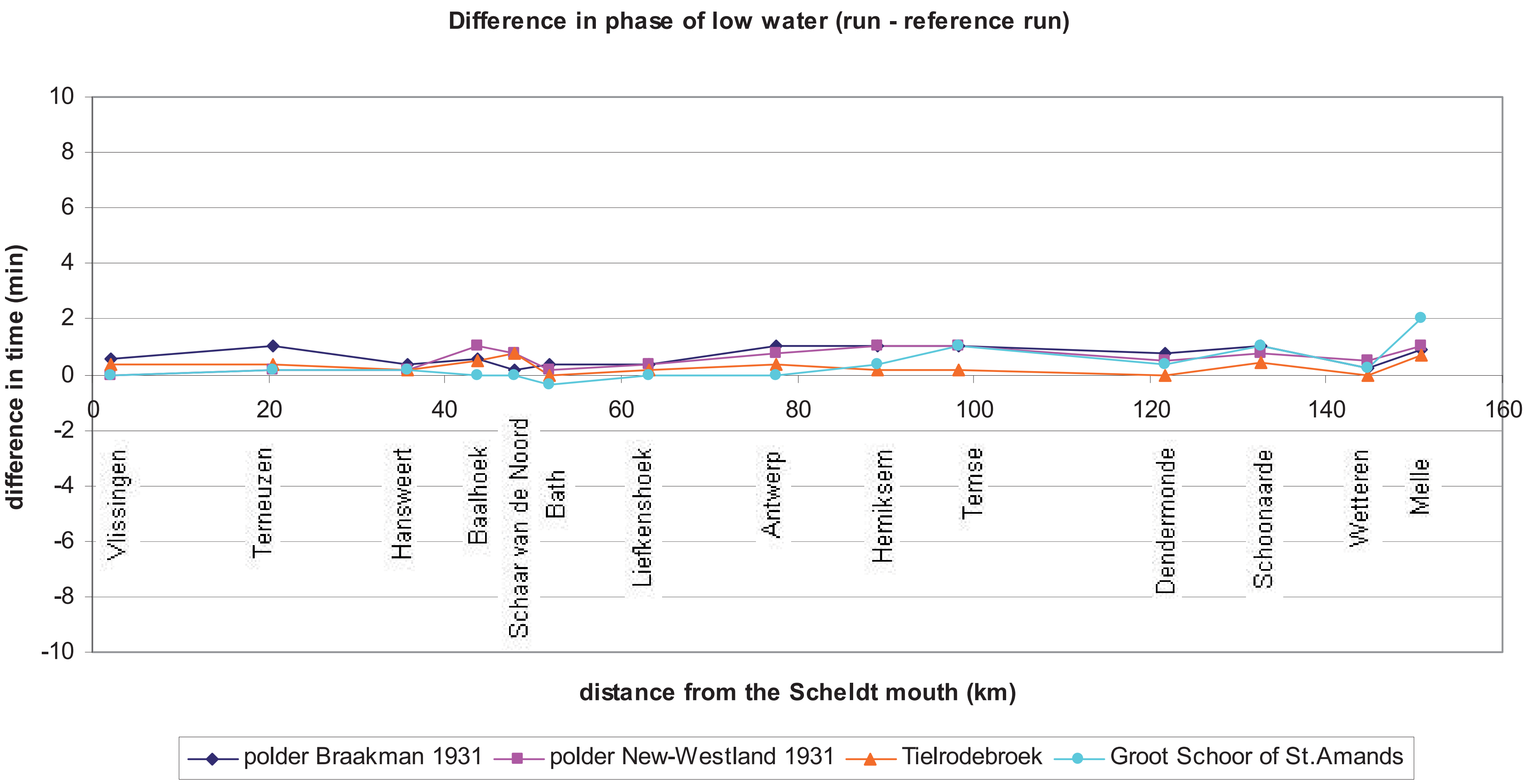


Figure 35 - Difference in phase of low water for scenarios with polders and reference situation
(positive value is later compared to the reference simulation)

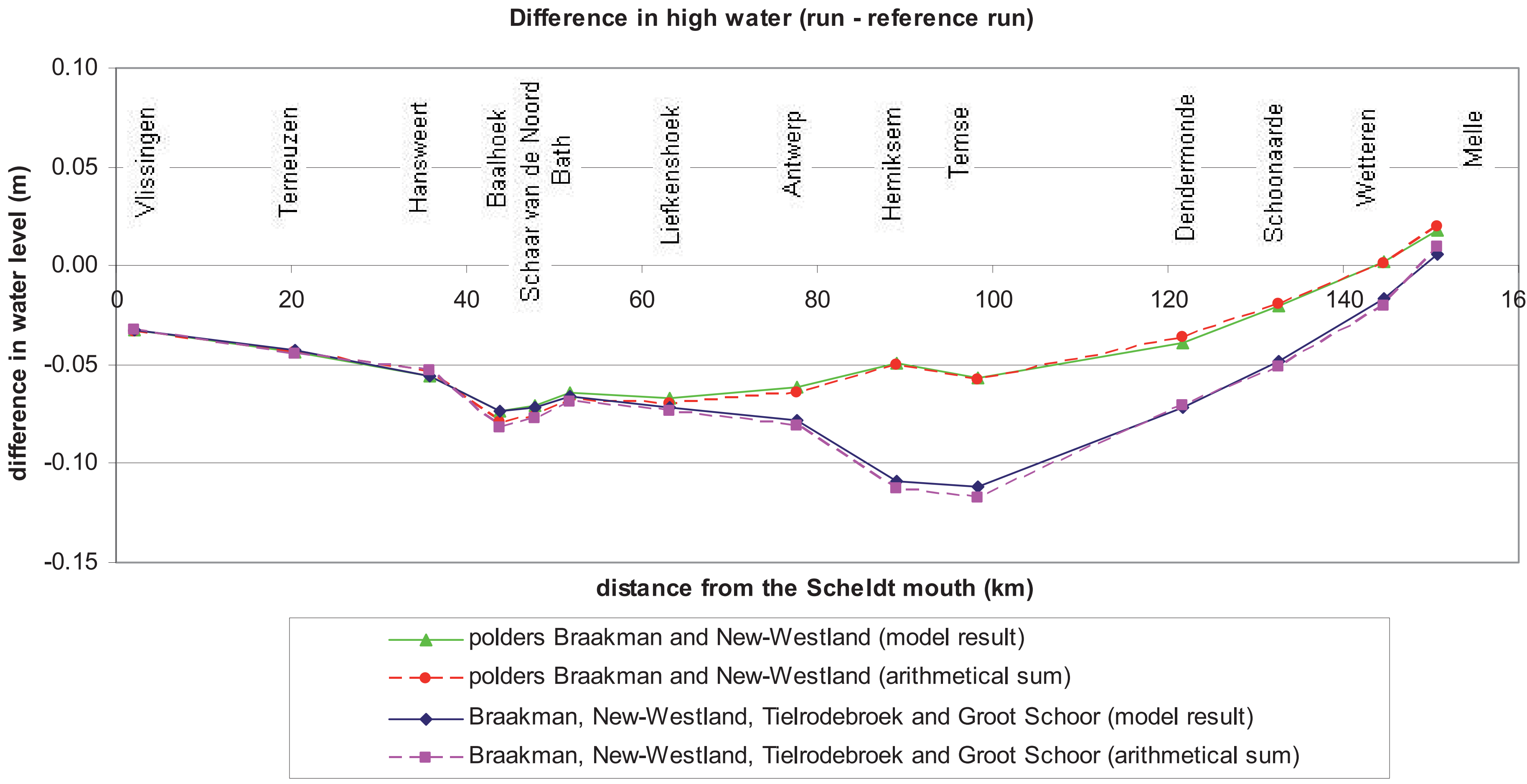


Figure 36 - Difference in high waters for scenarios with the group of polders and reference situation (positive value is higher high water compared to the reference simulation)

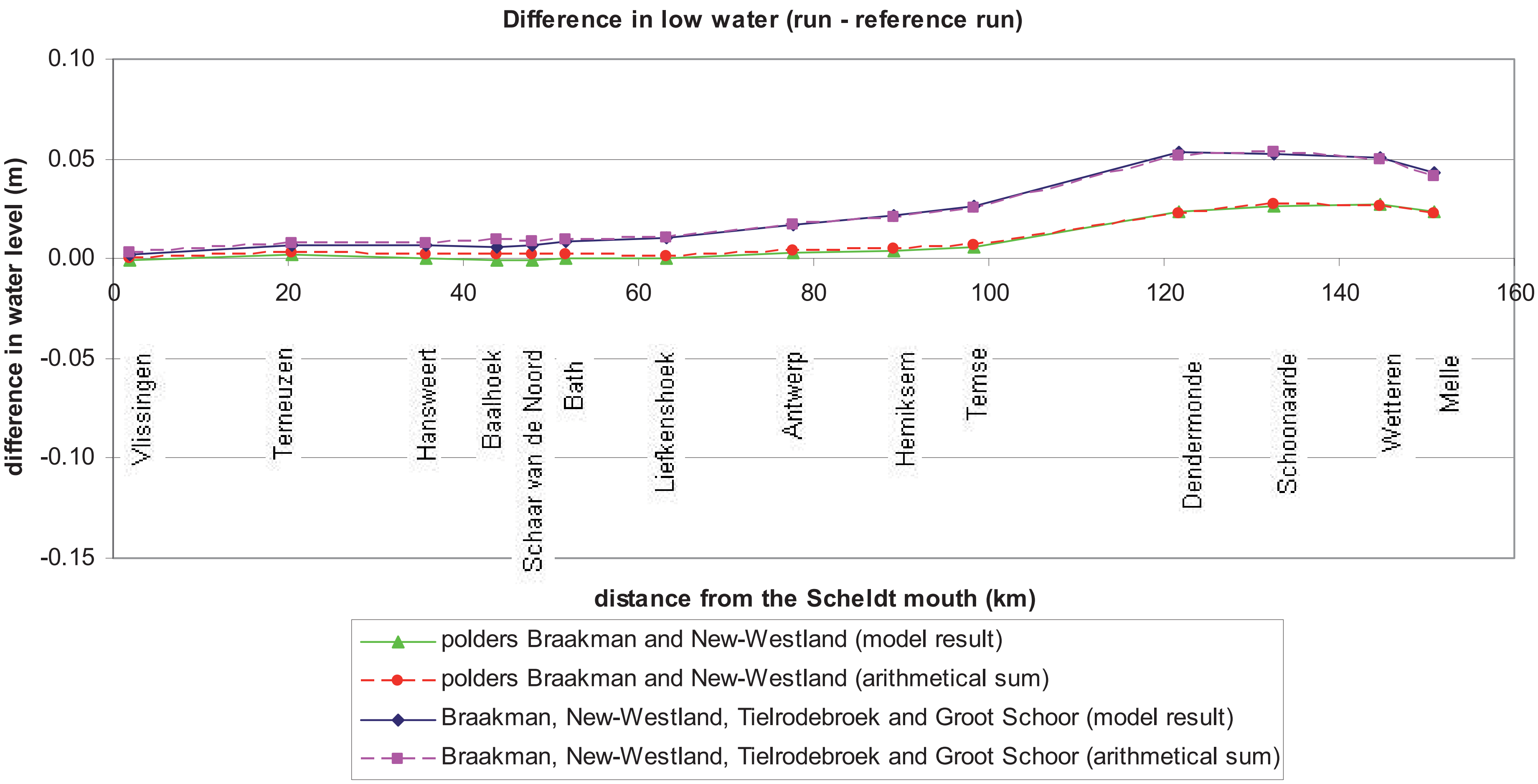


Figure 37 - Difference in low waters for scenarios with the group of polders and reference situation
(positive value is higher low water compared to the reference simulation)

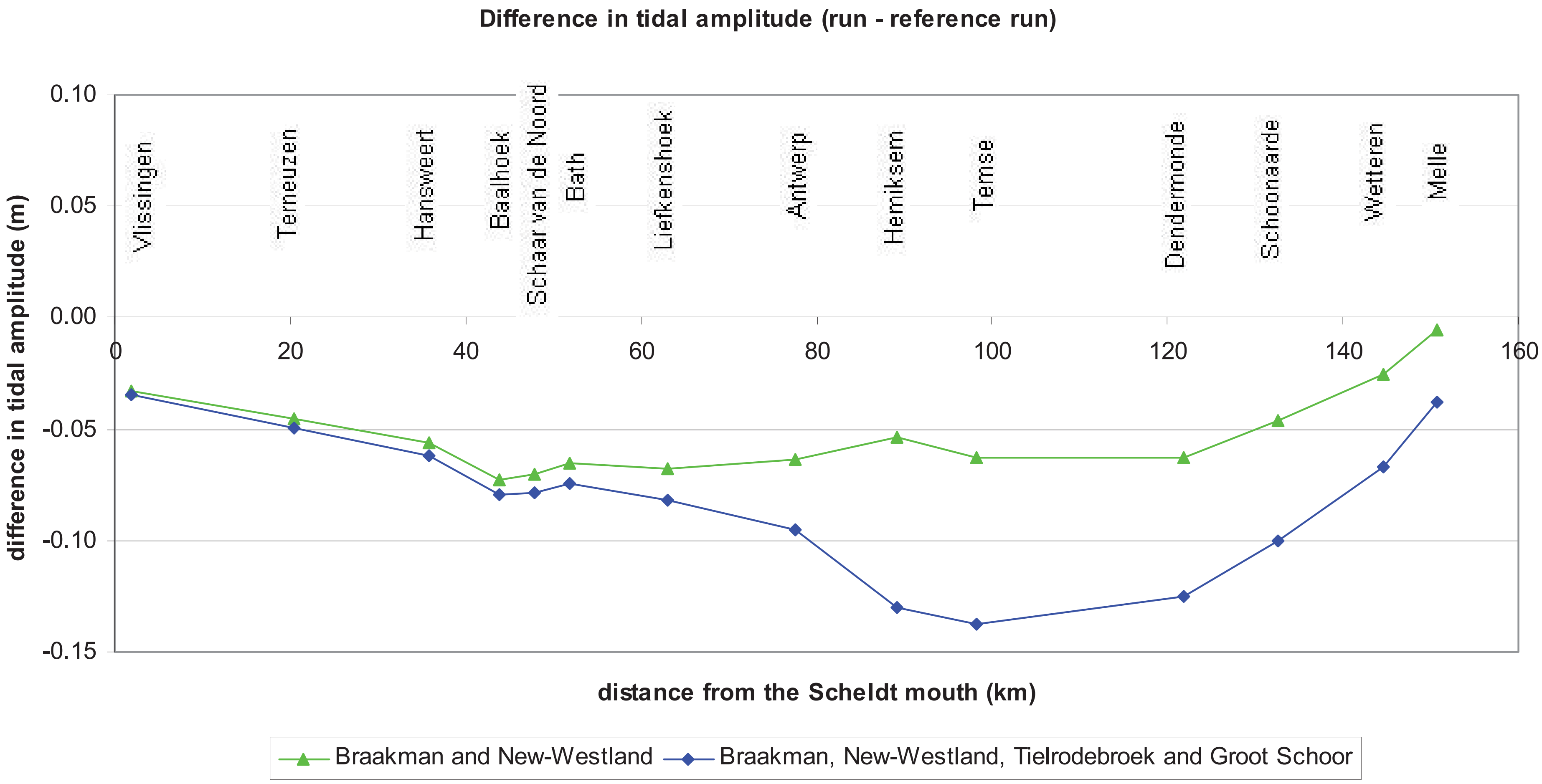


Figure 38 - Difference in tidal amplitude for scenarios with the group of polders and reference situation
(positive value is higher tidal amplitude compared to the reference simulation)

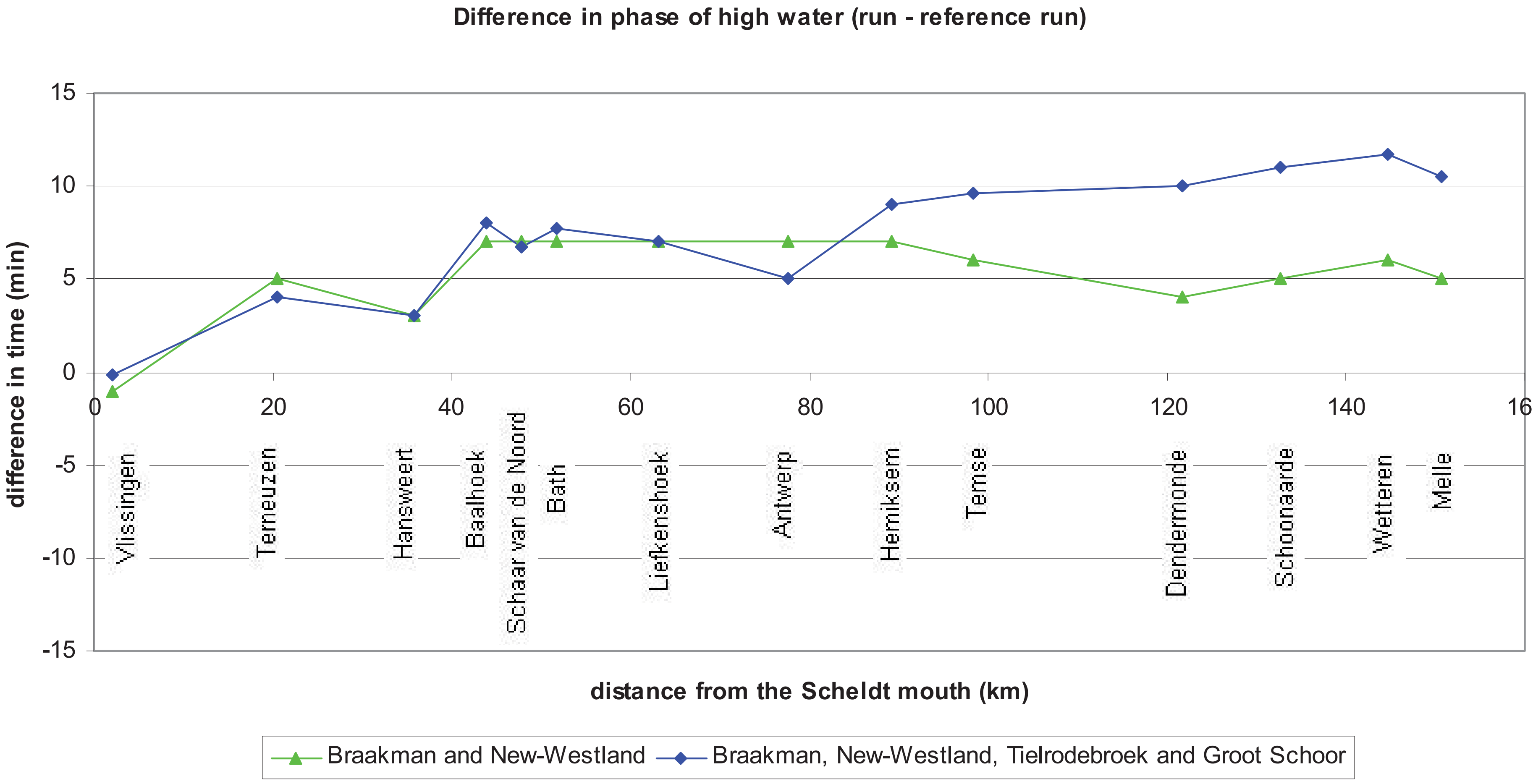


Figure 39 - Difference in phase of high water for scenarios with the group of polders and reference situation
(positive value is later compared to the reference simulation)

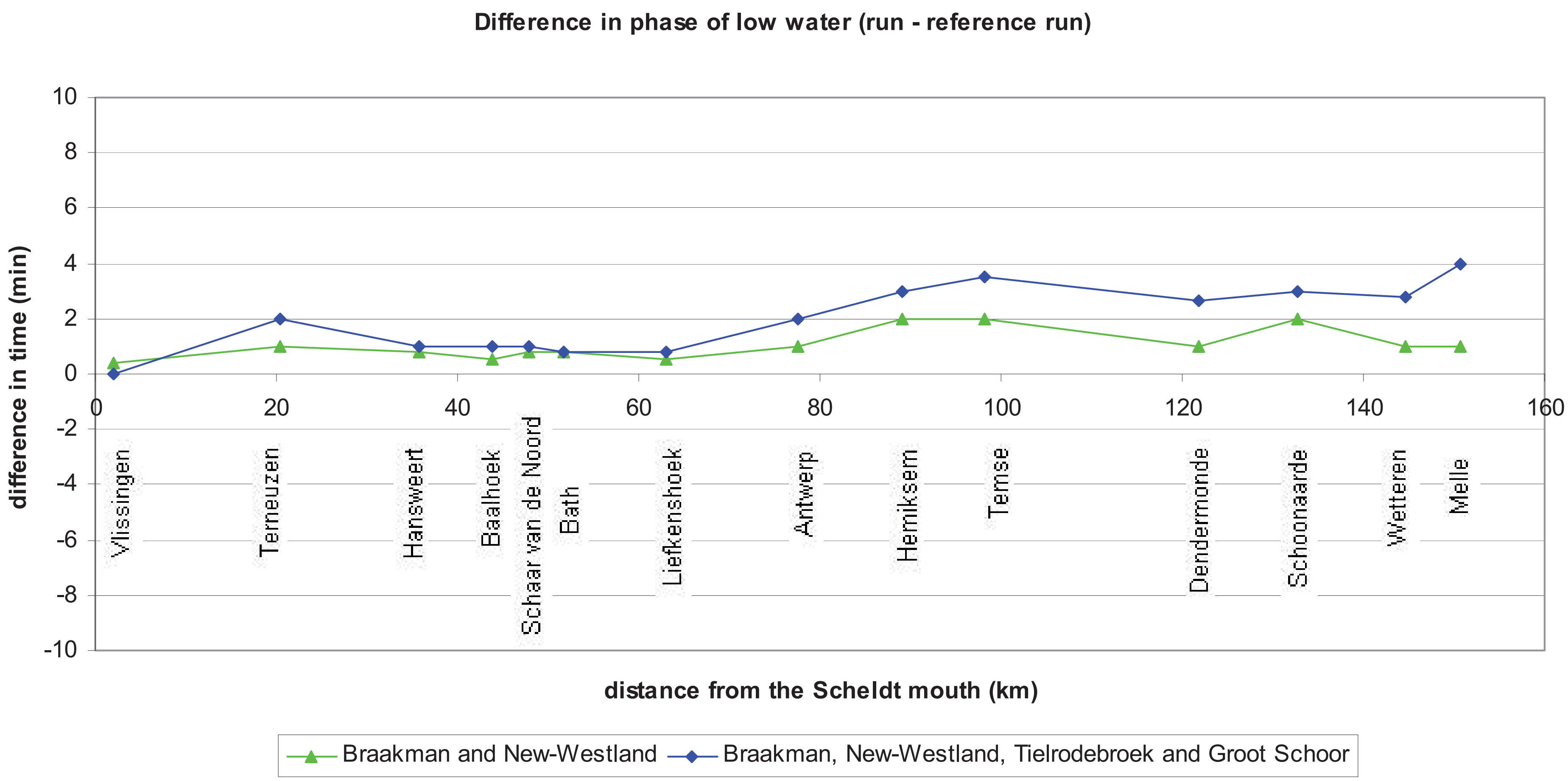


Figure 40 - Difference in phase of low water for scenarios with the group of polders and reference situation
(positive value is later compared to the reference simulation)

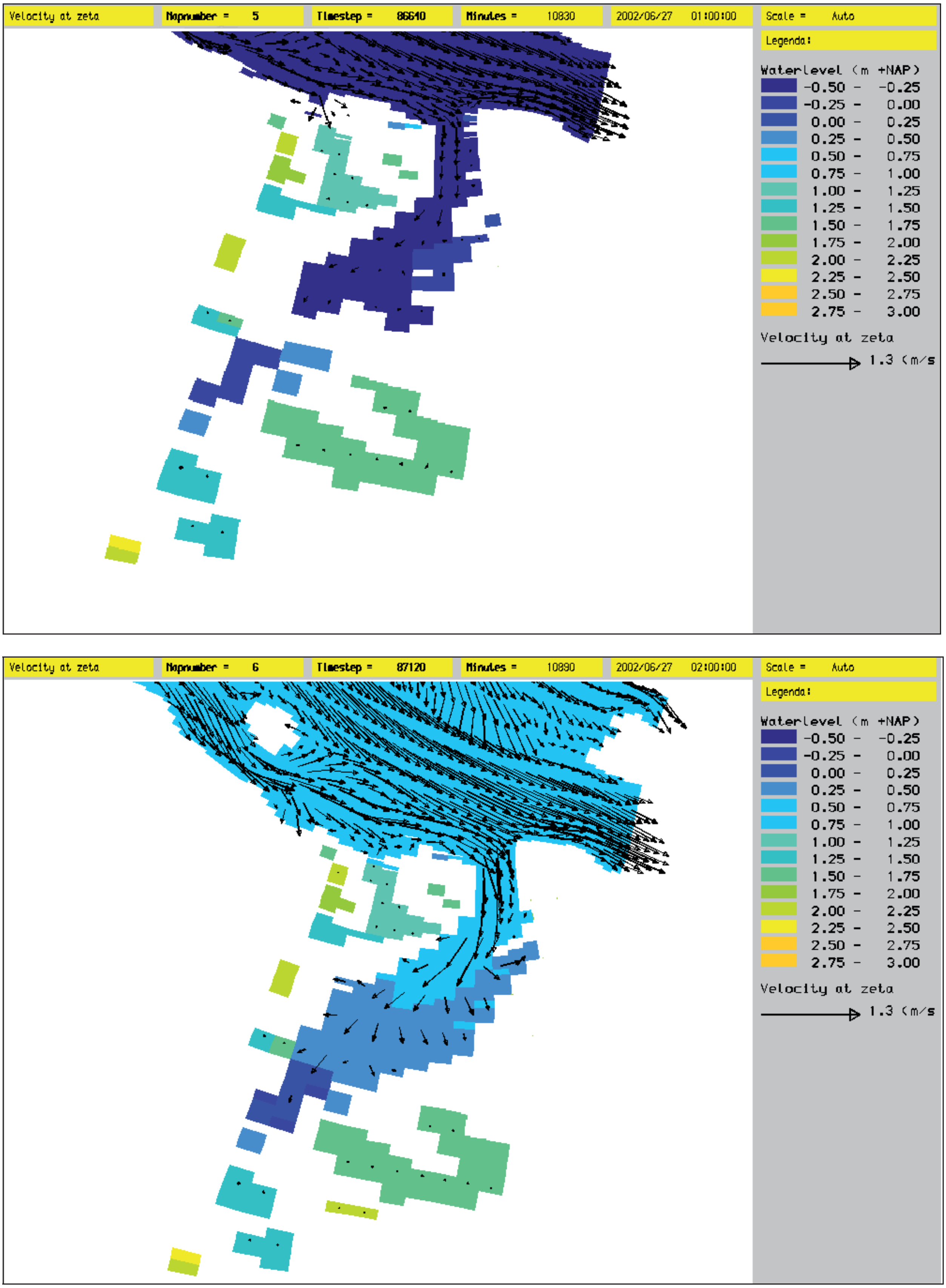


Figure 41 - Maps of the water level and velocity for the polder Braakman for the flood period

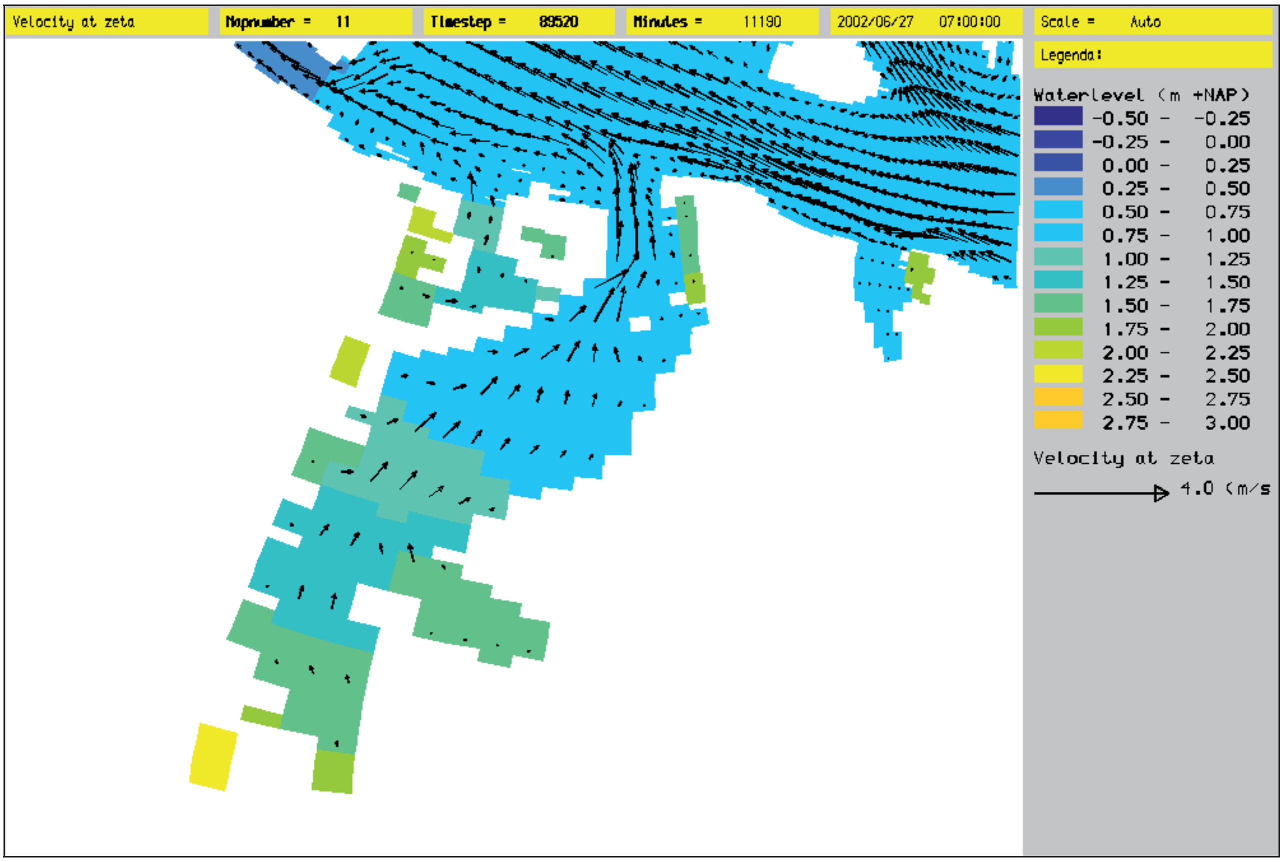


Figure 42 - Maps of the water level and velocity for the polder Braakman for the ebb period

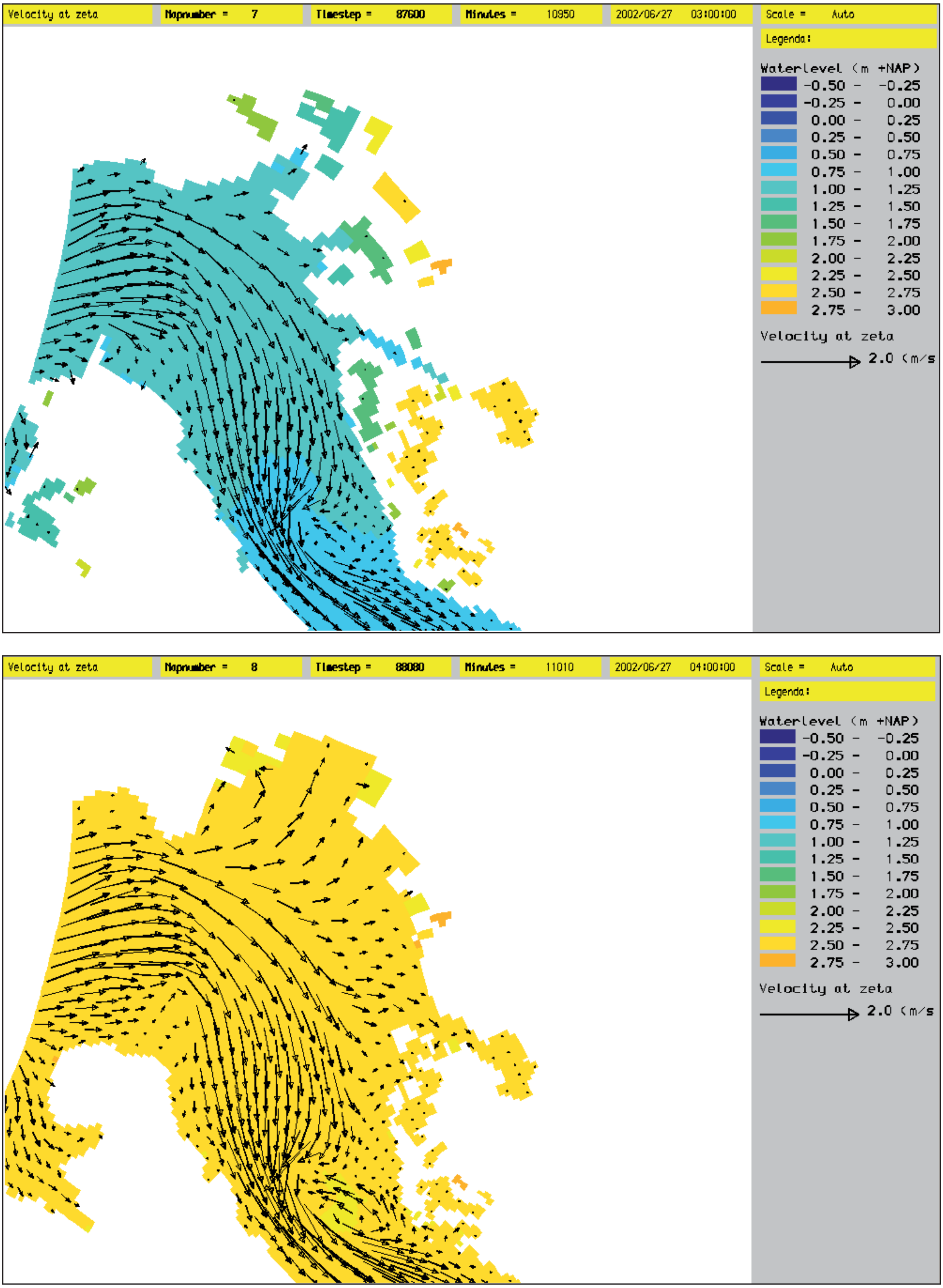


Figure 43 - Maps of the water level and velocity for the New-Westland polder for the flood period

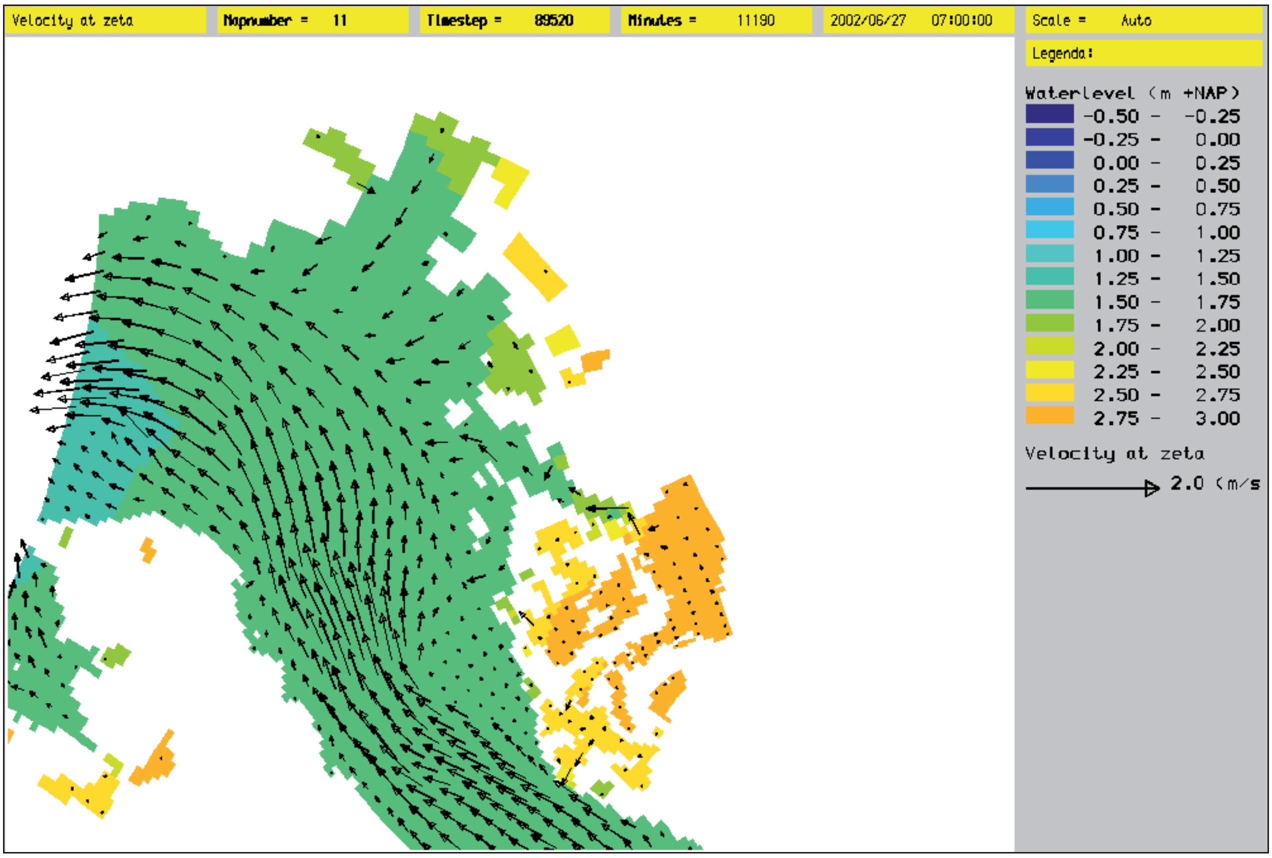


Figure 44 - Map of the water level and velocity for the New-Westland polder for the ebb period

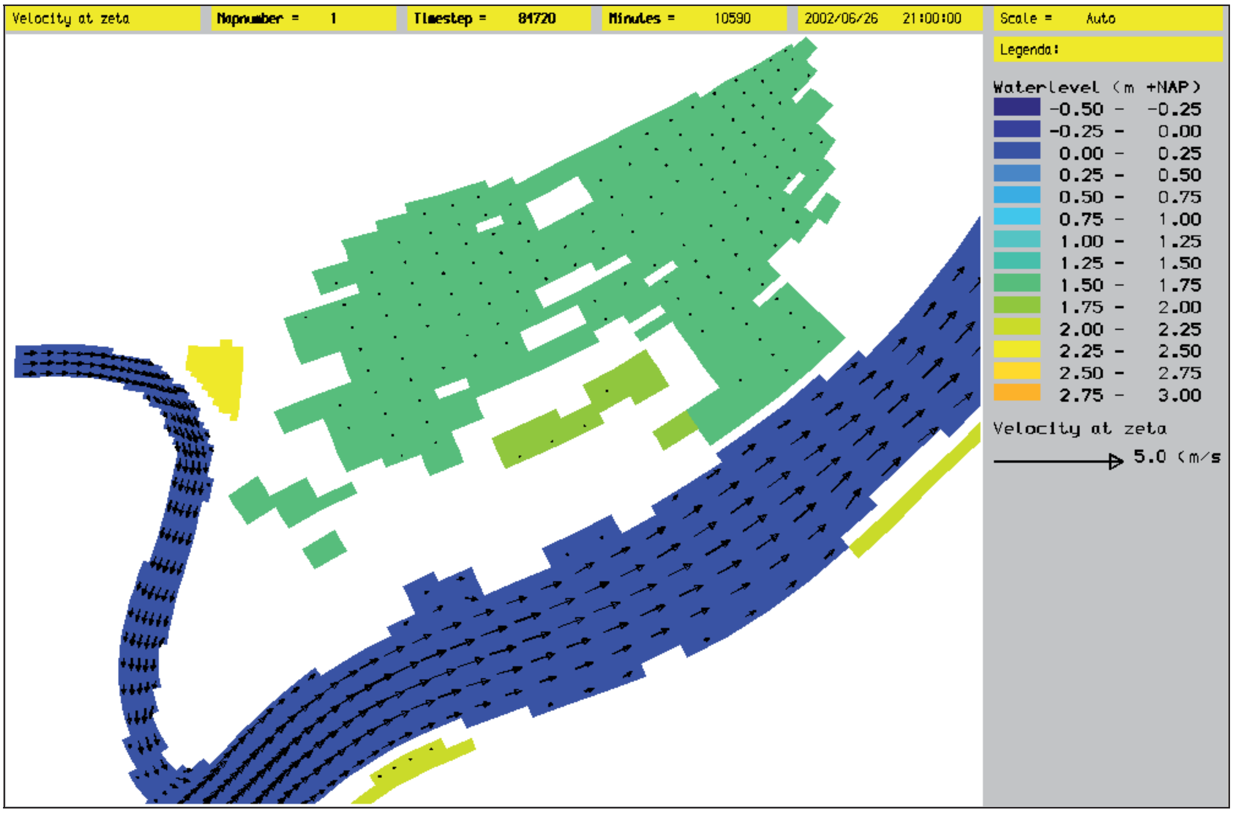


Figure 45 - Map of the water level and velocity for the Tielrodebroek for the ebb period

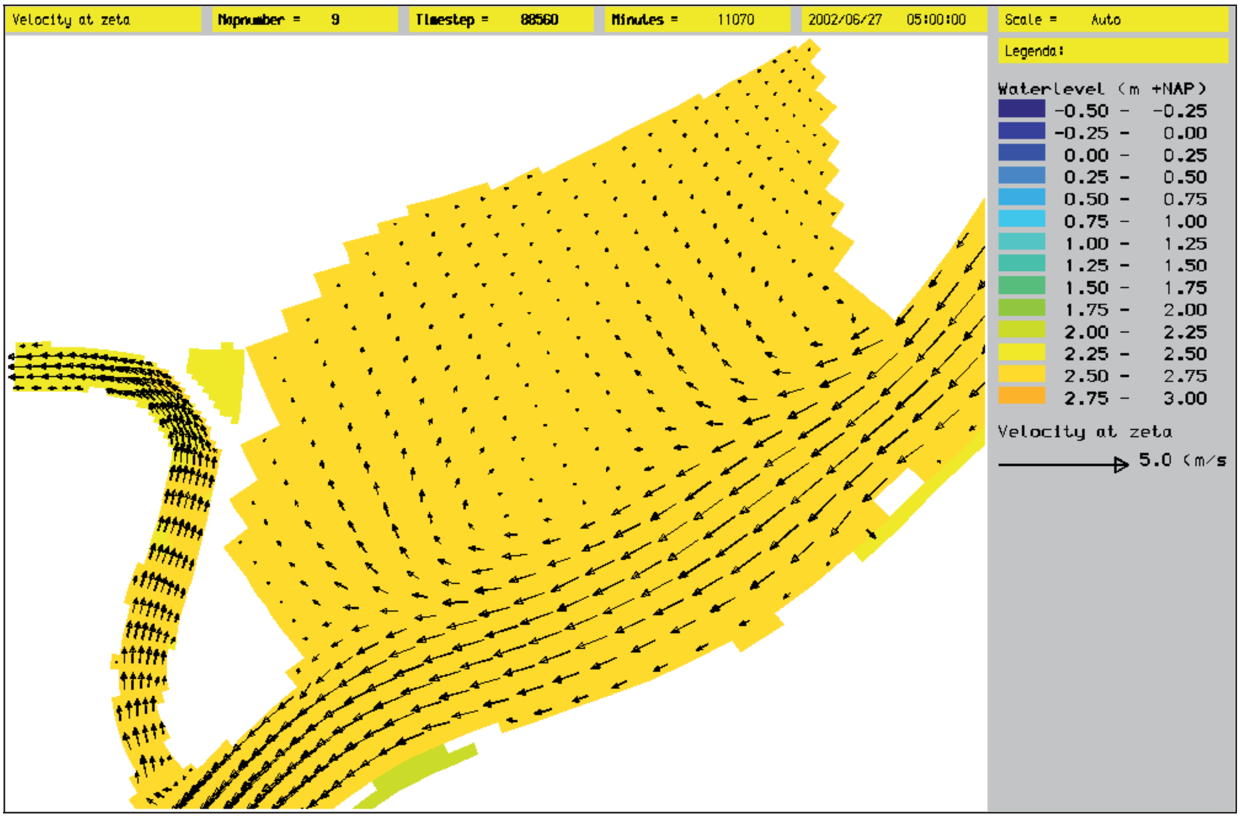


Figure 46 - Map of the water level and velocity for the Tielrodebroek for the flood period

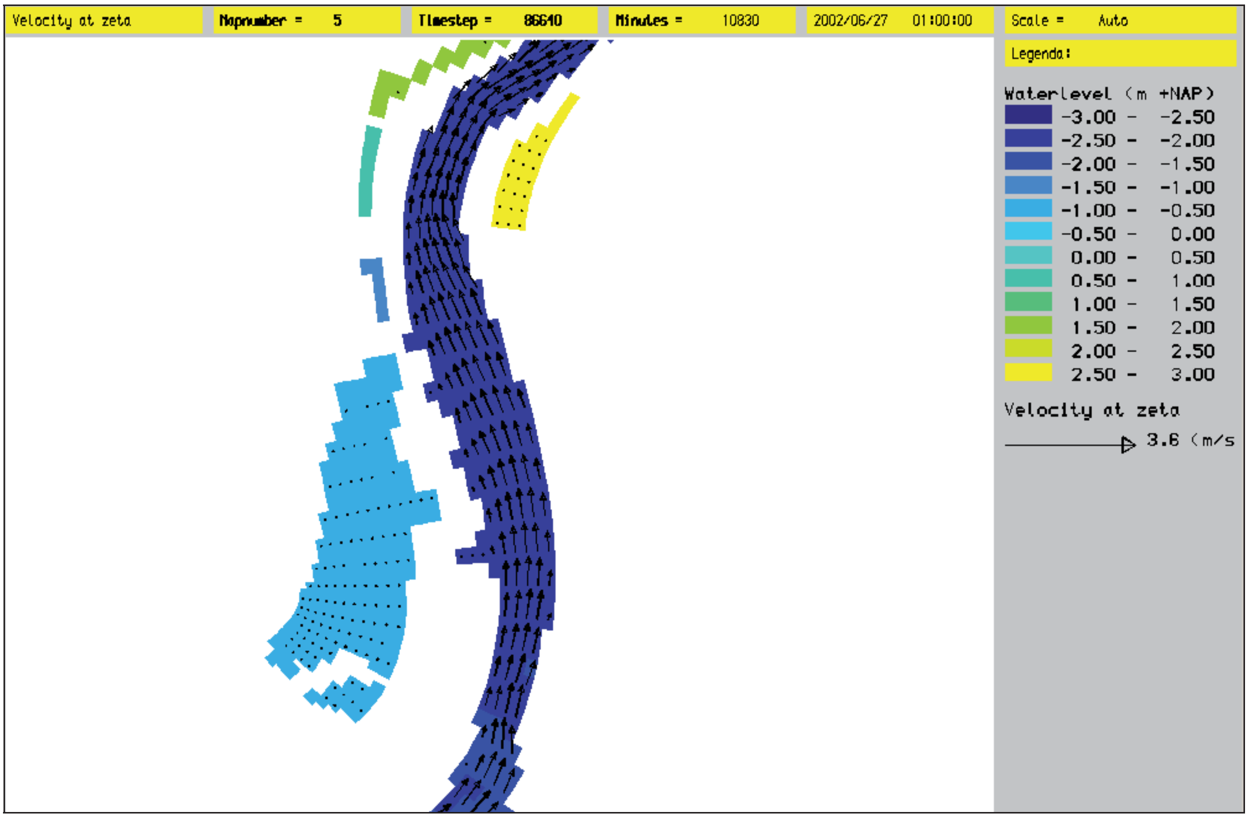


Figure 47 - Map of the water level and velocity for the Groot Schoor of St-Amands for the ebb period

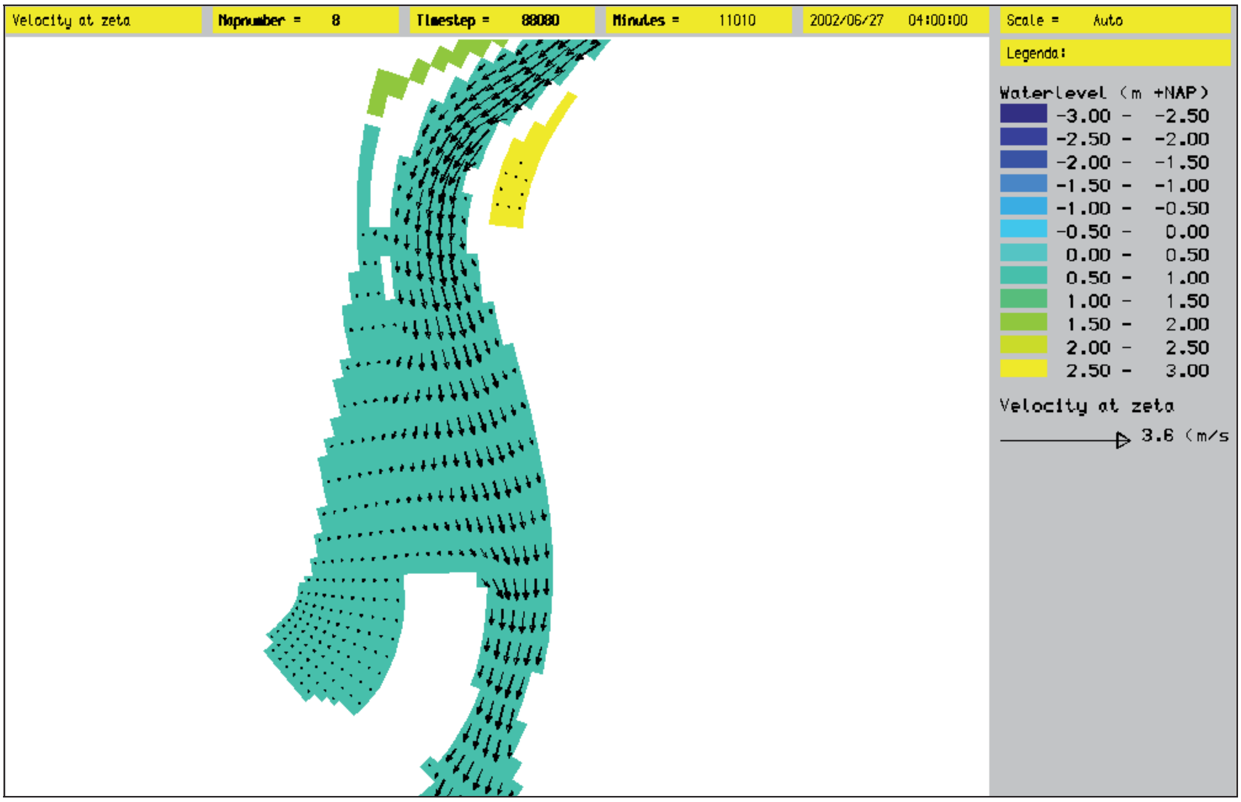
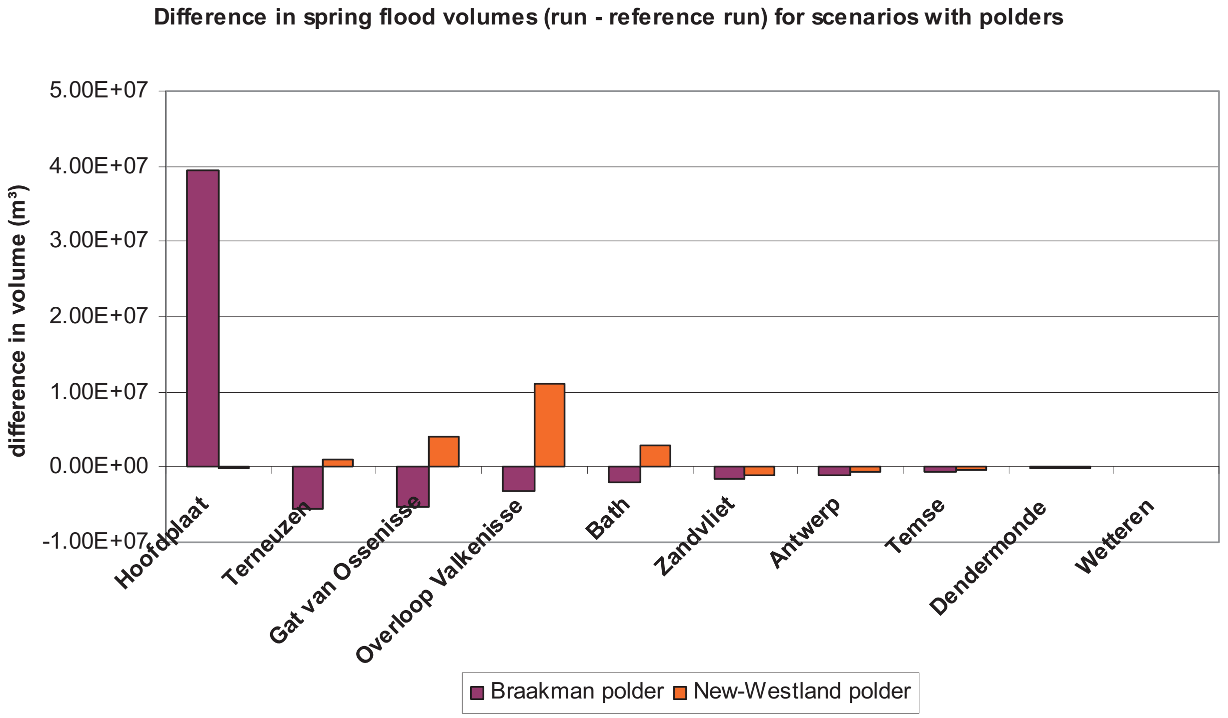


Figure 48 - Map of the water level and velocity for the Groot Schoor of St-Amands for the flood period



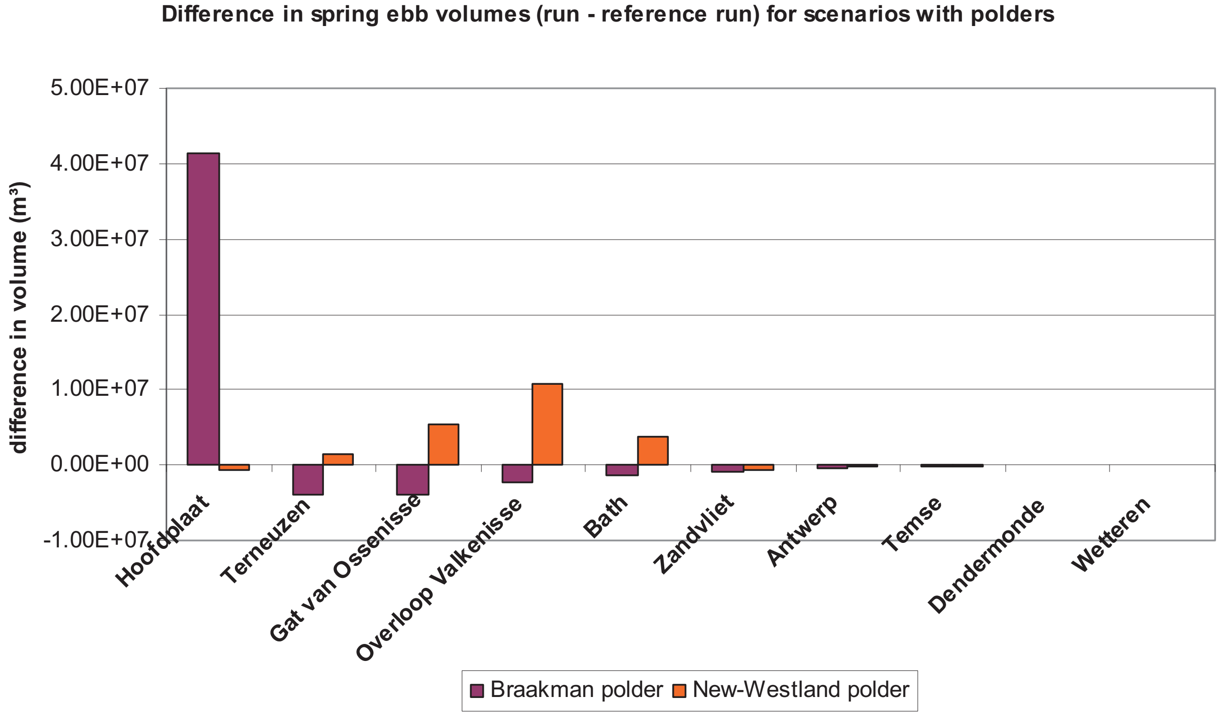
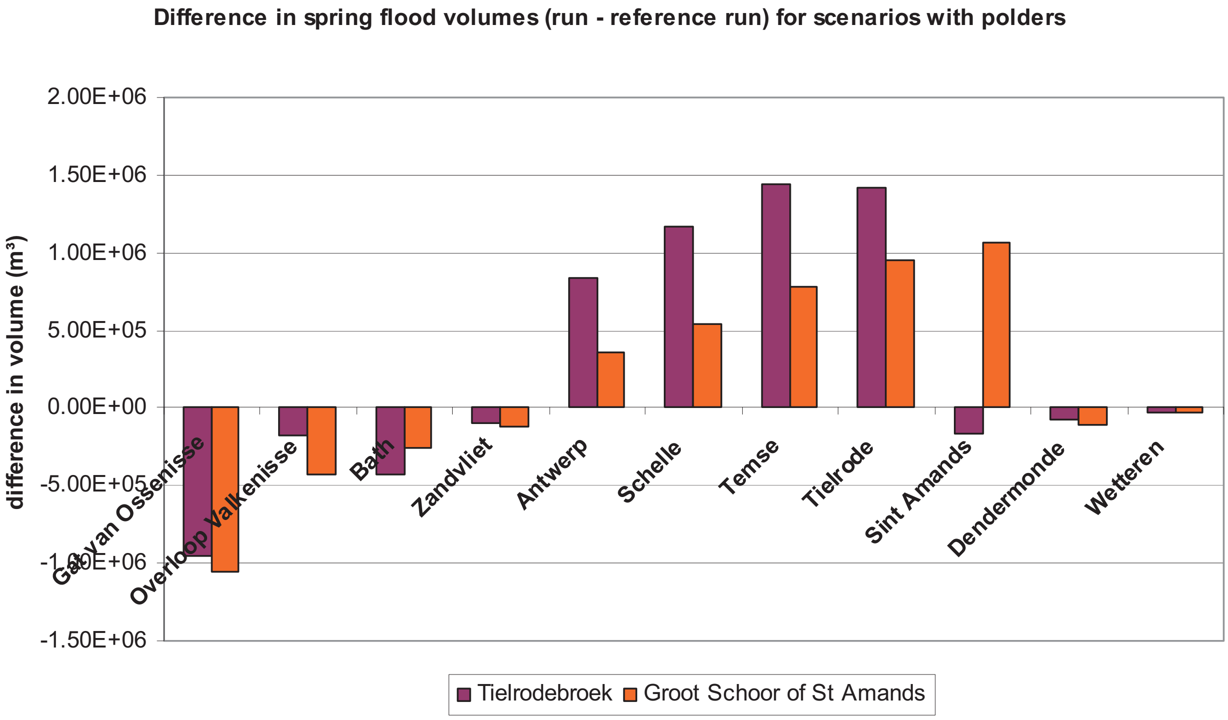


Figure 49 - Differences in the flood and ebb volumes for the scenarios with the Braakman and New-Westland polders and reference run



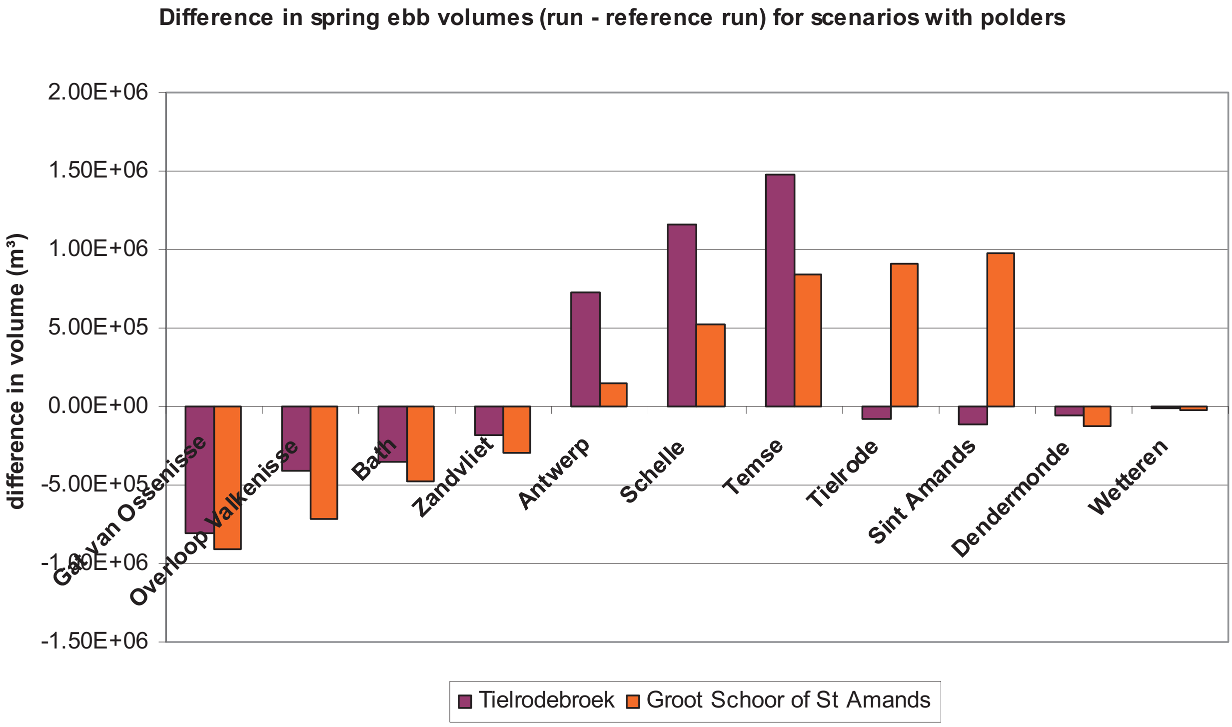


Figure 50 - Differences in the flood and ebb volumes for the scenarios with the Tielrodebroek and Groot Schoor of St-Amands and reference run

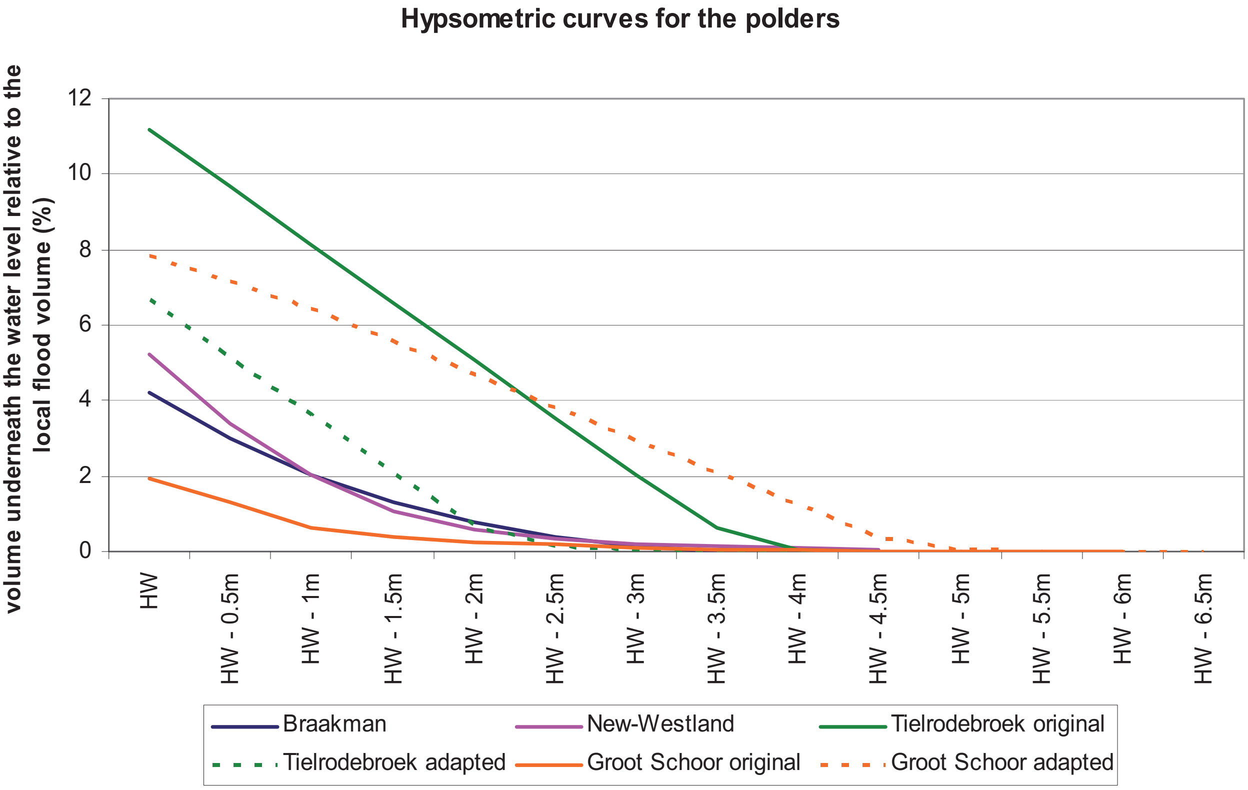


Figure 51 - Hypsometric curves for the different depoldered areas

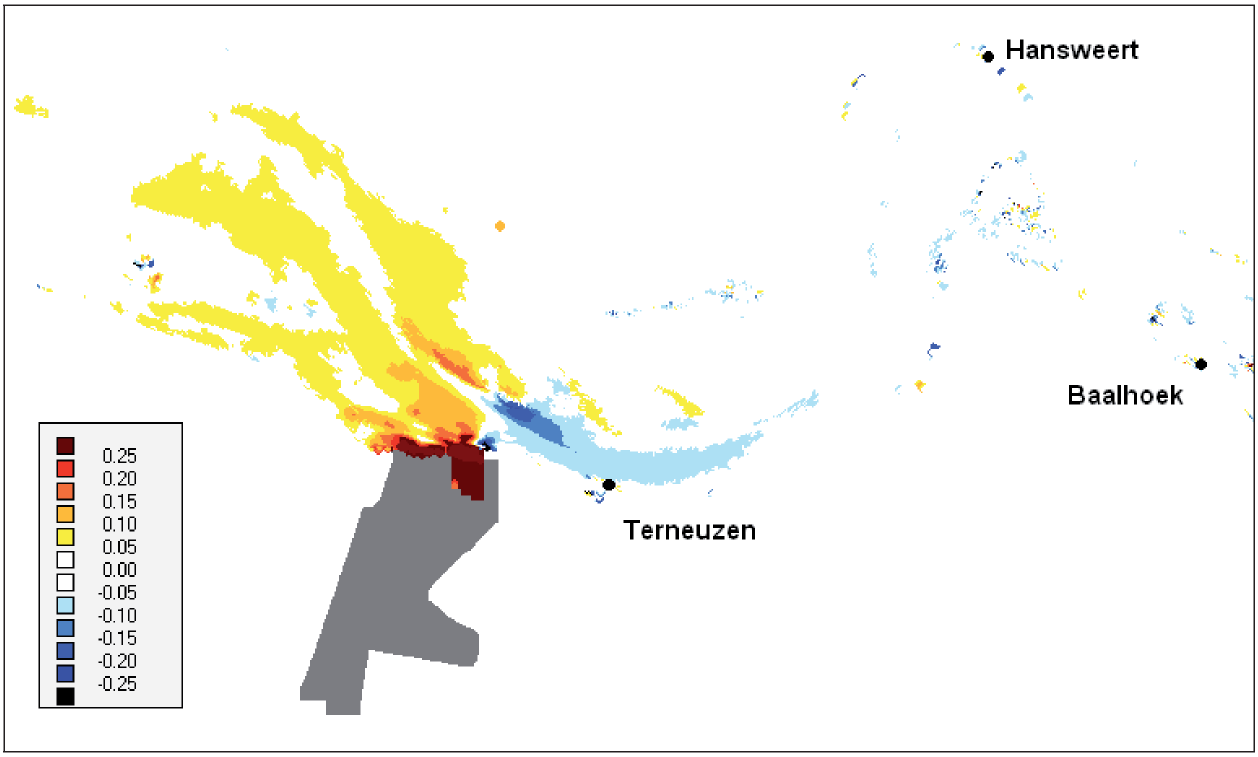


Figure 52 - Map of differences in velocity (m/s) for the Braakman polder (scenario minus reference run)
Moment of peak flood velocity

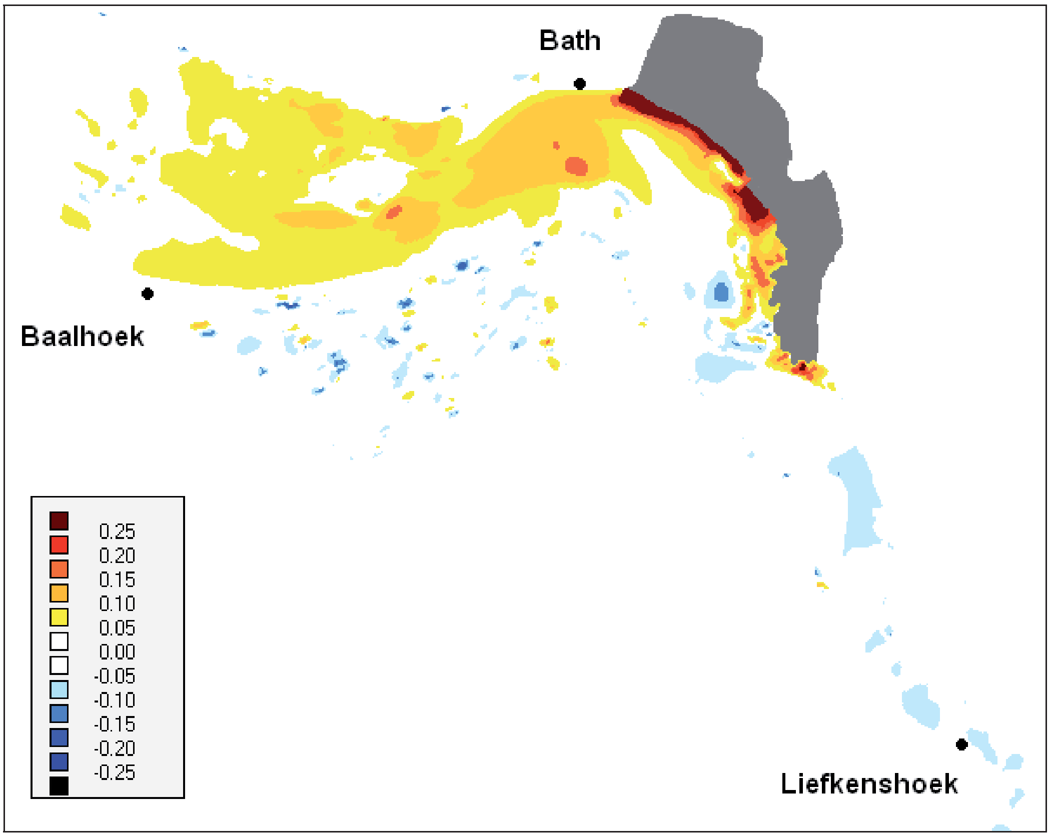


Figure 53 - Map of differences in velocity (m/s) for the New-Westland polder (scenario minus reference run)
Moment of peak flood velocity

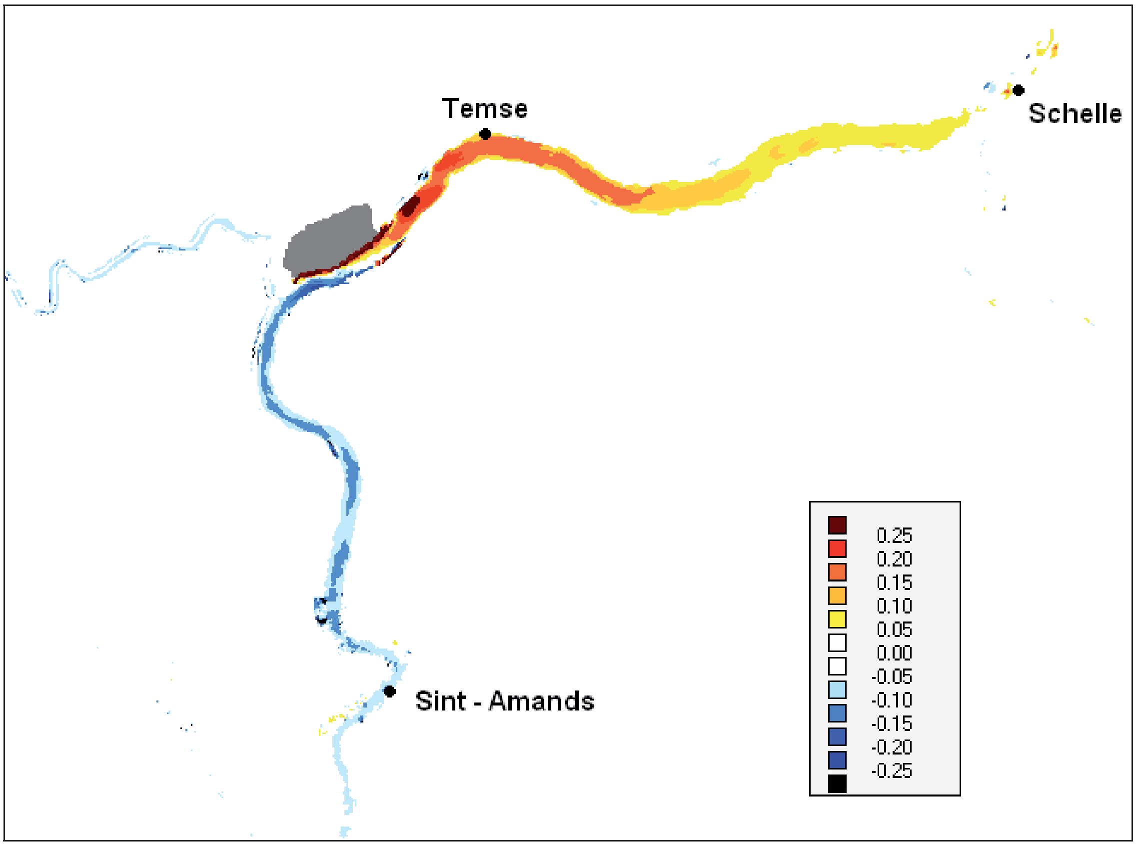


Figure 54 - Map of differences in velocity (m/s) for the Tielrodebroek polder (scenario minus reference run)
Moment of peak flood velocity

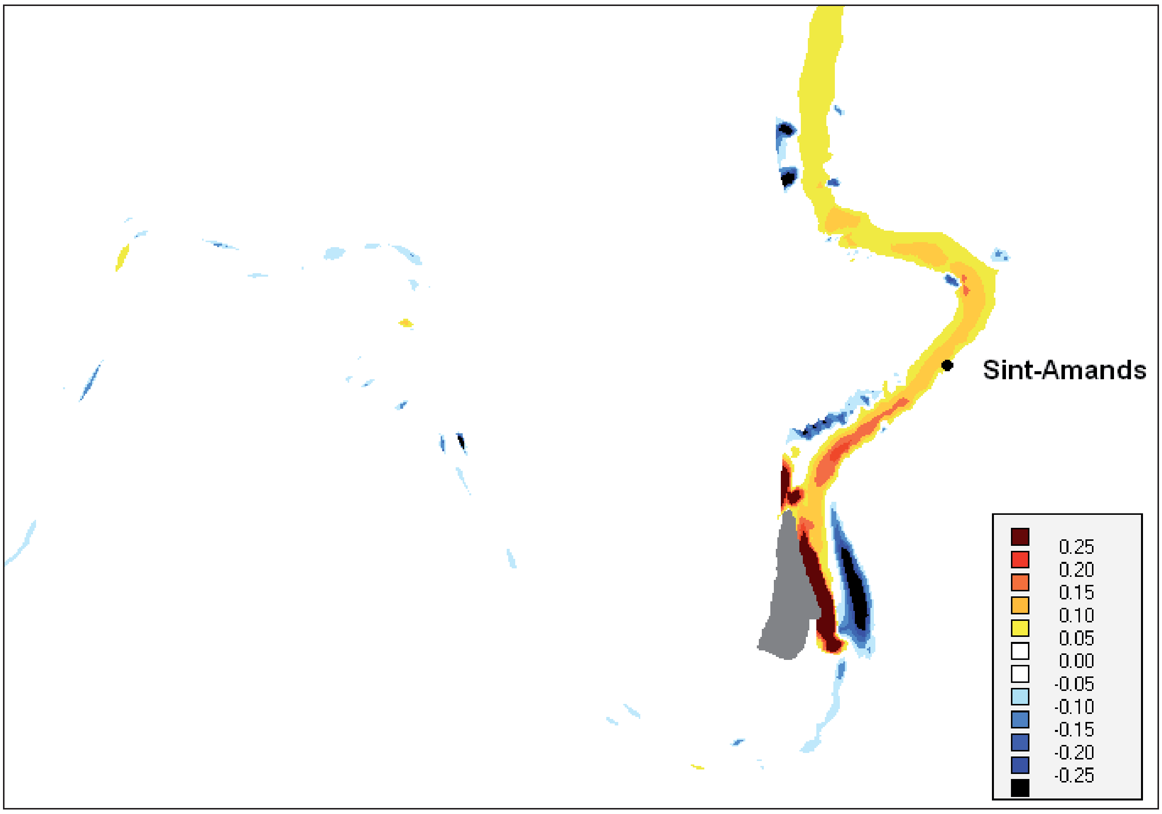


Figure 55 - Map of differences in velocity (m/s) for the Groot Schoor of St-Amands
(scenario minus reference run). Moment of peak flood velocity

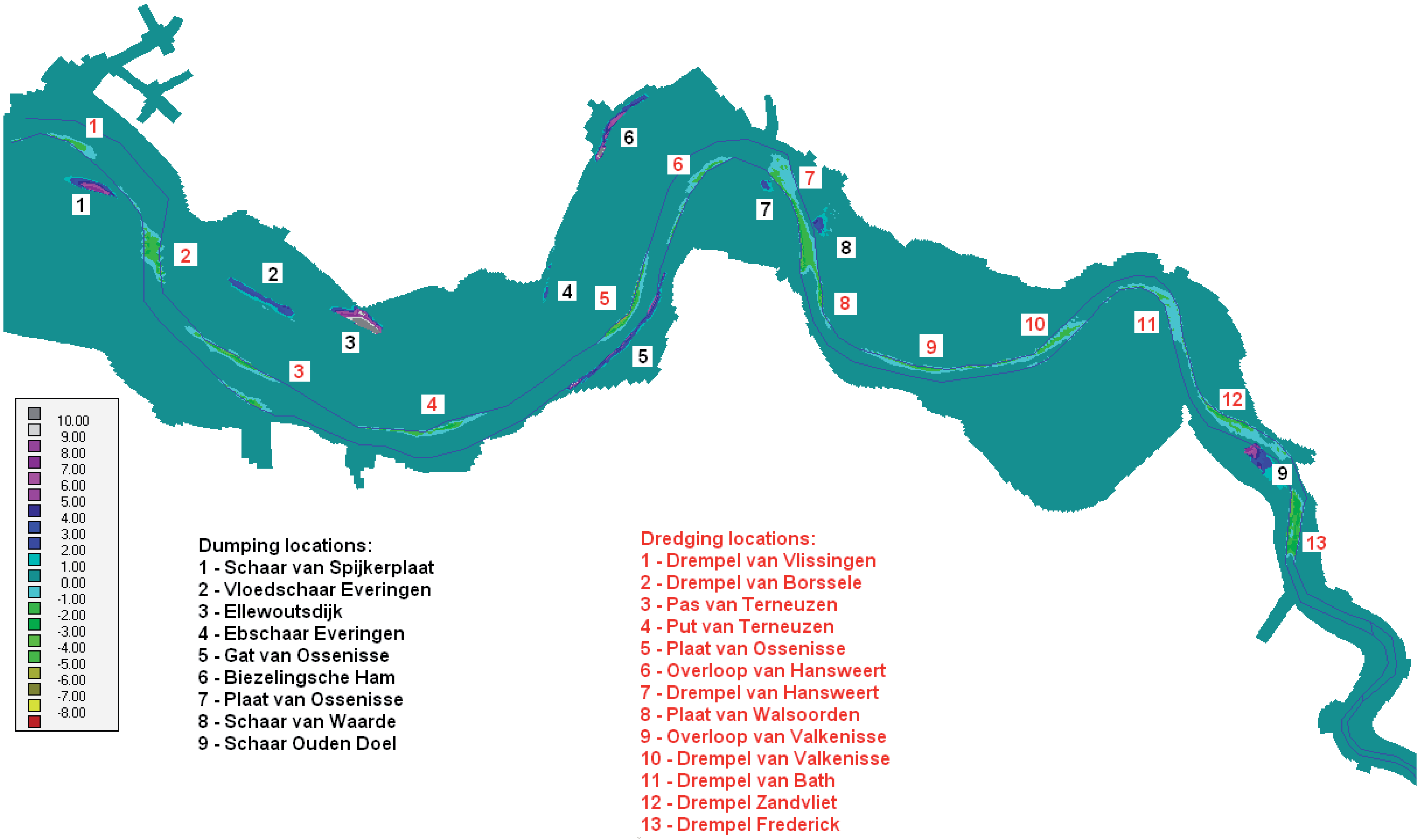


Figure 56 - Changes in bathymetry of the Western Scheldt after enlargement of the navigation channel (positive depth: disposal locations; negative depth: dredging locations)

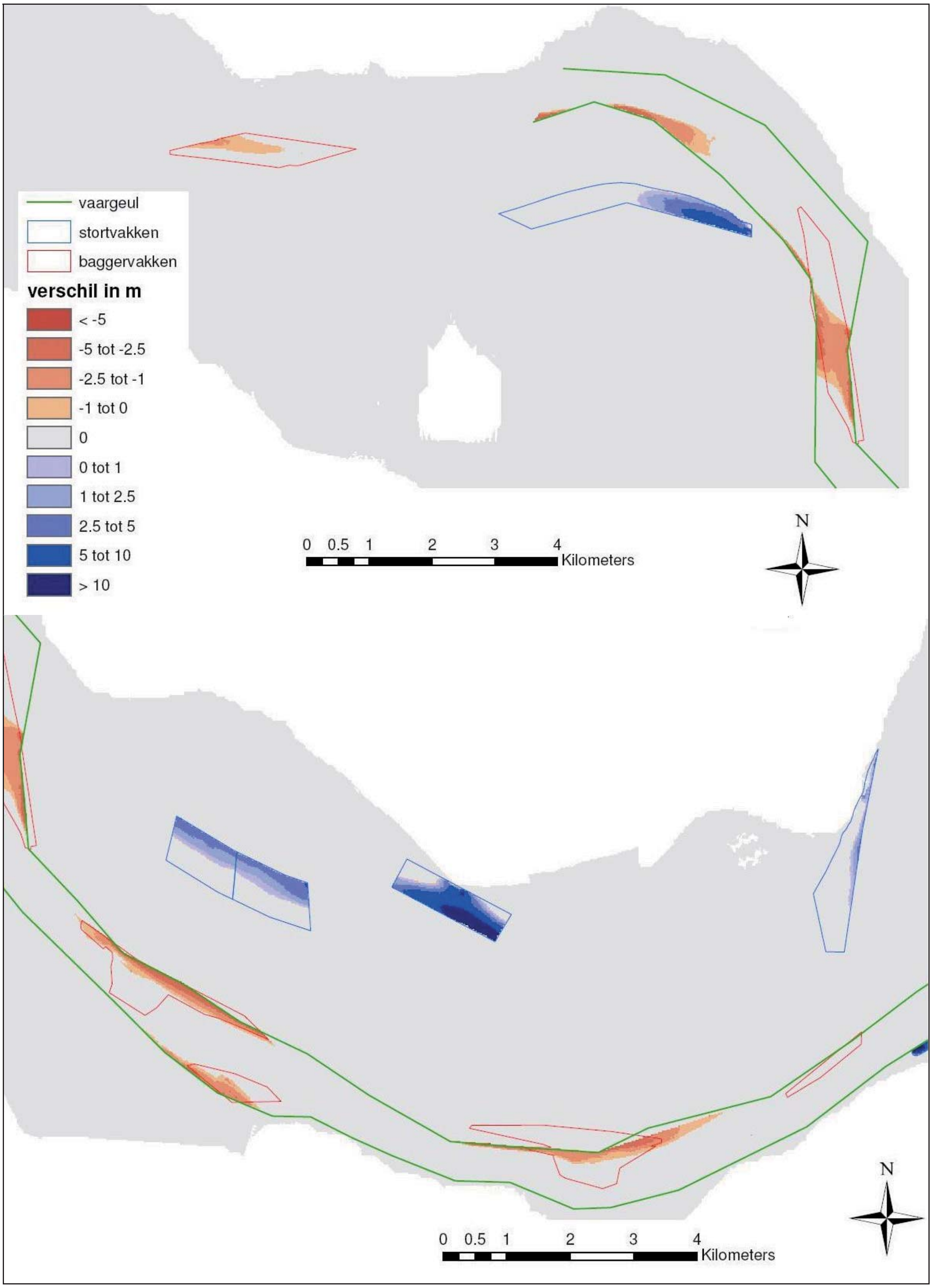


Figure 57 - Changes in bathymetry after enlargement of the navigation channel (locations 1 and 2). Green line: navigation channel, pink line: licensed dredging location, blue line: licensed disposal location

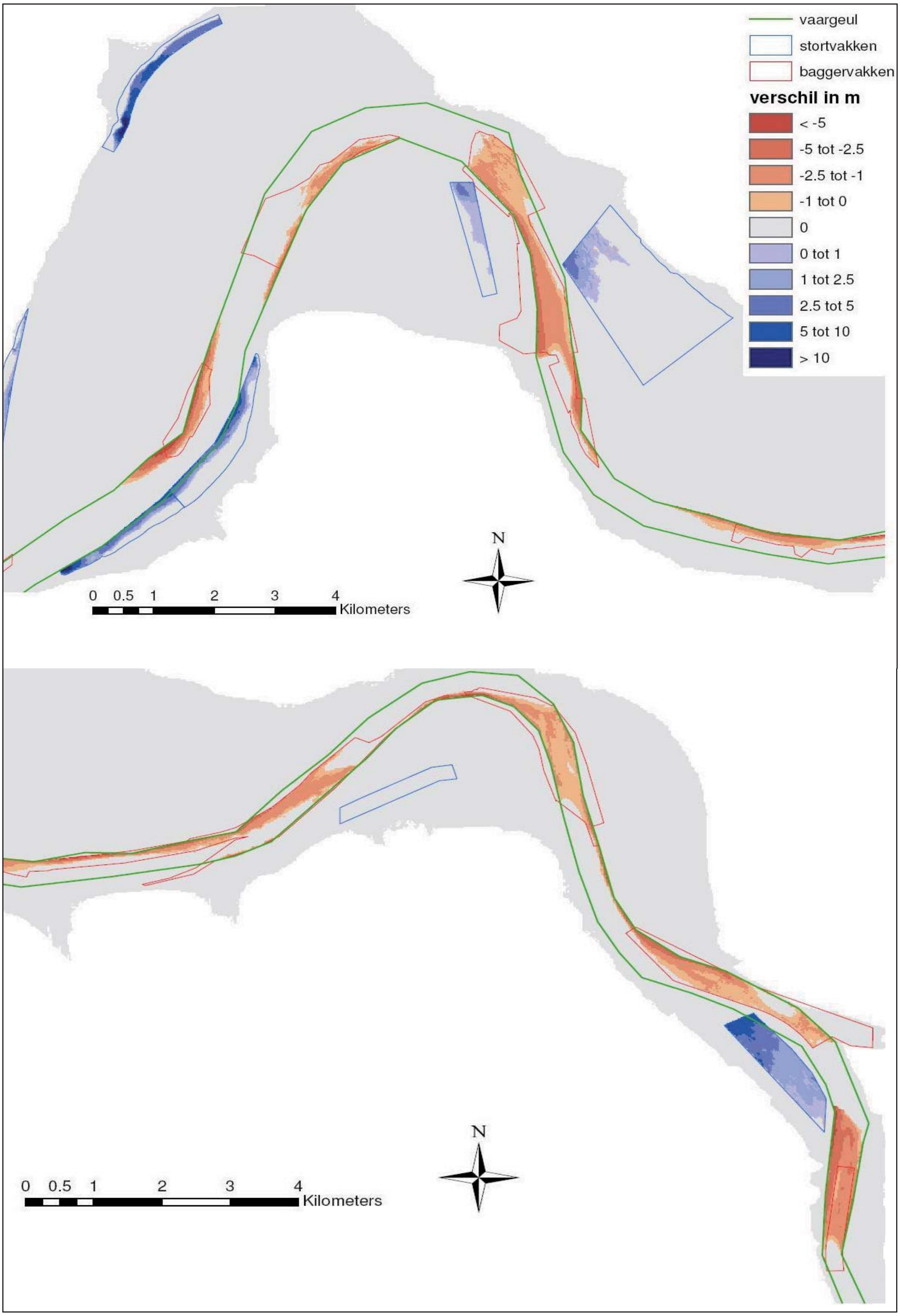


Figure 58 - Changes in bathymetry after enlargement of the navigation channel (locations 3 and 4)
Green line: navigation channel, pink line: licensed dredging location, blue line: licensed disposal location

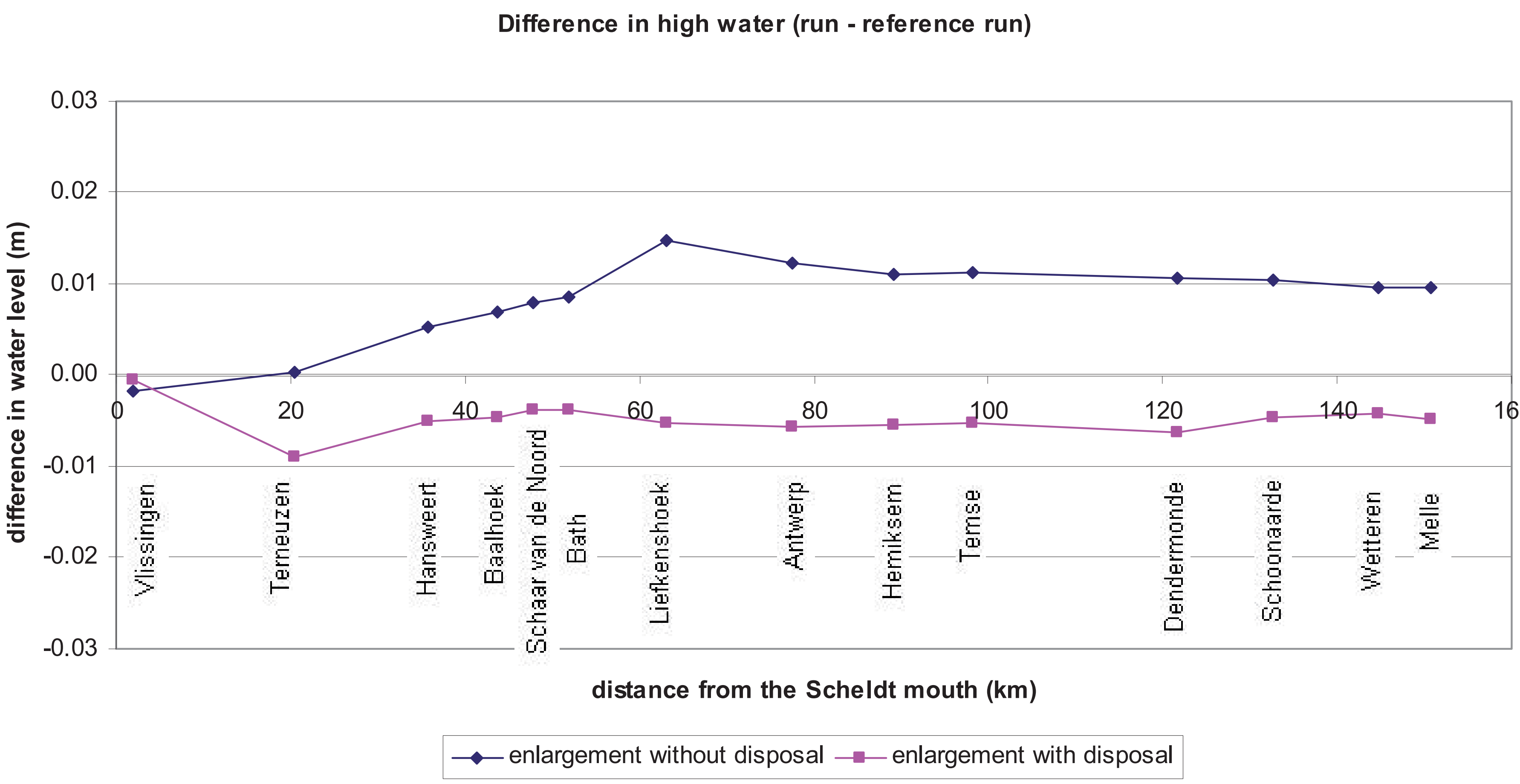


Figure 59 - Difference in high water for scenarios with enlargement and reference situation
(positive value is higher high water compared to the reference simulation)

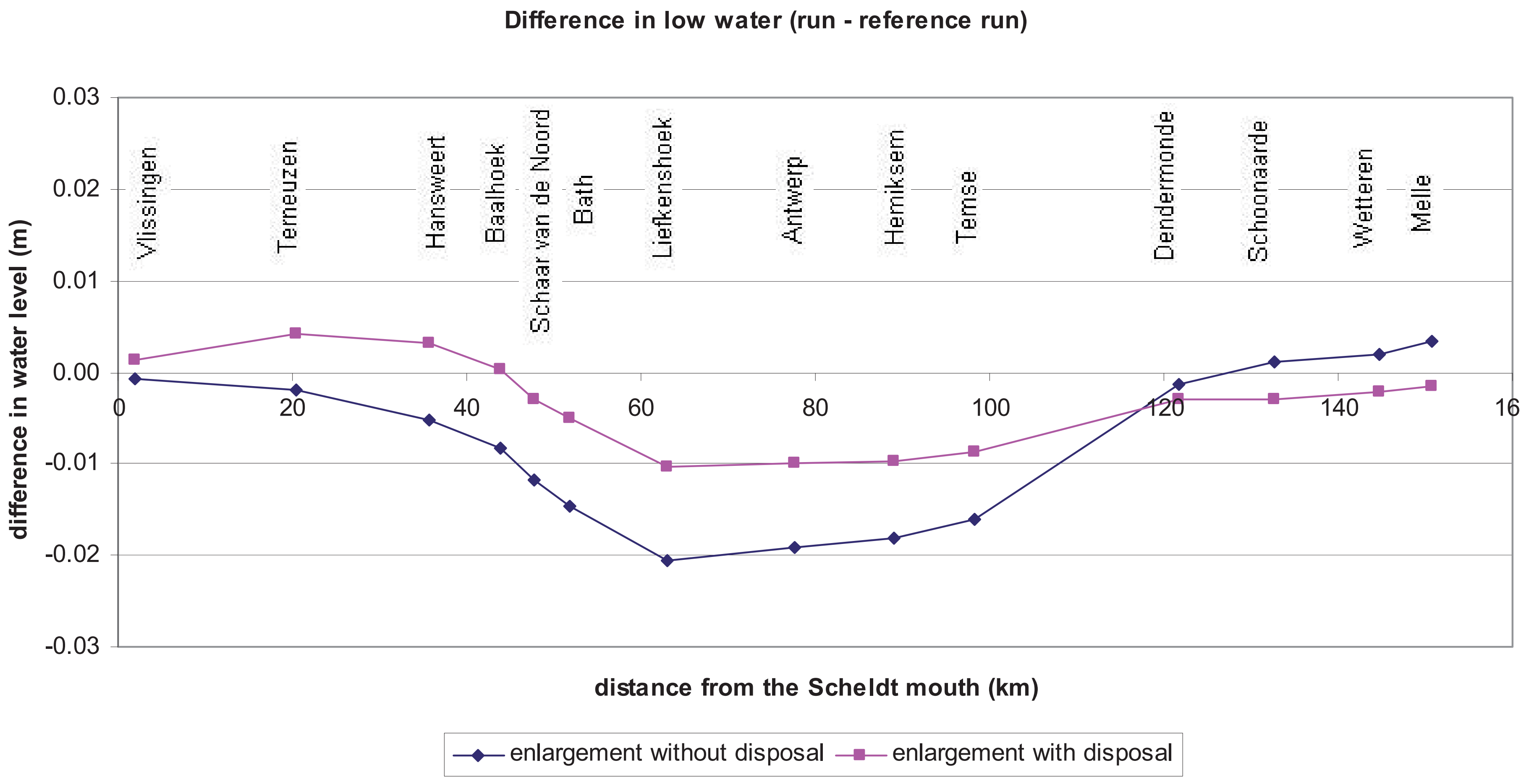


Figure 60 - Difference in low water for scenarios with enlargement and reference situation
(positive value is higher low water compared to the reference simulation)

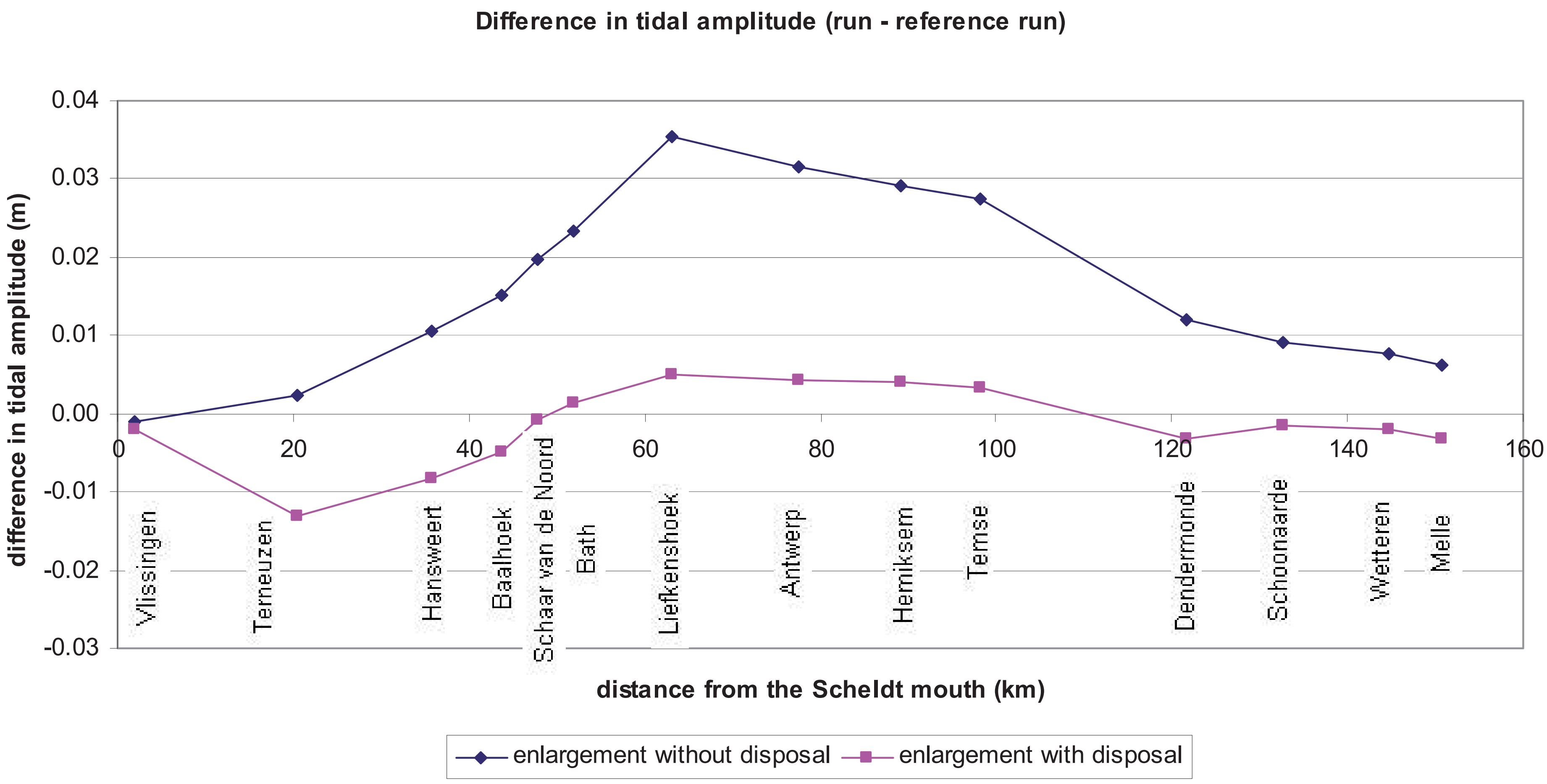


Figure 61 - Difference in tidal amplitude for scenarios with enlargement and reference situation
(positive value is higher tidal amplitude compared to the reference simulation)

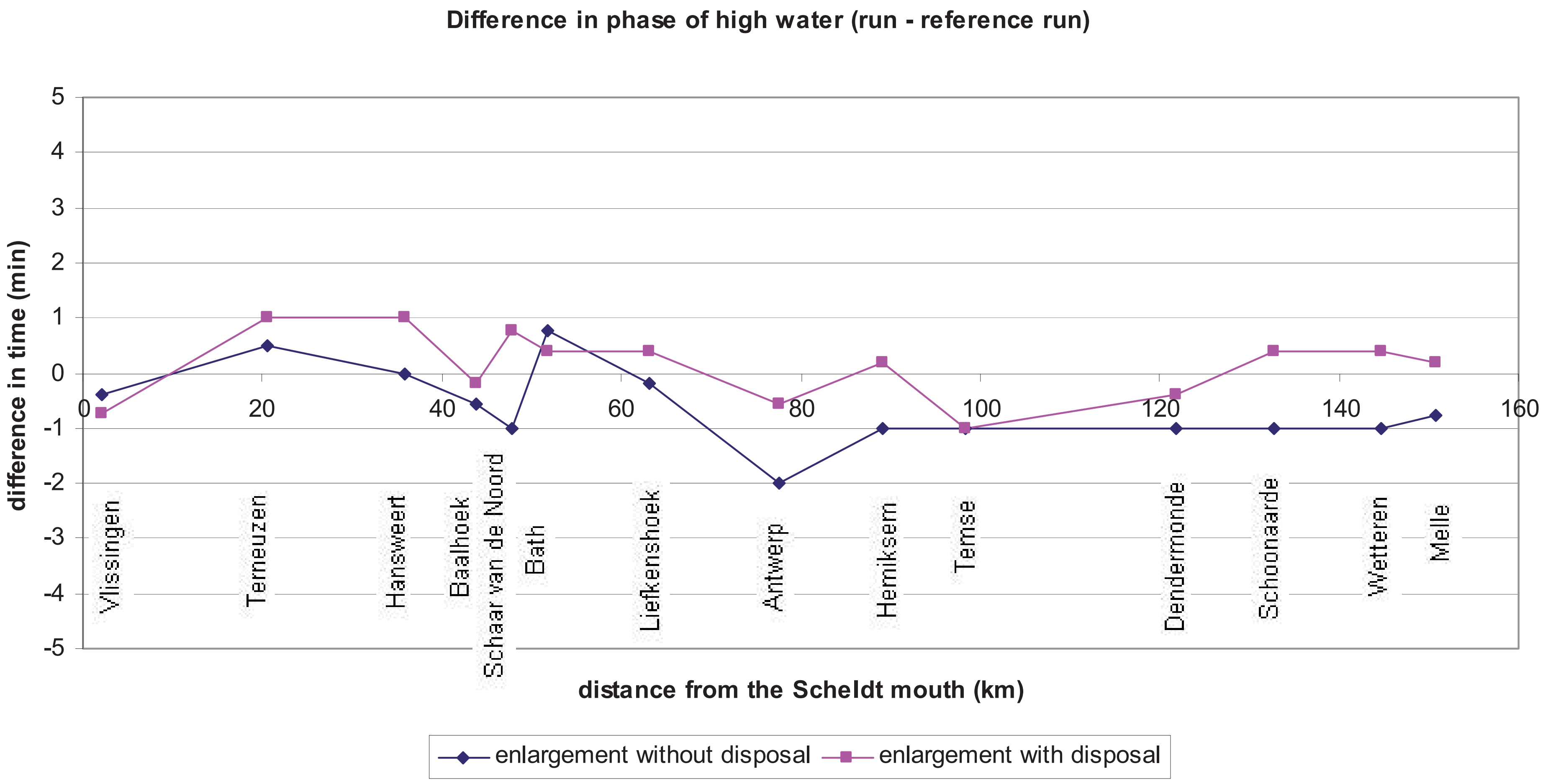


Figure 62 - Difference in phase of high water for scenarios with enlargement and reference situation
(positive value is later compared to the reference simulation)

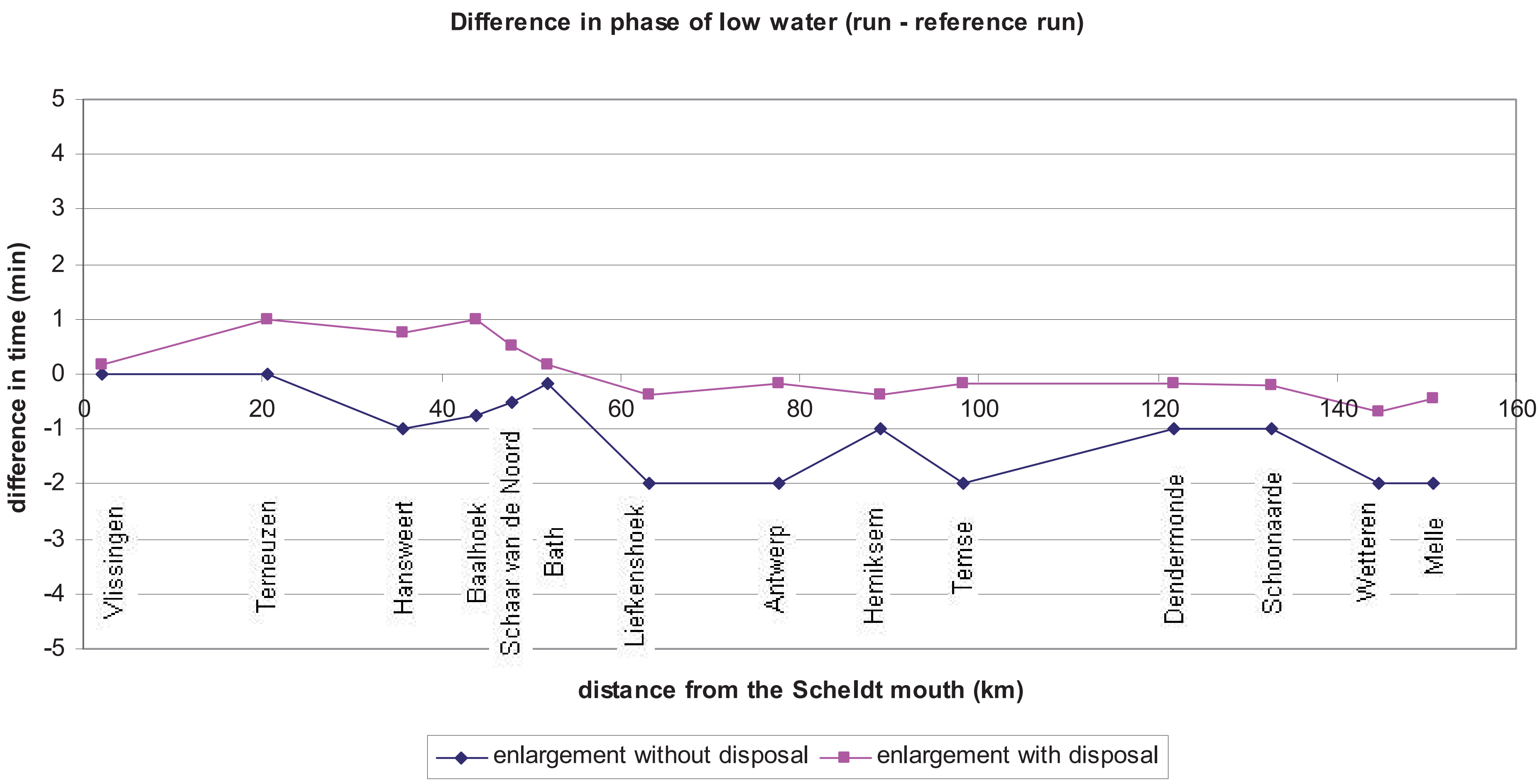


Figure 63 - Difference in phase of low water for scenarios with enlargement and reference situation
(positive value is later compared to the reference simulation)

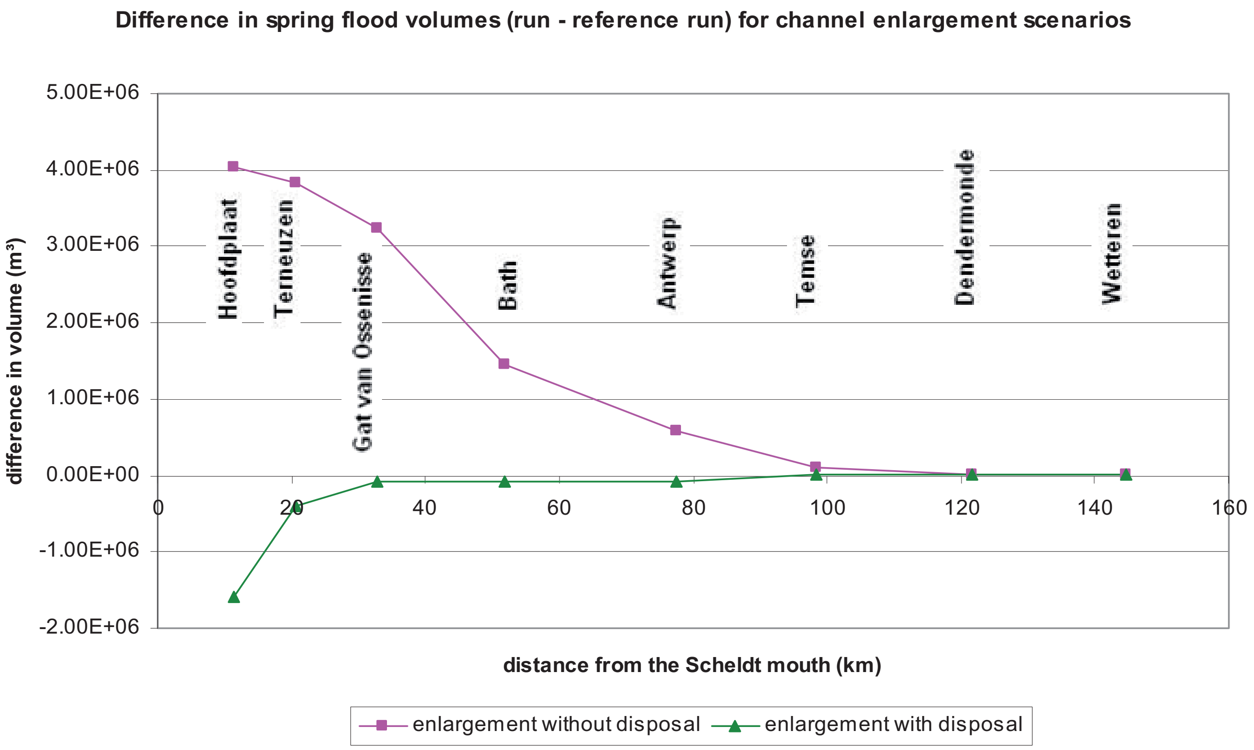


Figure 64 - Difference in the flood volumes for the scenarios with enlargement of the navigation channel

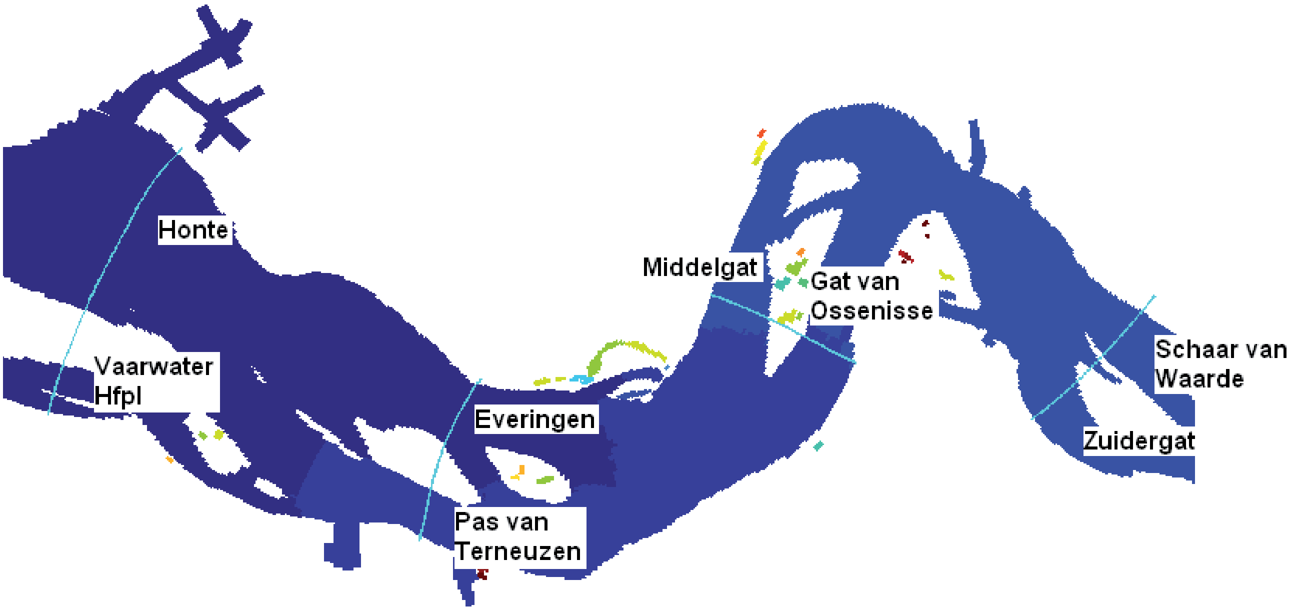
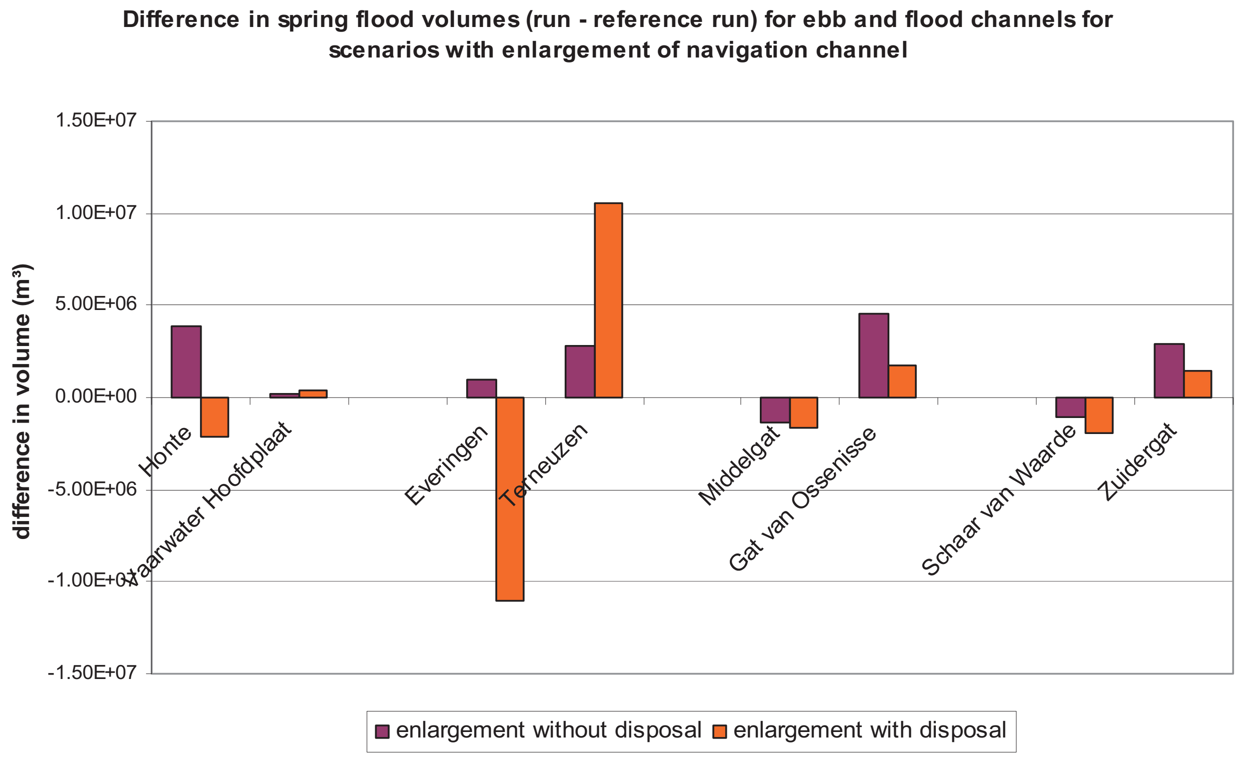


Figure 65 - Locations of the cross sections in the ebb and flood channels in the Western Scheldt



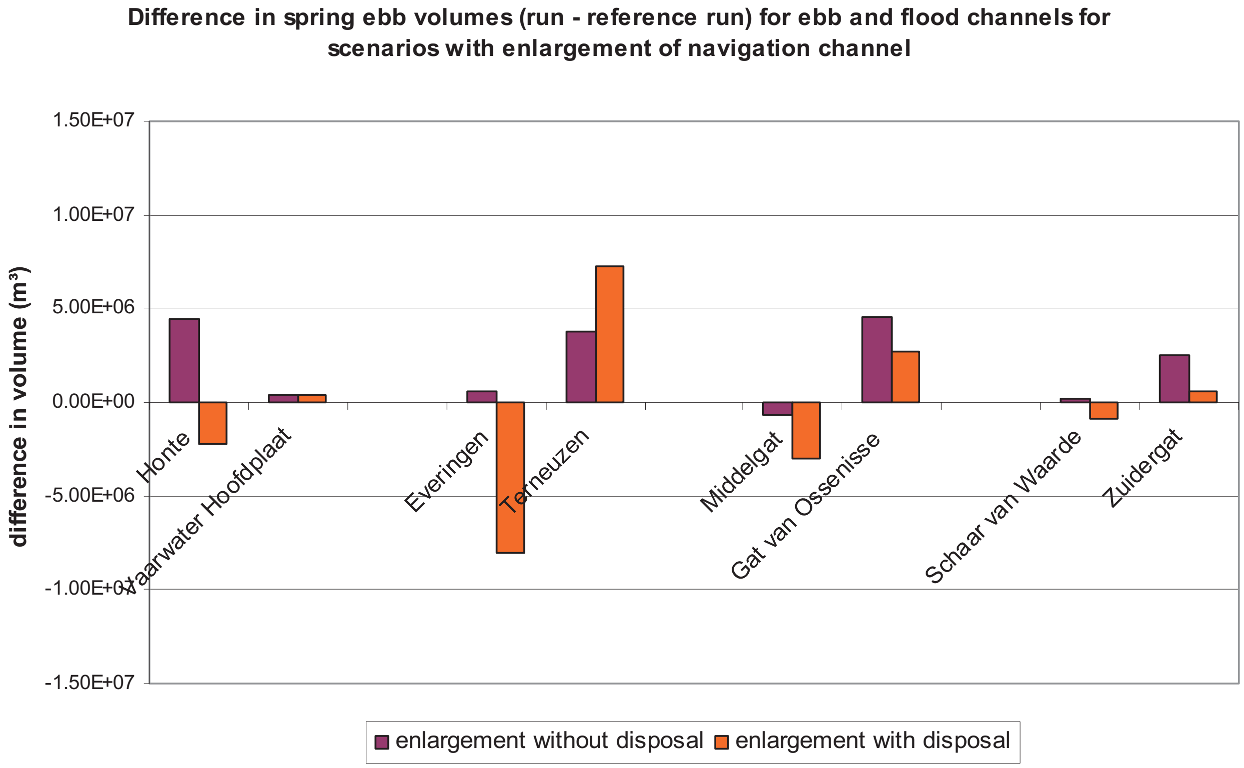
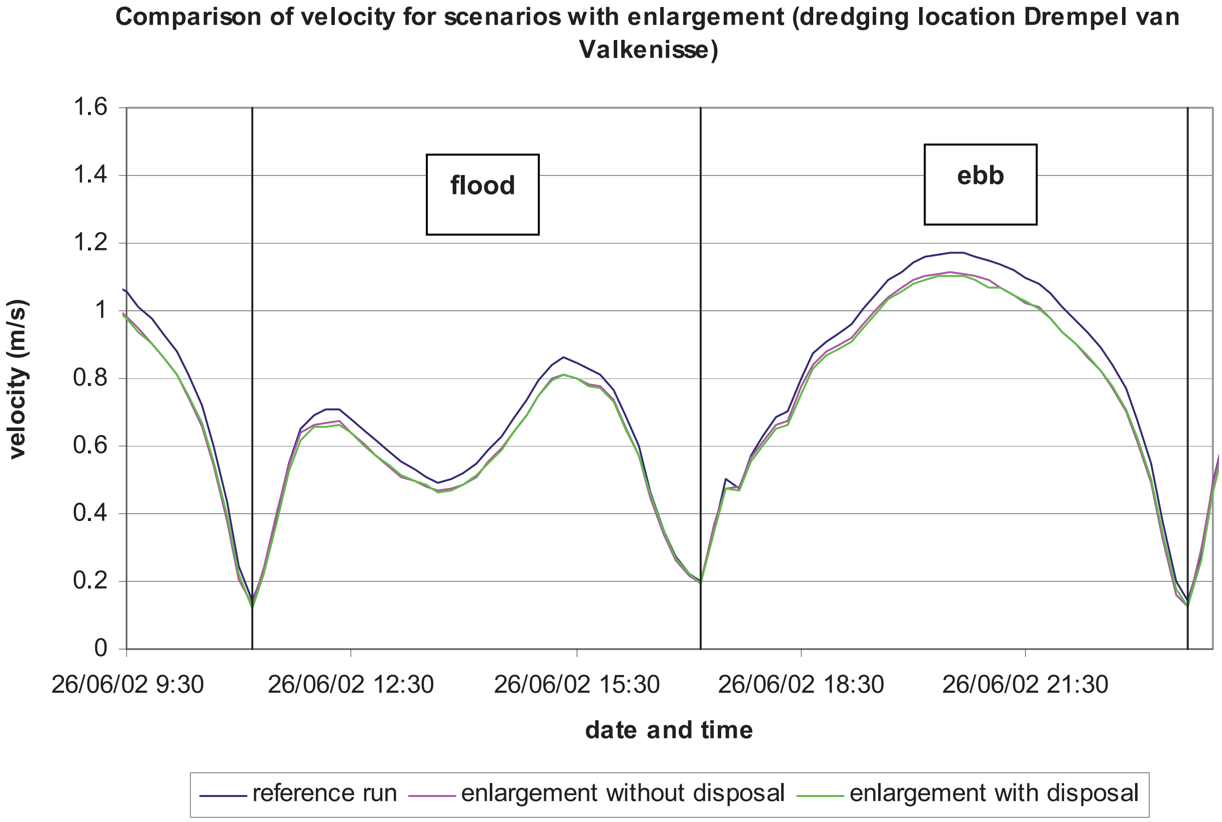


Figure 66 - Differences in the flood and ebb volumes for the ebb and flood channels for the scenarios with enlargement of the navigation channel



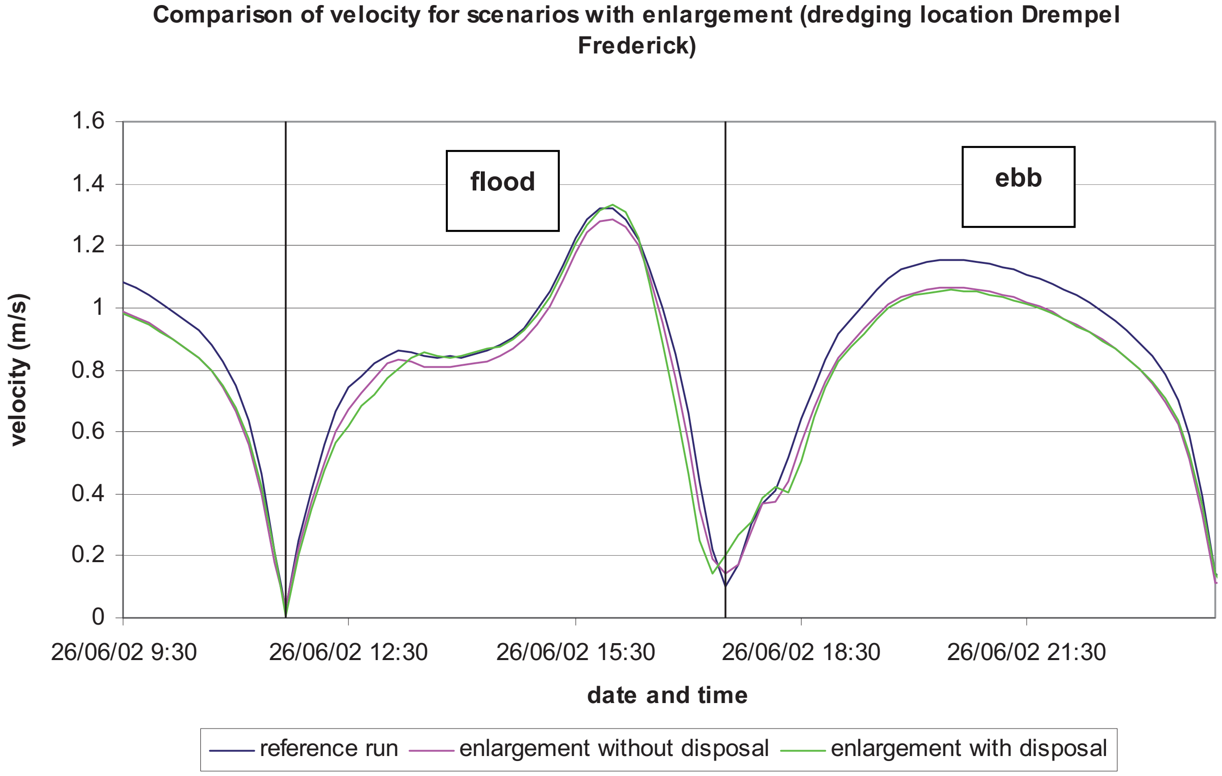


Figure 67 - Comparison of the velocity for scenarios with enlargement :
Drempel van Valkenisse (above), Drempel Frederick (below)

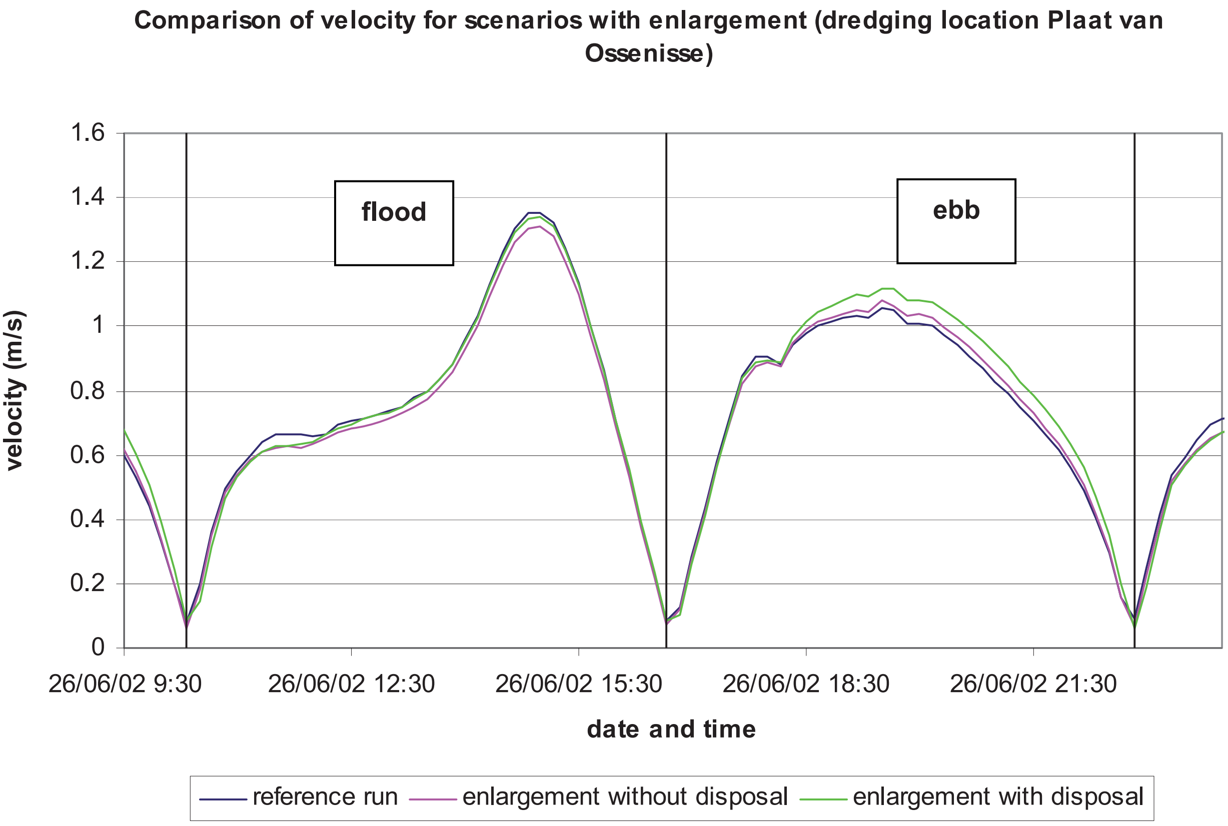


Figure 68 - Comparison of the velocity for scenarios with enlargement :
dredging location Plaat van Ossenisse

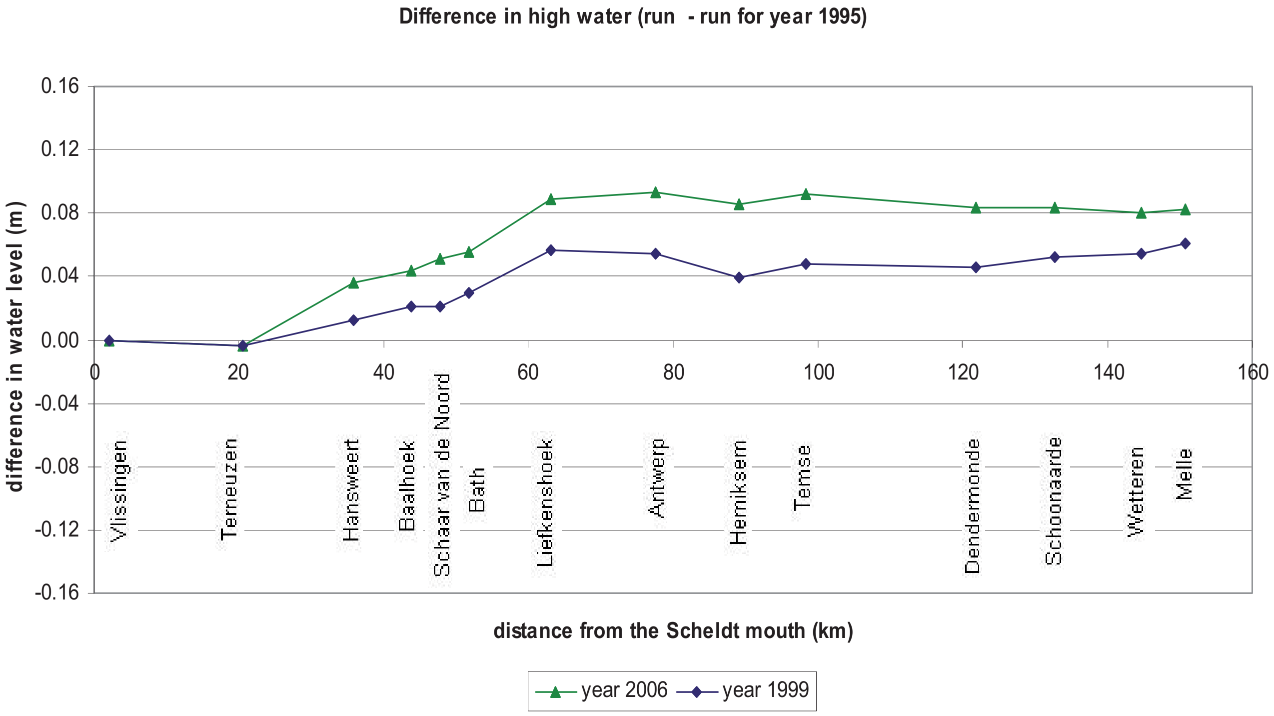


Figure 69 - Difference in high waters for the years 2006, 1999 and 1995
(positive value is higher high water compared to the year 1995)

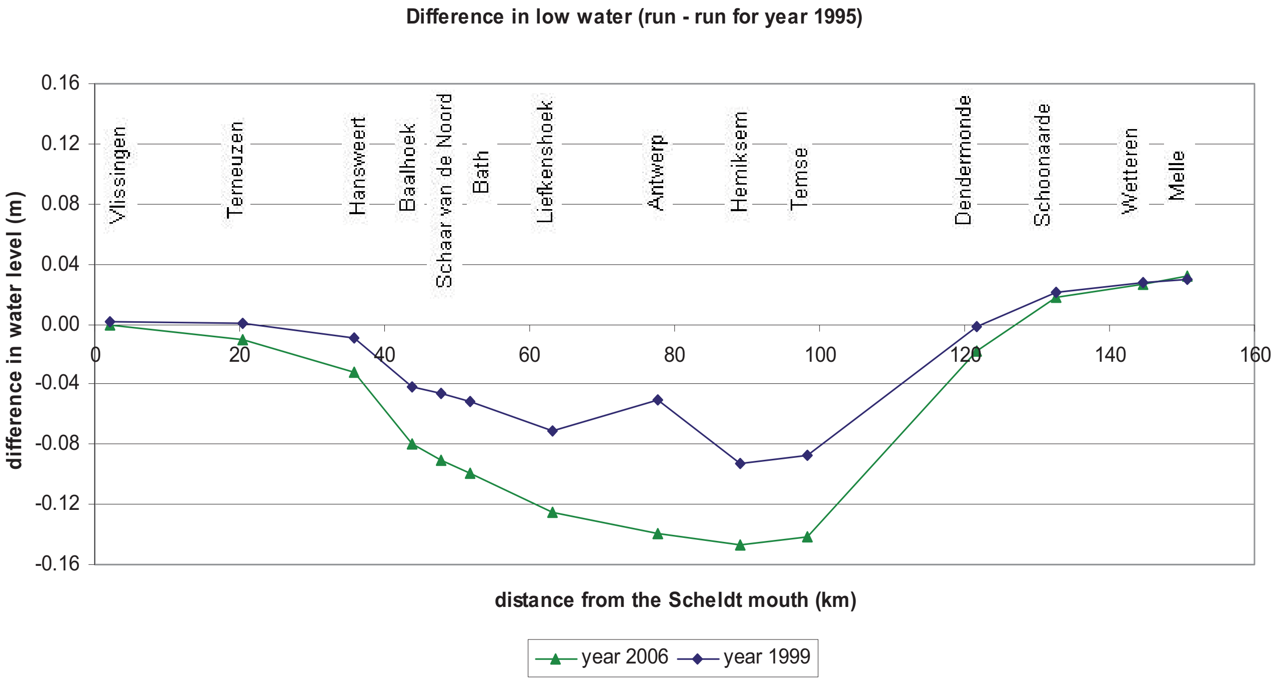


Figure 70 - Difference in low water for the years 2006, 1999 and 1995
(positive value is higher low water compared to the year 1995)

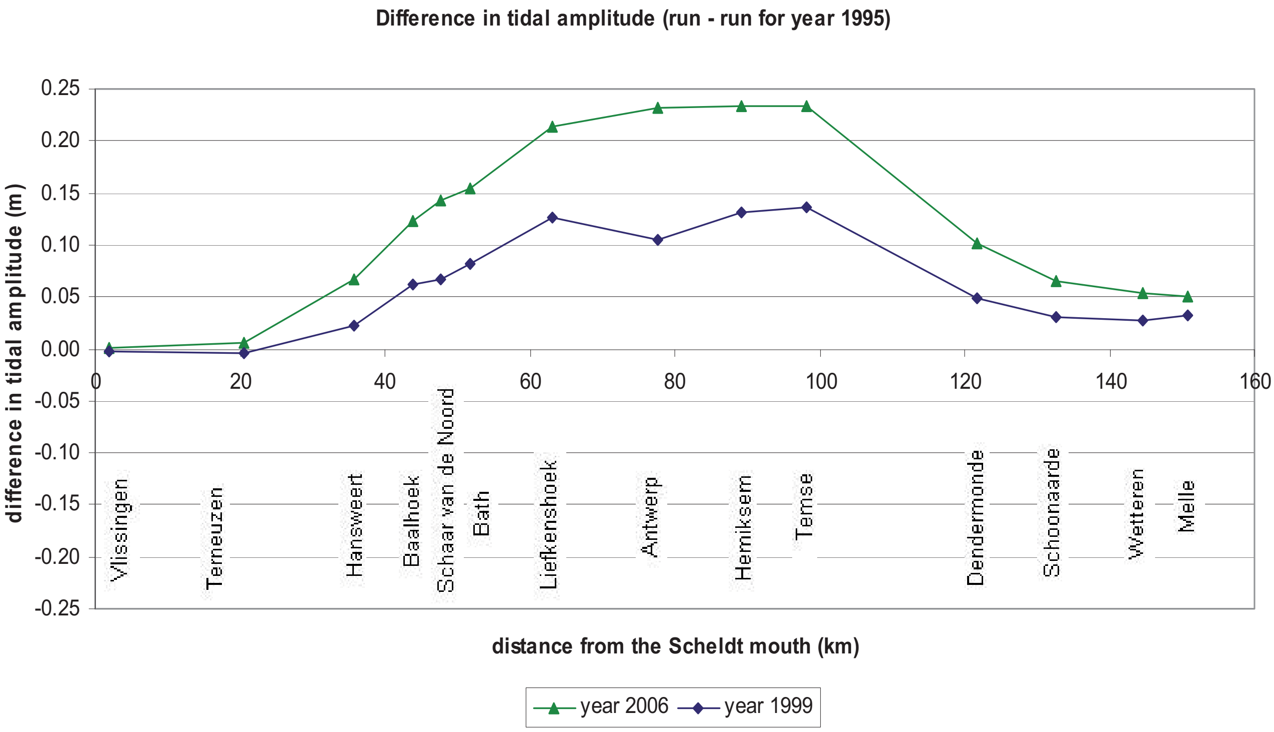


Figure 71 - Difference in tidal amplitude for the years 2006, 1999 and 1995
(positive value is higher tidal amplitude compared to the year 1995)

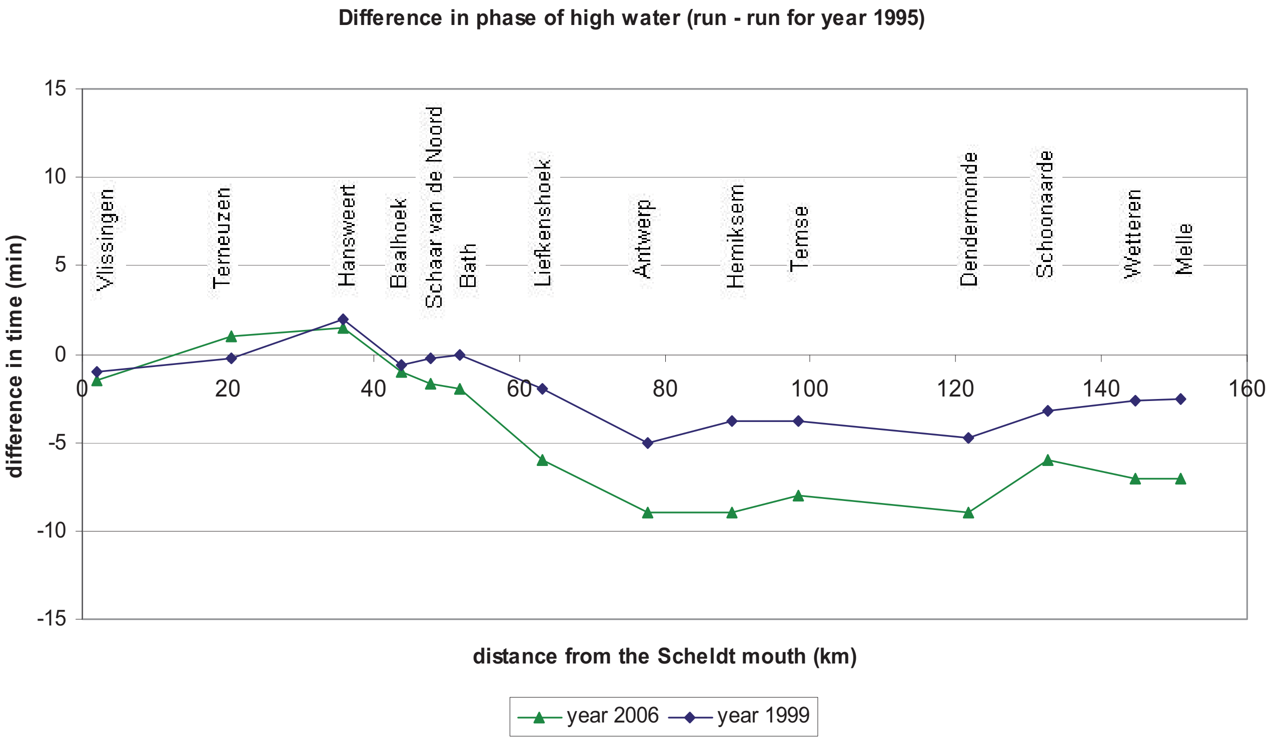


Figure 72 - Difference in phase of high water for the years 2006, 1999 and 1995
(positive value is later compared to the year 1995)

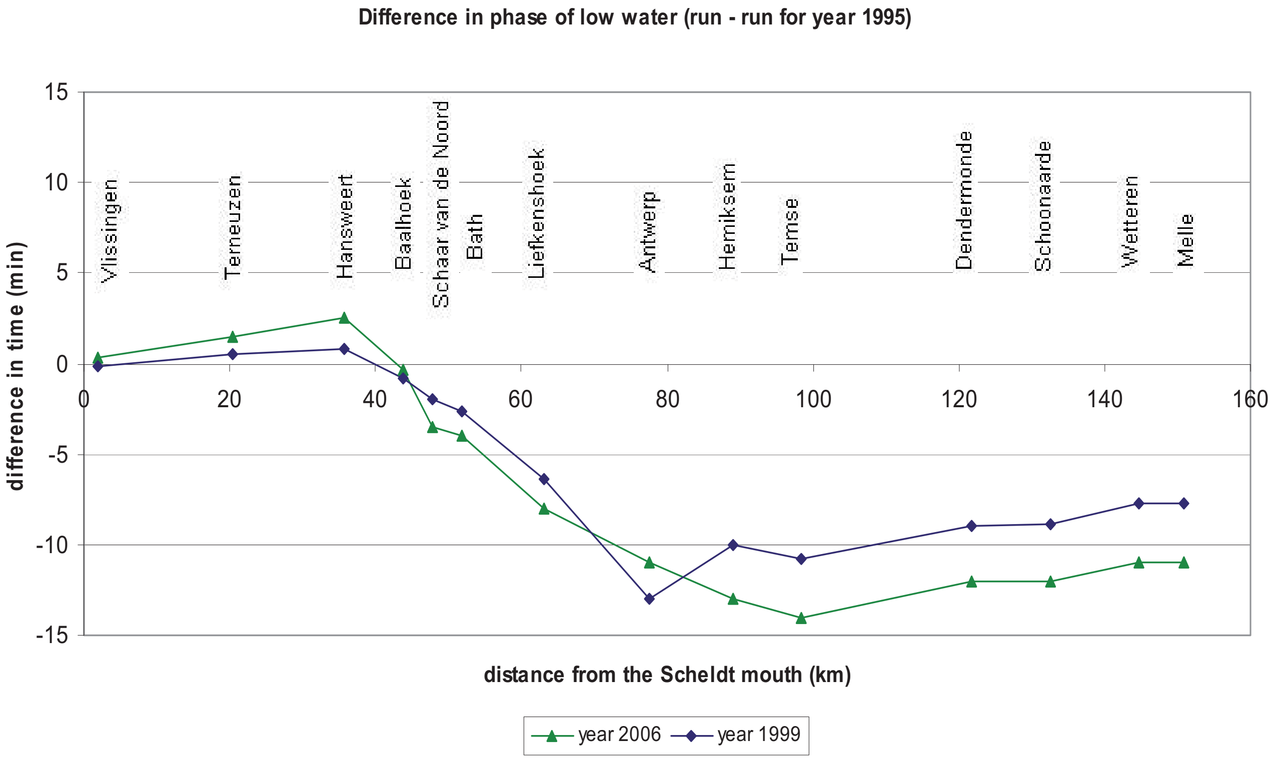


Figure 73 - Difference in phase of low water for the years 2006, 1999 and 1995
(positive value is later compared to the year 1995)

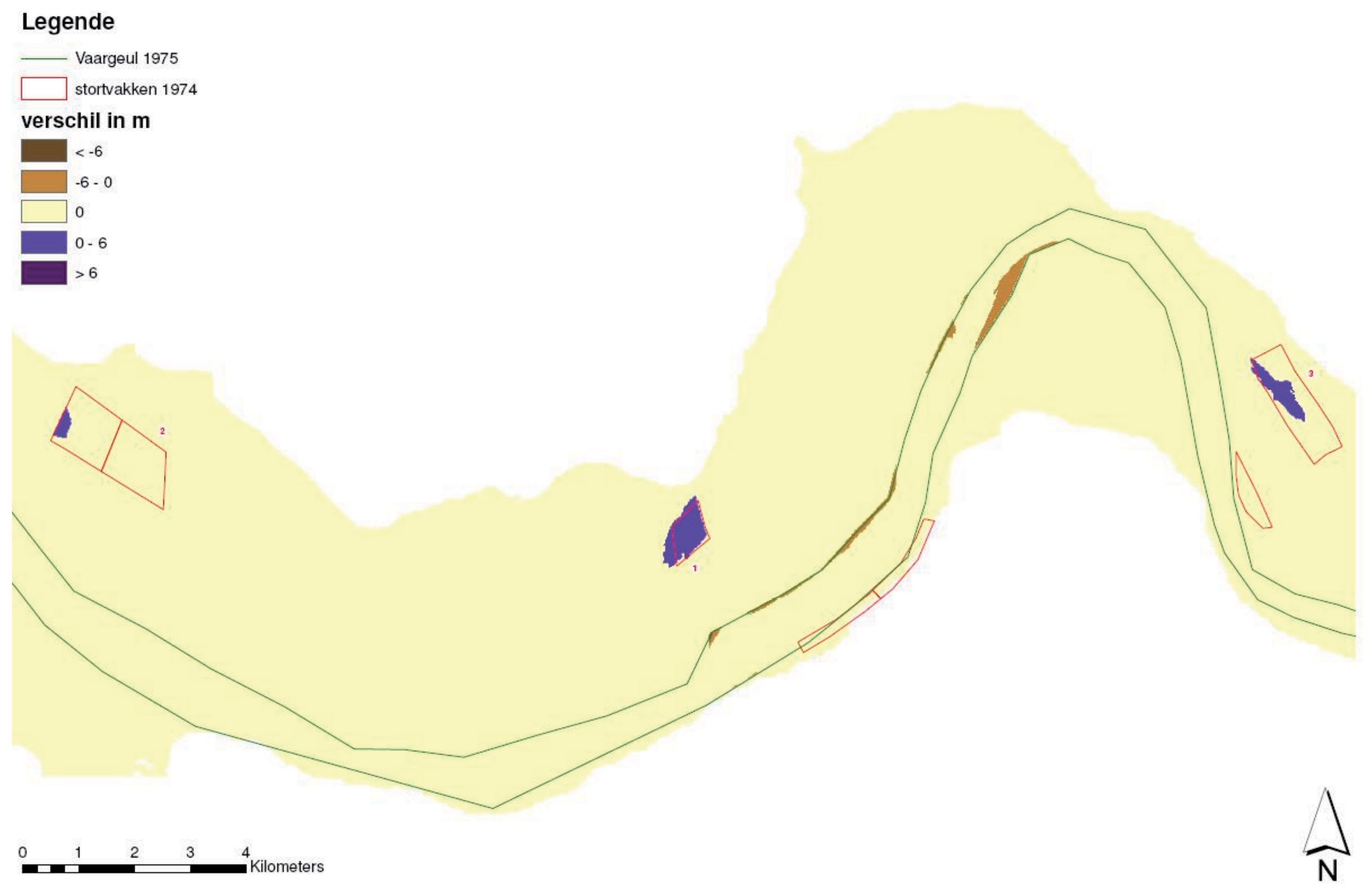


Figure 74 - Difference in bathymetry for the Gat van Ossenisse - Middelgat (scenario 1)

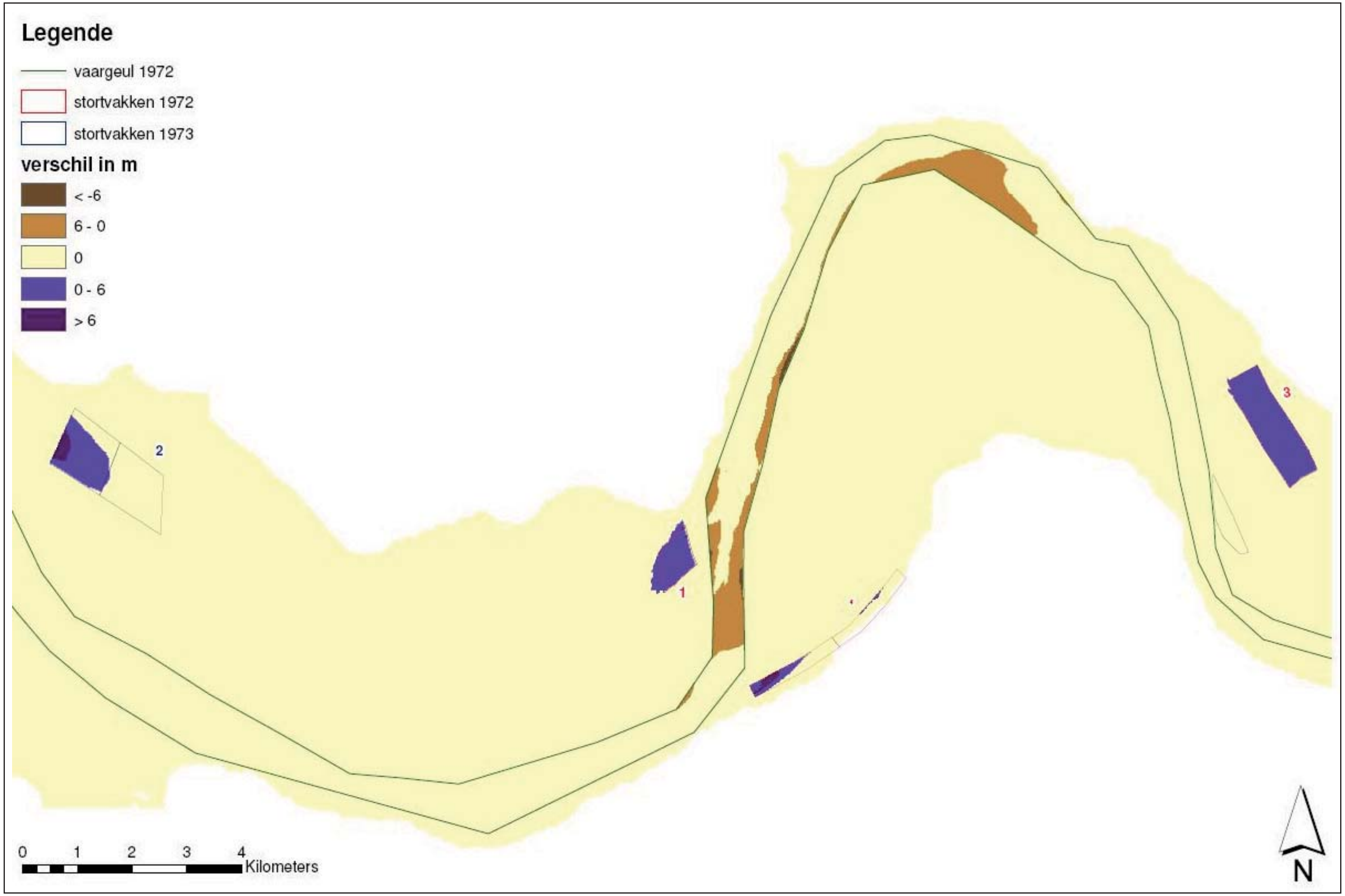


Figure 75 - Difference in bathymetry for the Gat van Ossenisse - Middelgat (scenario 2)

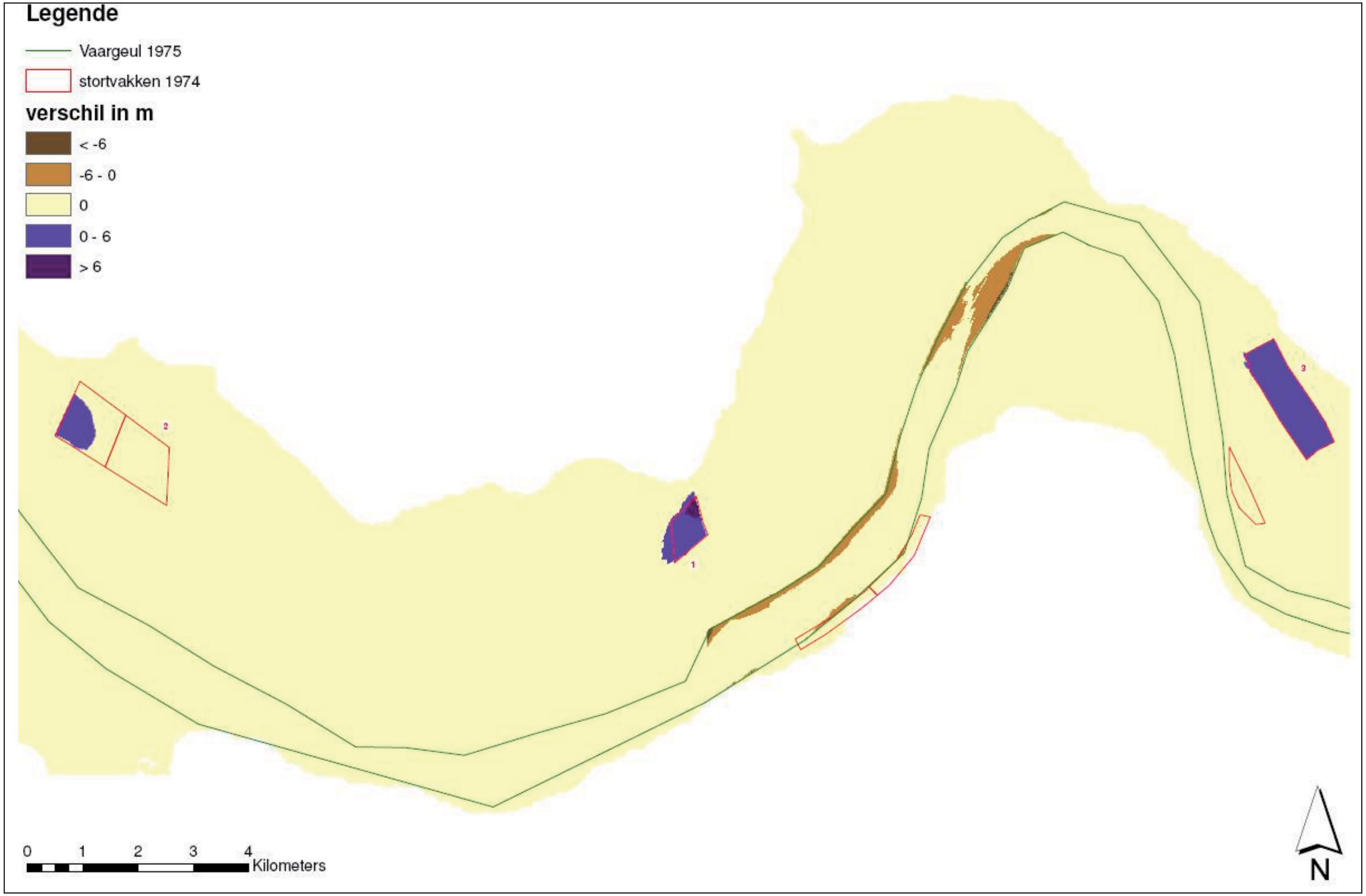


Figure 76 - Difference in bathymetry for the Gat van Ossenisse – Middelgat (scenario 3)

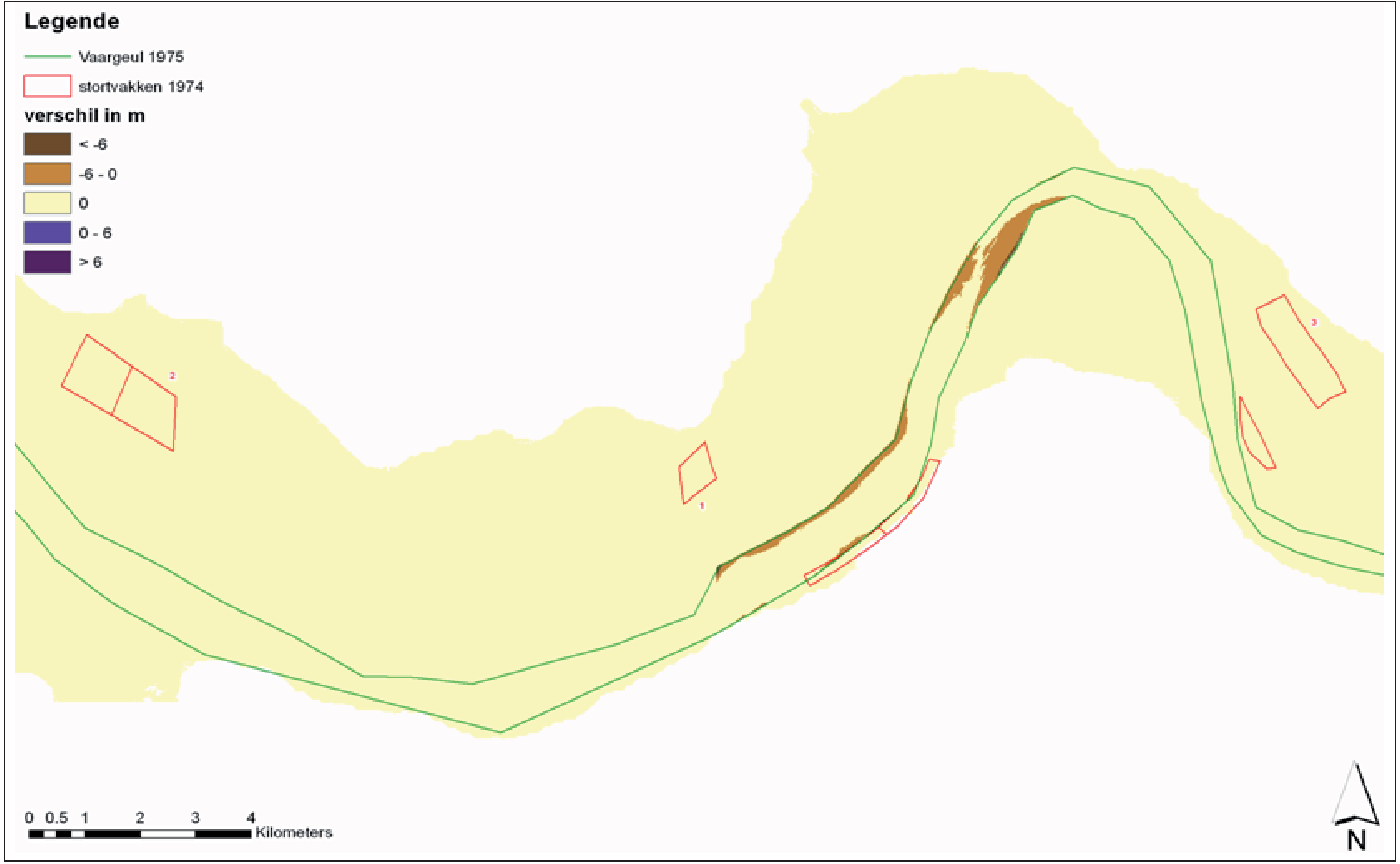


Figure 77 - Difference in bathymetry for the Gat van Ossenisse - Middelgat (scenario 4)

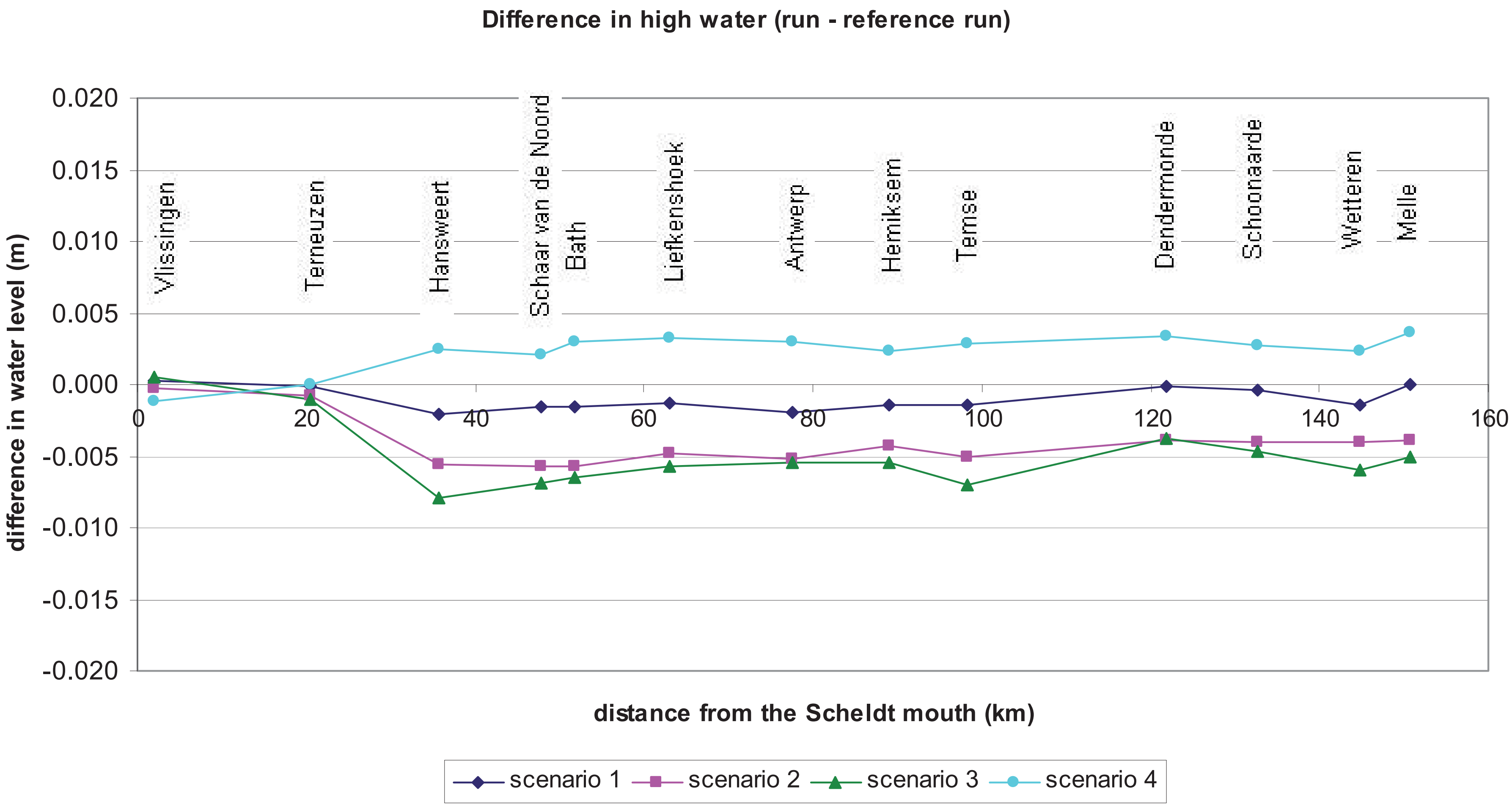


Figure 78 - Difference in high water for the scenarios with the changes at the Gat van Ossenisse – Middelgat and reference situation (positive value is higher high water compared to the reference simulation for 1970)

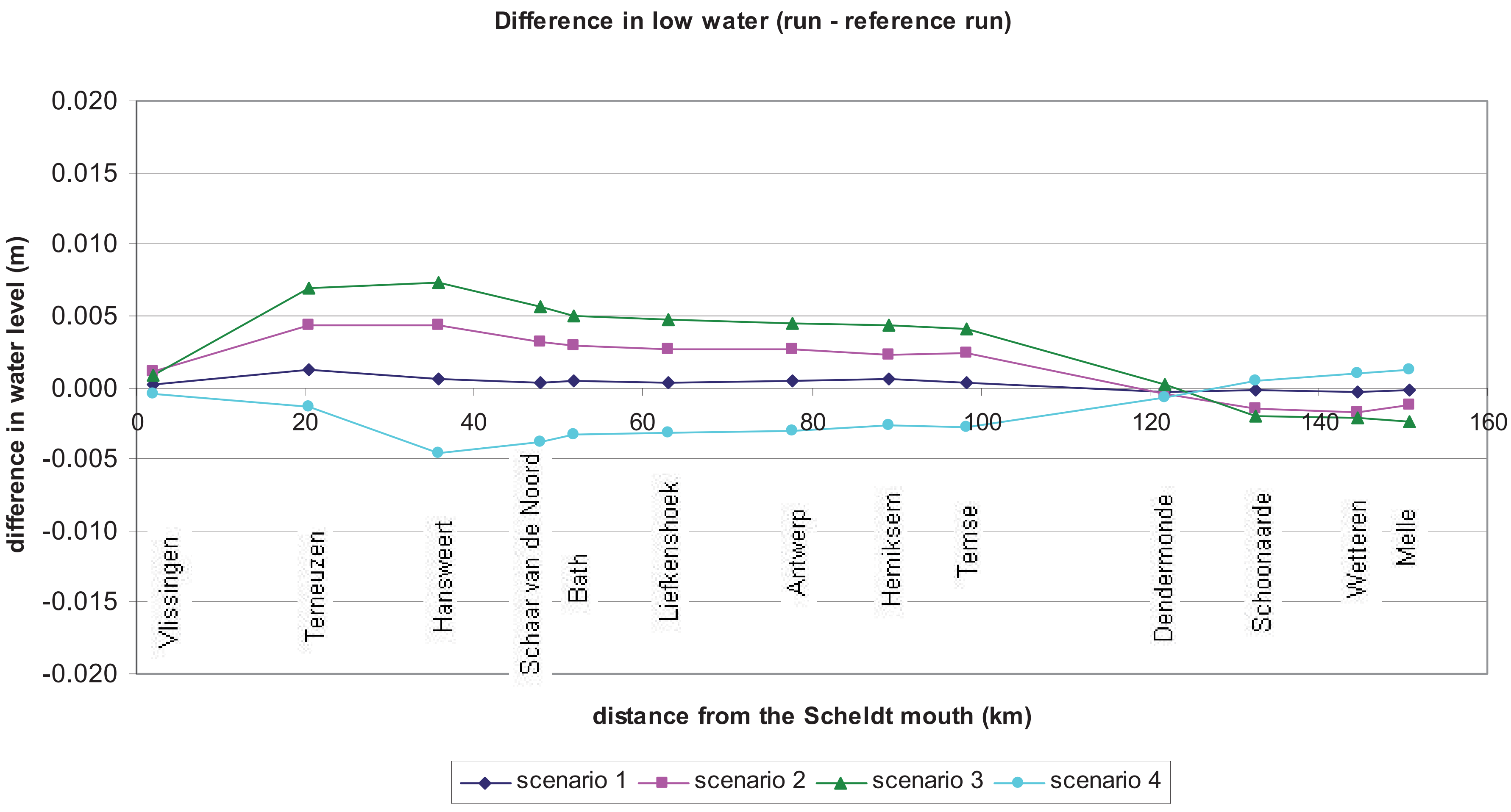


Figure 79 - Difference in low water for the scenarios with the changes at the Gat van Ossenisse – Middelgat and reference situation (positive value is higher low water compared to the reference simulation for 1970)

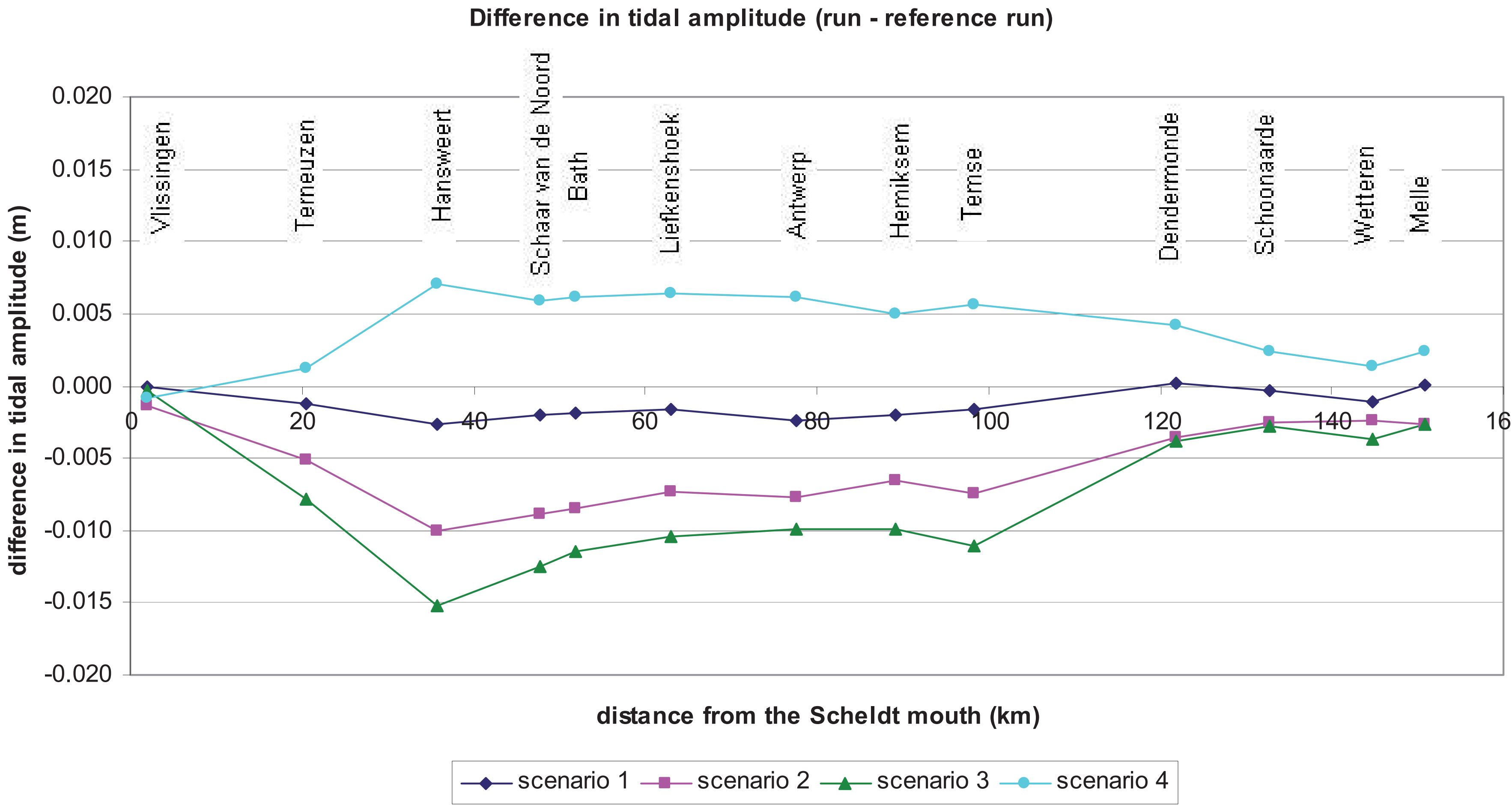


Figure 80 - Difference in tidal amplitude for the scenarios with the changes at the Gat van Ossenisse – Middelgat and reference situation (positive value is higher tidal amplitude compared to the reference simulation for 1970)

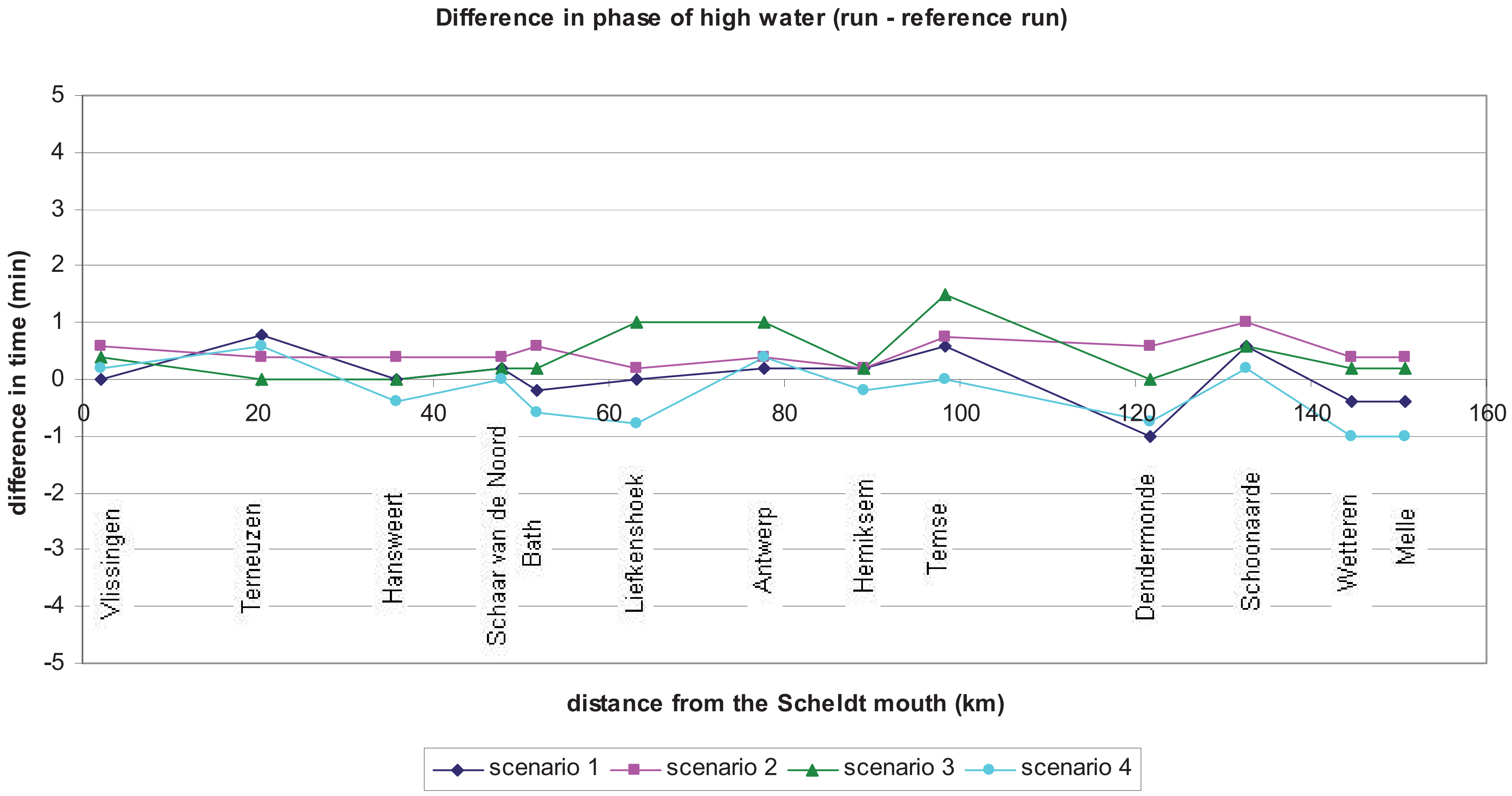


Figure 81 - Difference in phase of high water for the scenarios with the changes at the Gat van Ossenisse – Middelgat and reference situation (positive value is later compared to the reference simulation for 1970)

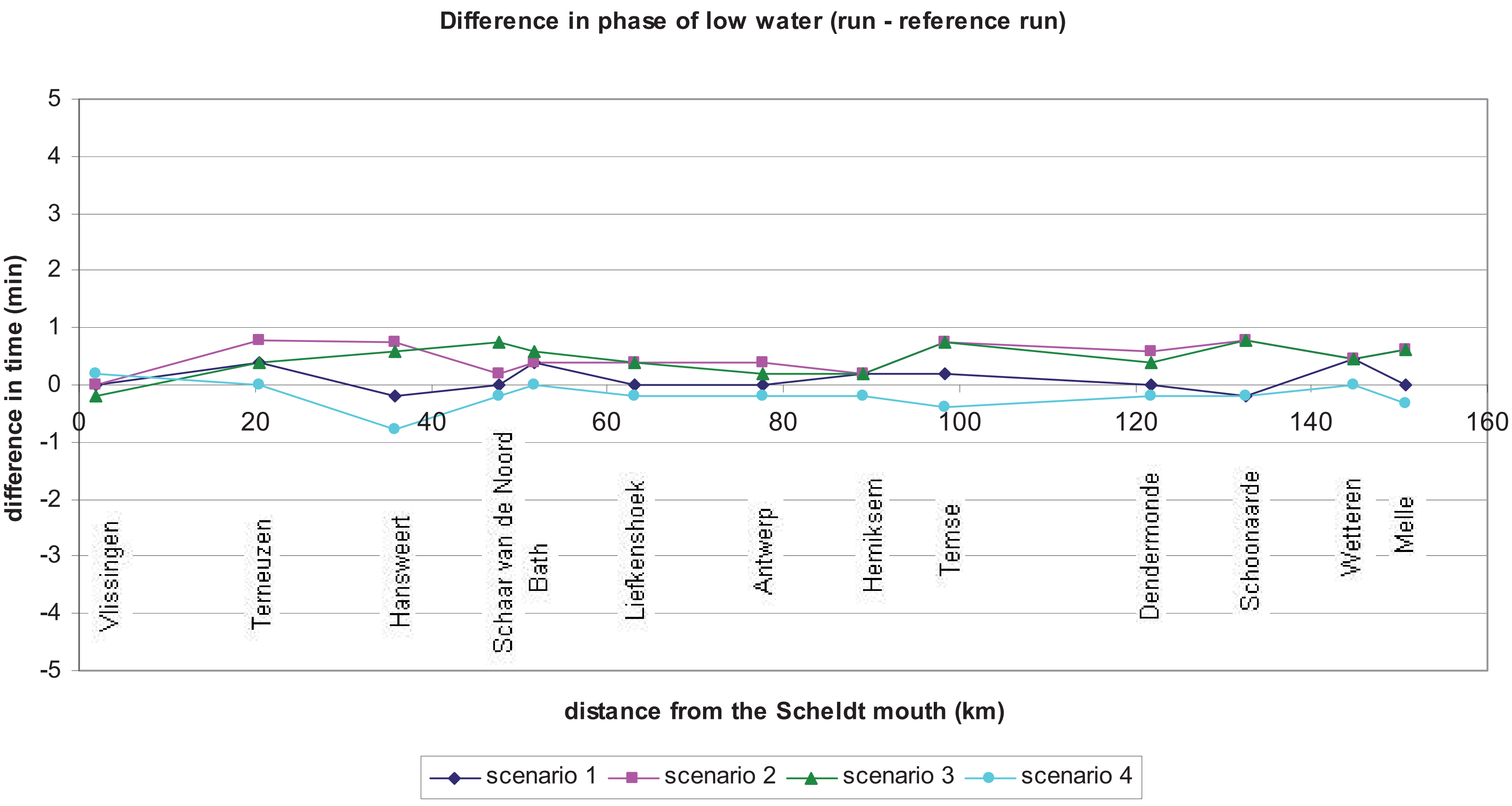


Figure 82 - Difference in phase of low water for the scenarios with the changes at the Gat van Ossenisse – Middelgat and reference situation (positive value is later compared to the reference simulation for 1970)

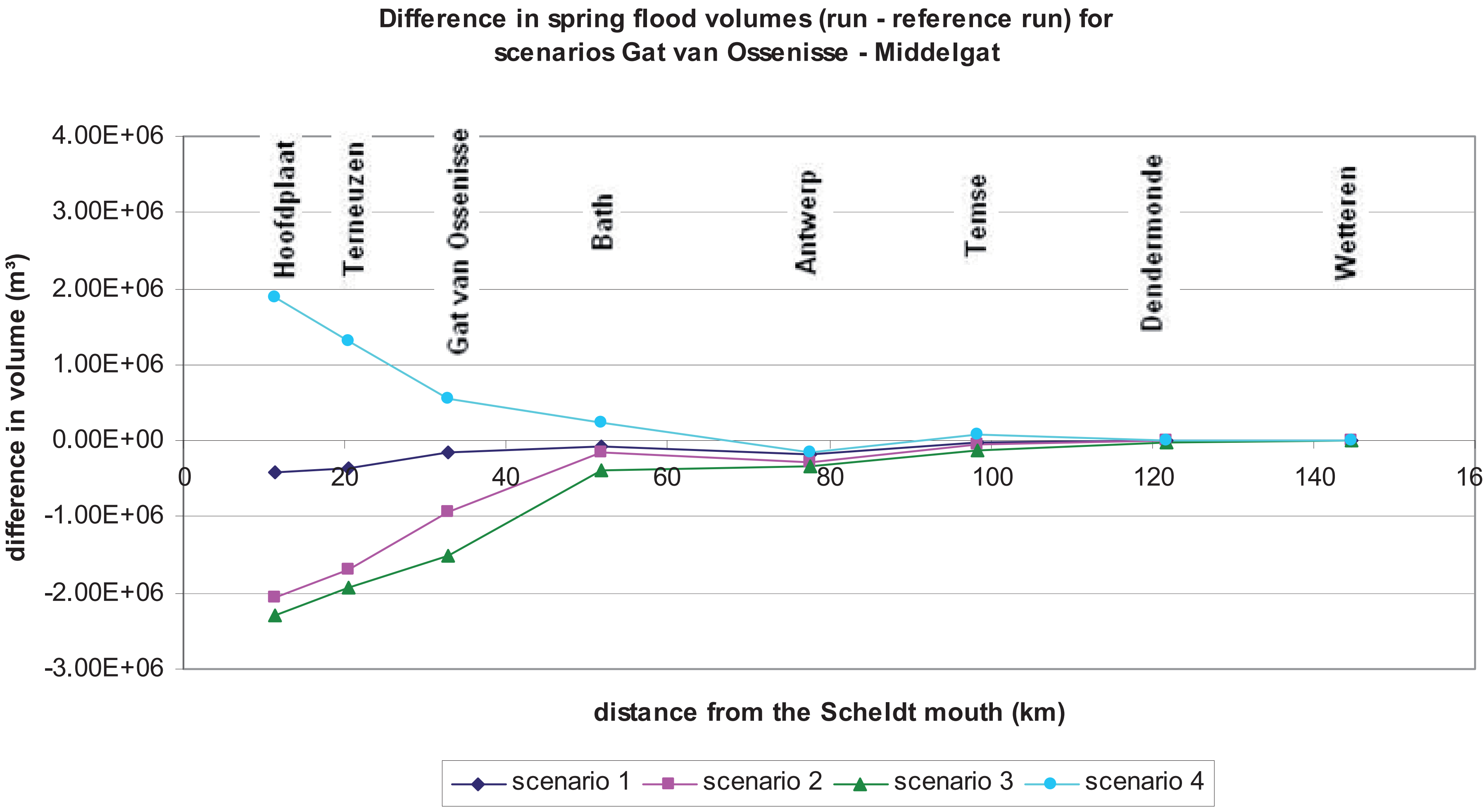
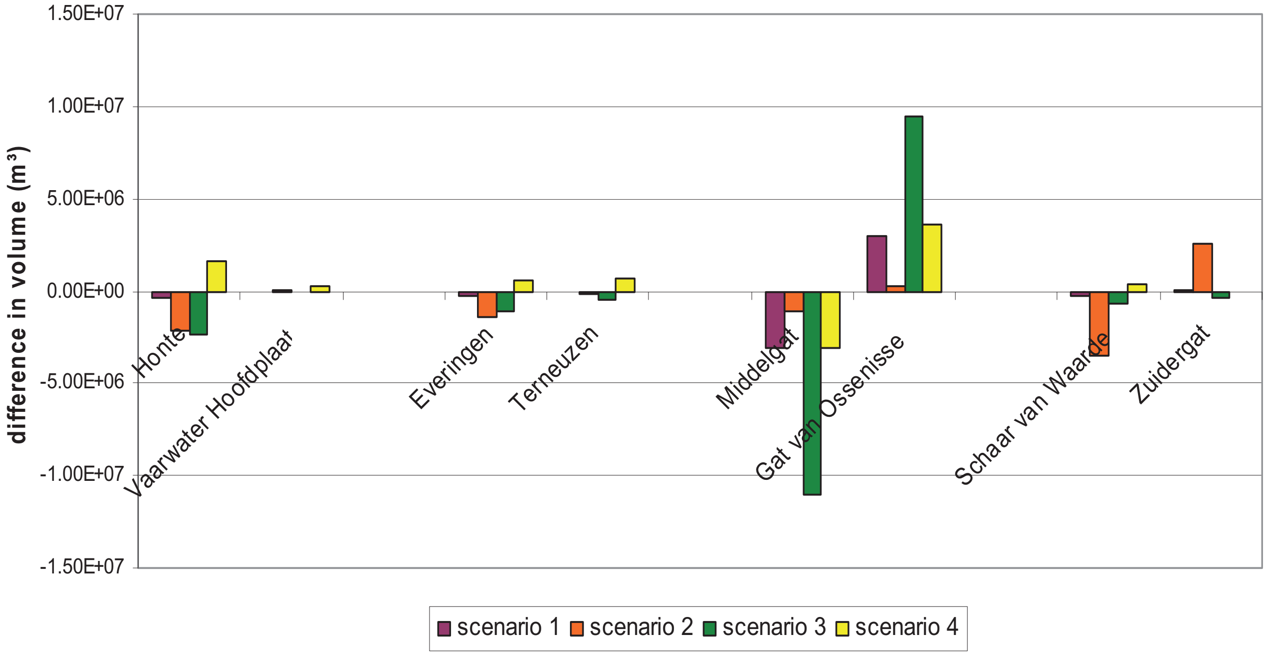


Figure 83 - Difference in the flood volumes for the scenarios with changes at the Gat van Ossenisse – Middelgat

Difference in spring flood volumes (run - reference run) for ebb and flood channels for scenarios Gat van Ossenisse-Middelgat



Difference in spring ebb volumes (run - reference run) for ebb and flood channels for scenarios Gat van Ossenisse-Middelgat

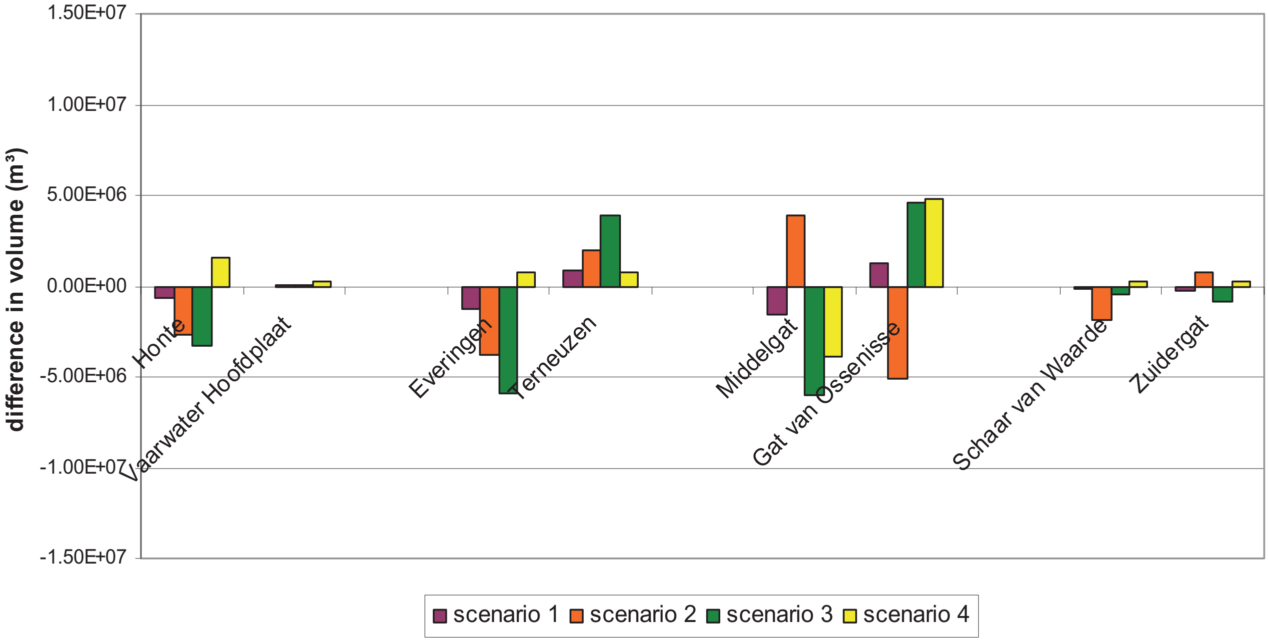
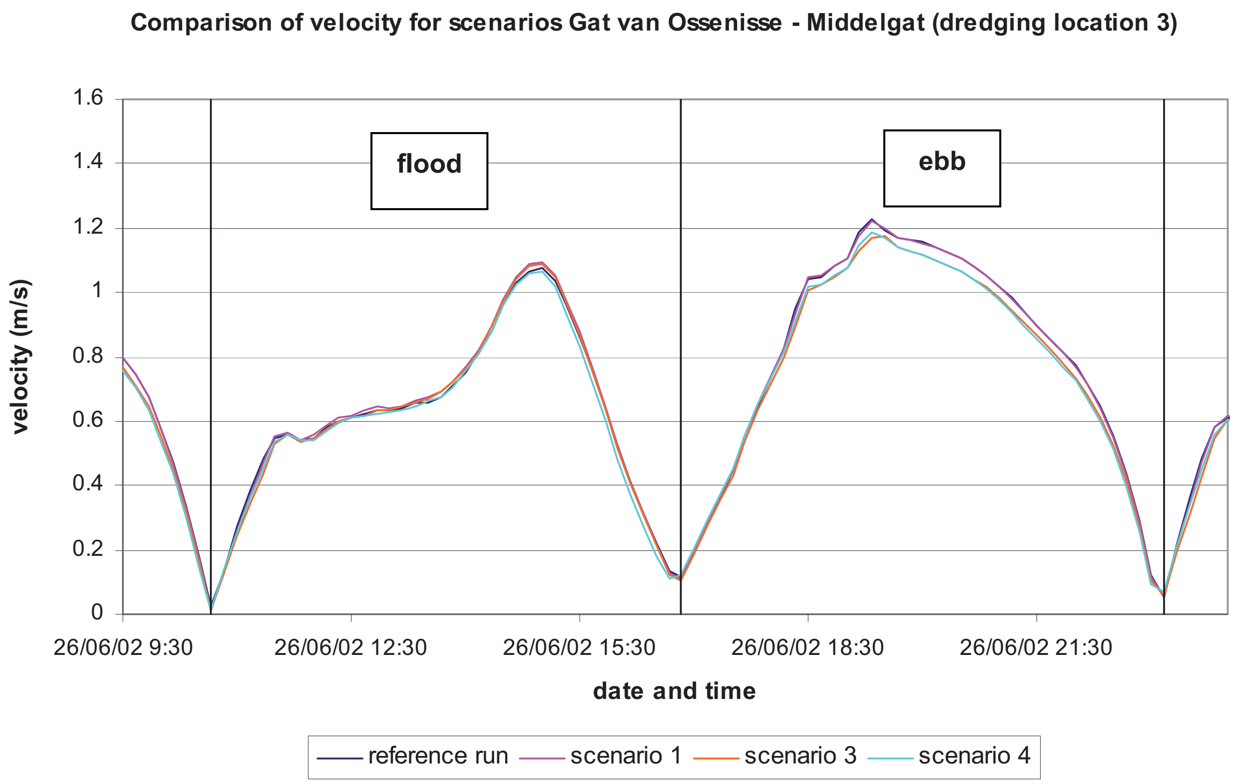


Figure 84 - Difference in the flood and ebb volumes for the ebb and flood channels for the scenarios with changes at the Gat van Ossenisse – Middelgat



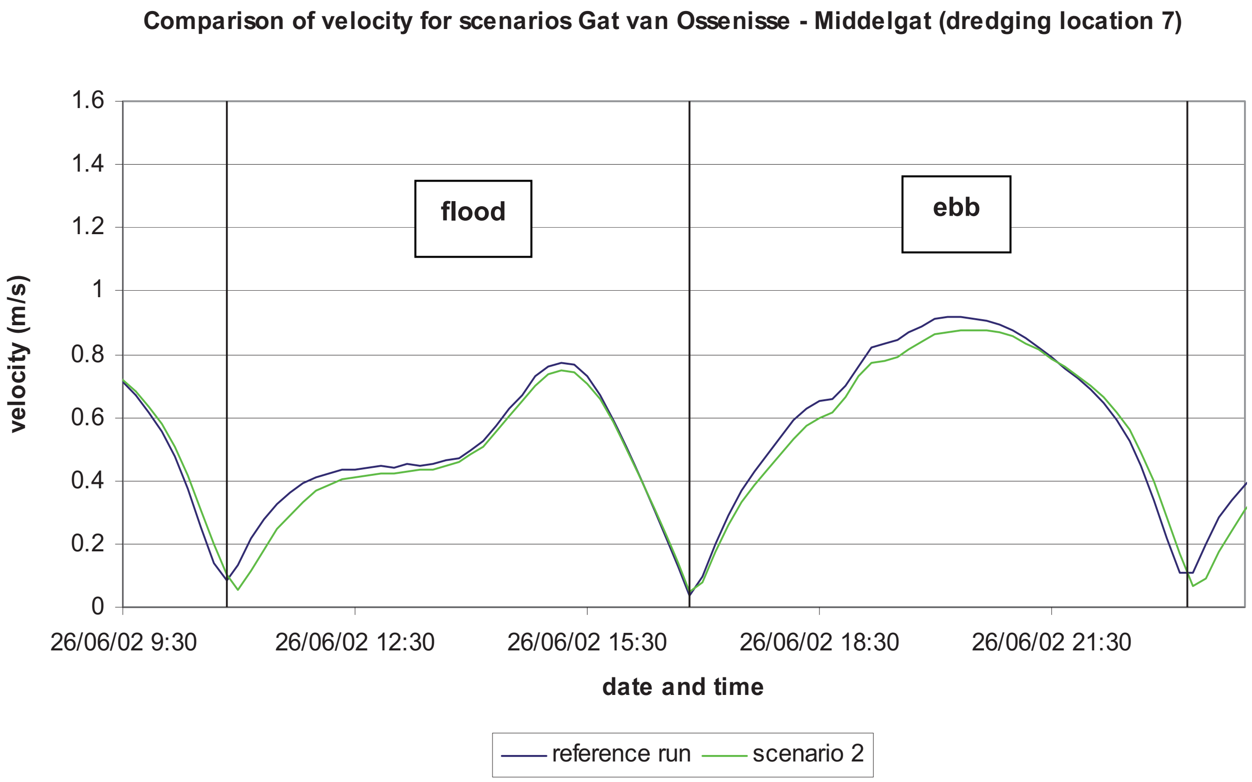
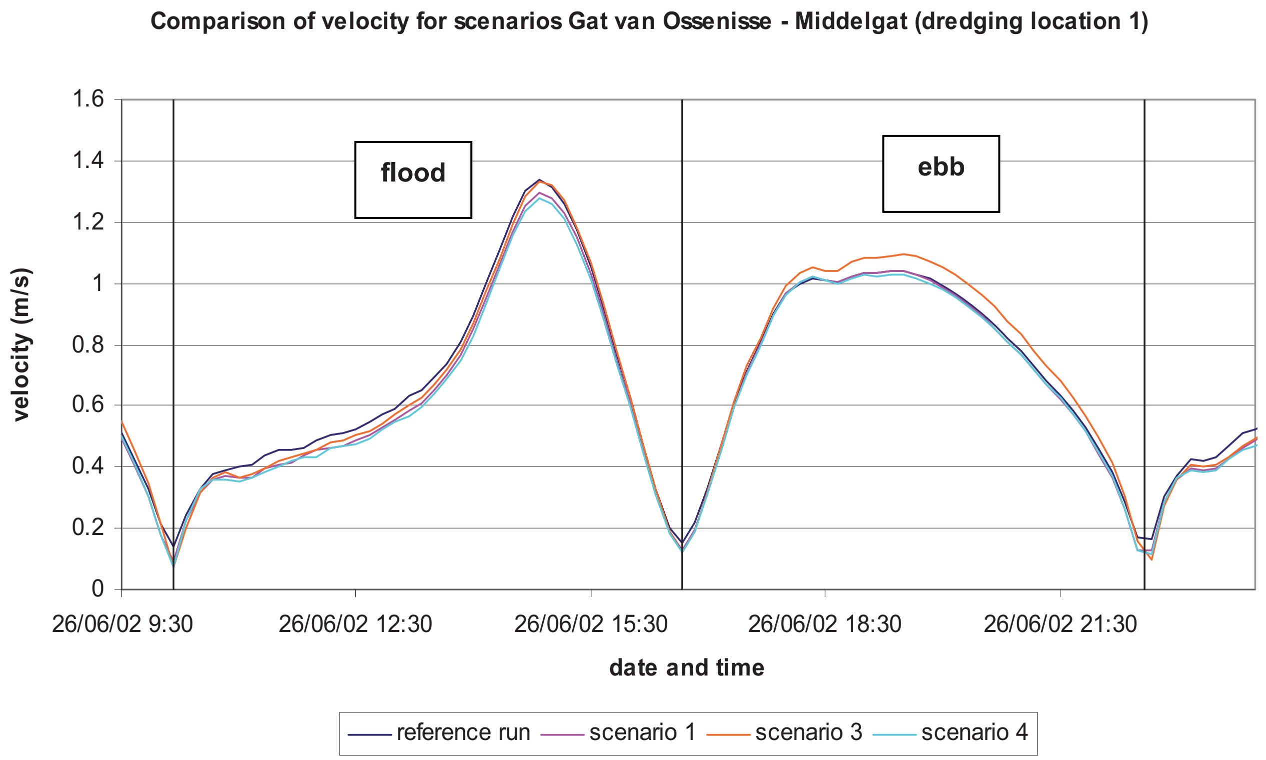


Figure 85 - Comparison of the velocity for the scenarios with the changes at the Gat van Ossenisse – Middelgat (dredging locations with decreased velocity)



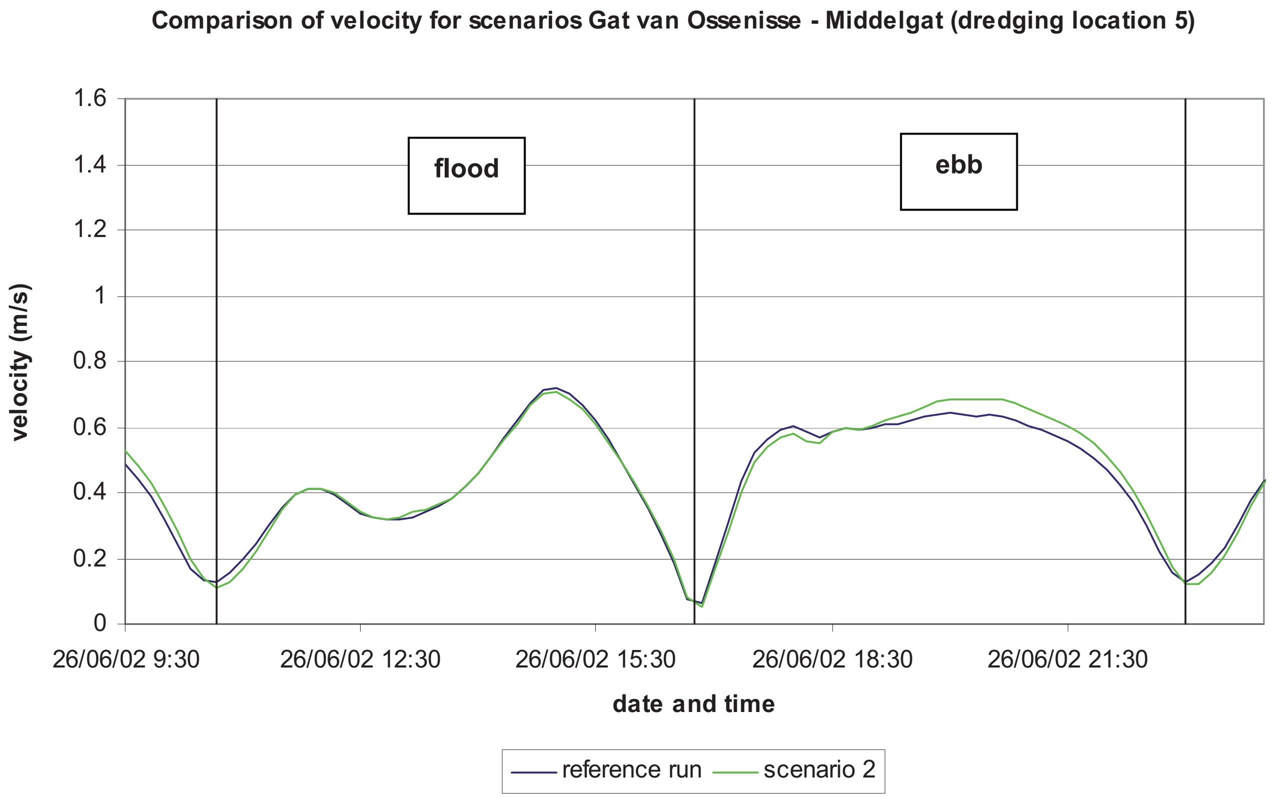


Figure 86 - Comparison of the velocity for the scenarios with the changes at the Gat ven Ossenisse – Middelgat (dredging locations with increased velocity)

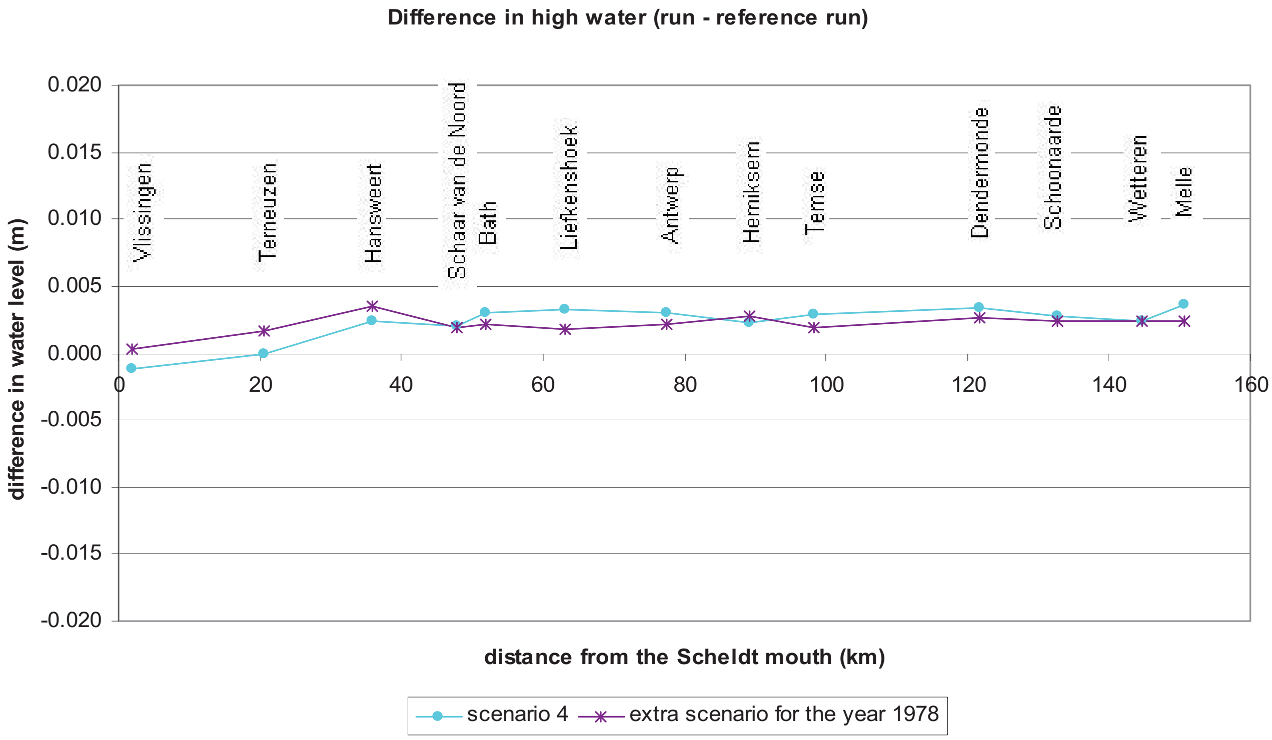


Figure 87 - Difference in high water for the year 1978 with the changes at the Gat van Ossenisse – Middelgat and the reference situation for 1970 (positive value is higher high water compared to the reference simulation)

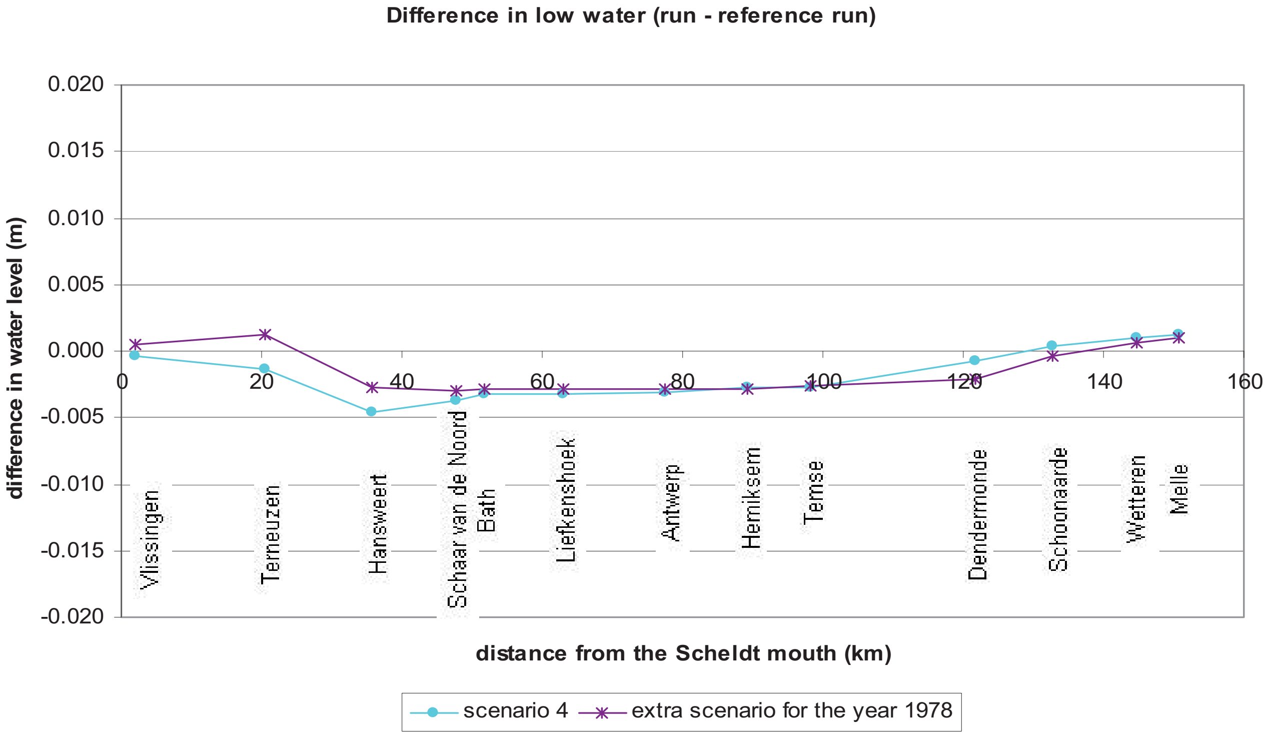


Figure 88 - Difference in low water for the year 1978 with the changes at the Gat van Ossenisse – Middelgat and the reference situation for 1970 (positive value is higher low water compared to the reference simulation)

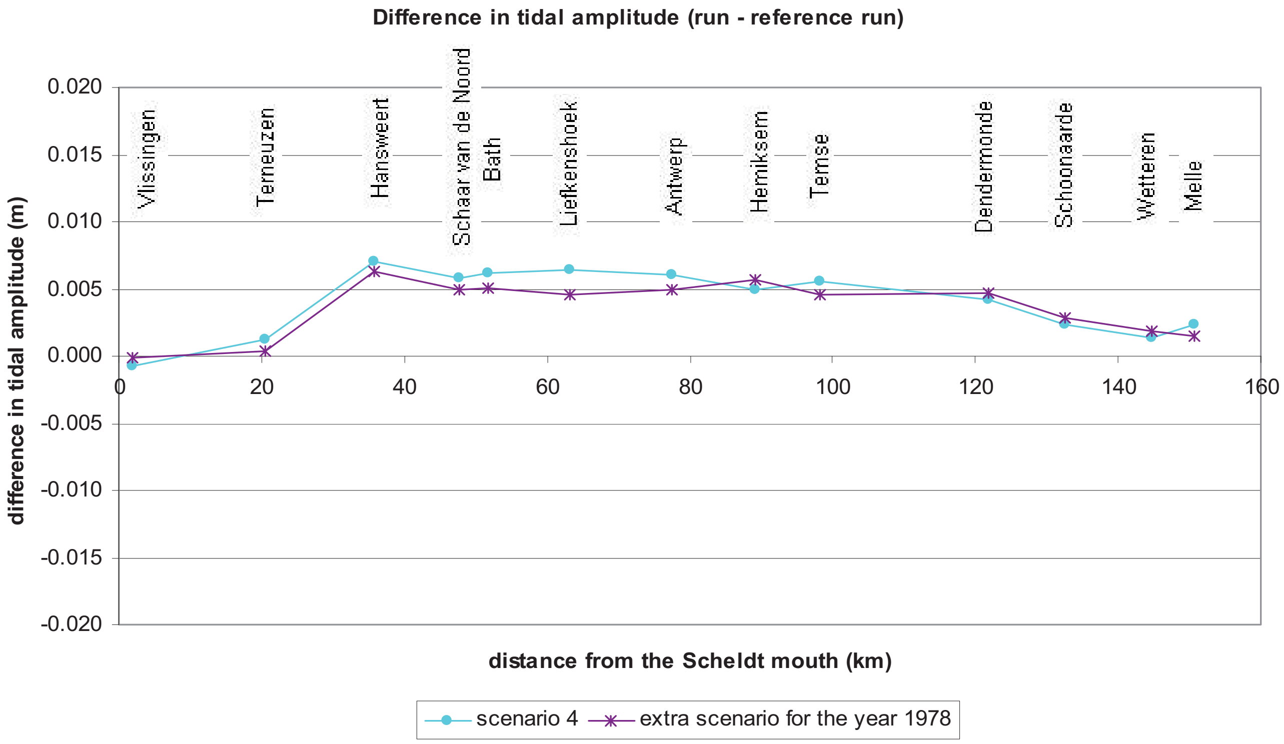


Figure 89 - Difference in tidal amplitude for the year 1978 with the changes at the Gat van Ossenisse – Middelgat and the reference situation for 1970 (positive value is higher amplitude compared to the reference simulation)

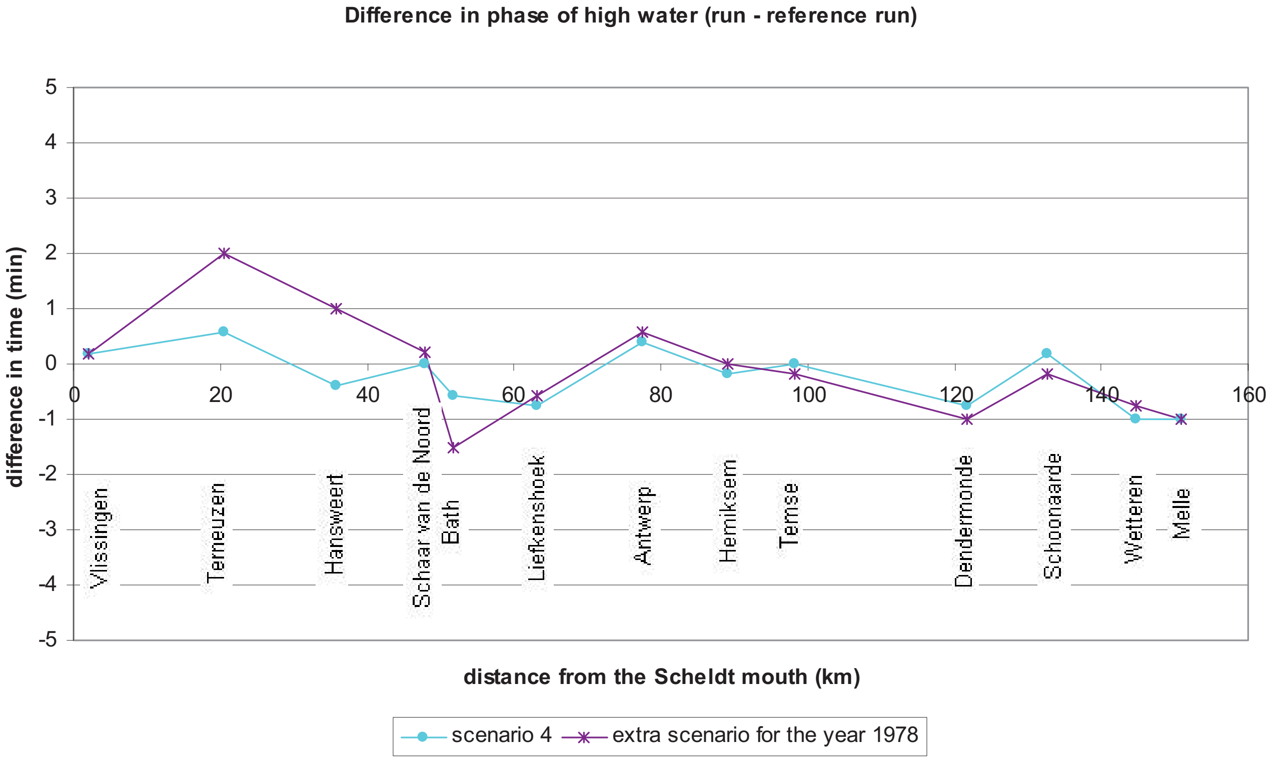


Figure 90 - Difference in phase of high water for the year 1978 with the changes at the Gat van Ossenisse – Middelgat and the reference situation for 1970 (positive value is later compared to the reference simulation)

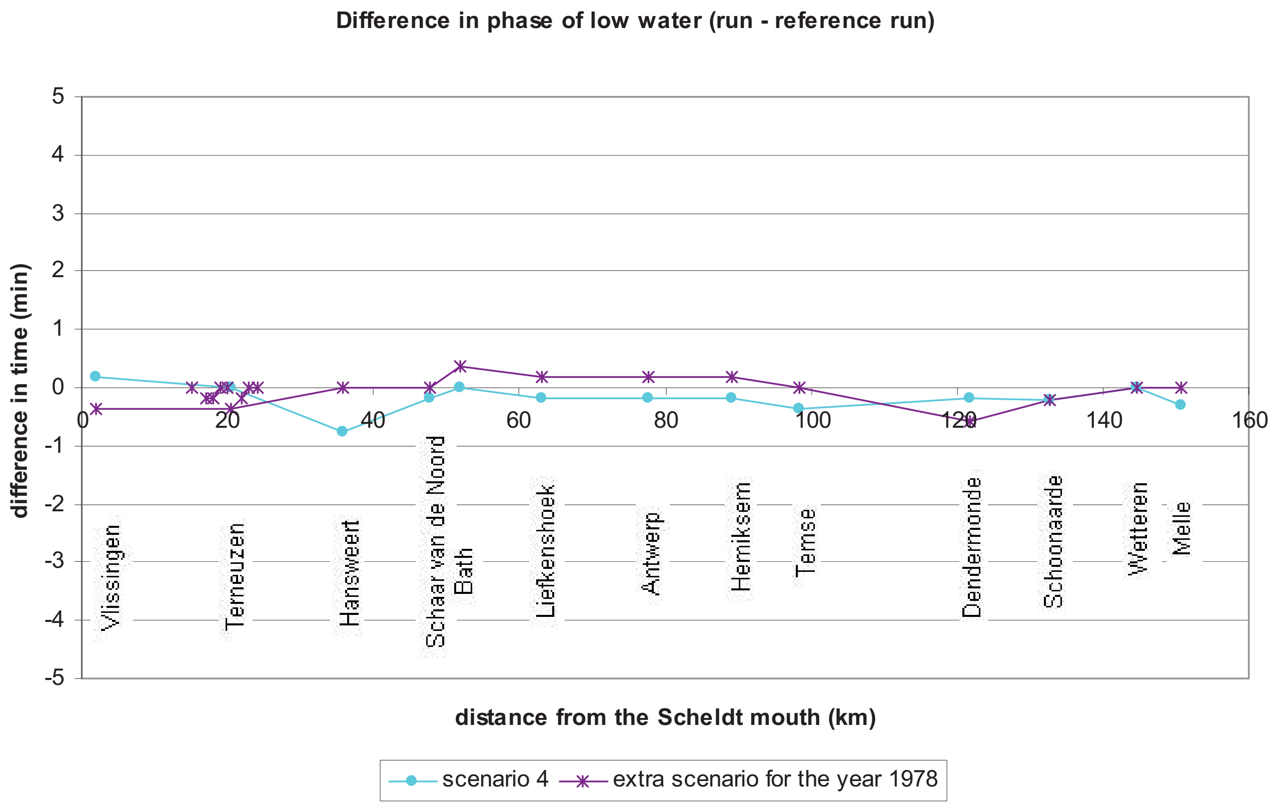


Figure 91 - Difference in phase of low water for the year 1978 with the changes at the Gat van Ossenisse – Middelgat and the reference situation for 1970 (positive value is later compared to the reference simulation)

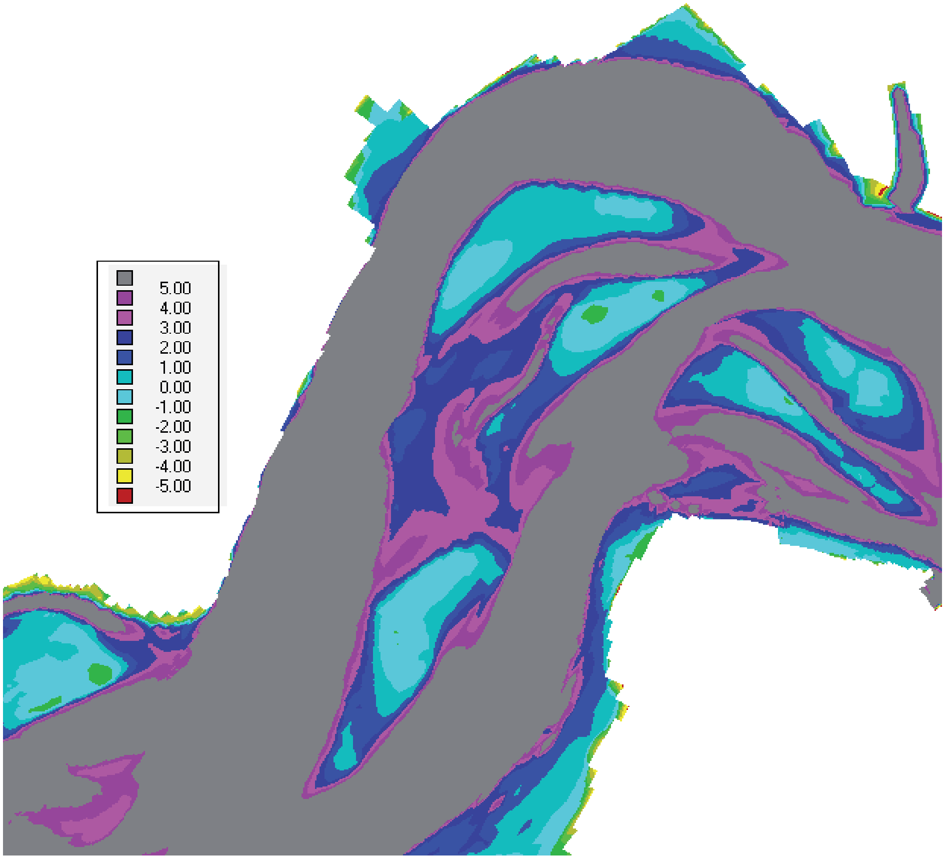


Figure 92 - Bathymetry near the Gat van Ossenisse – Middelgat in 1955 (m NAP)

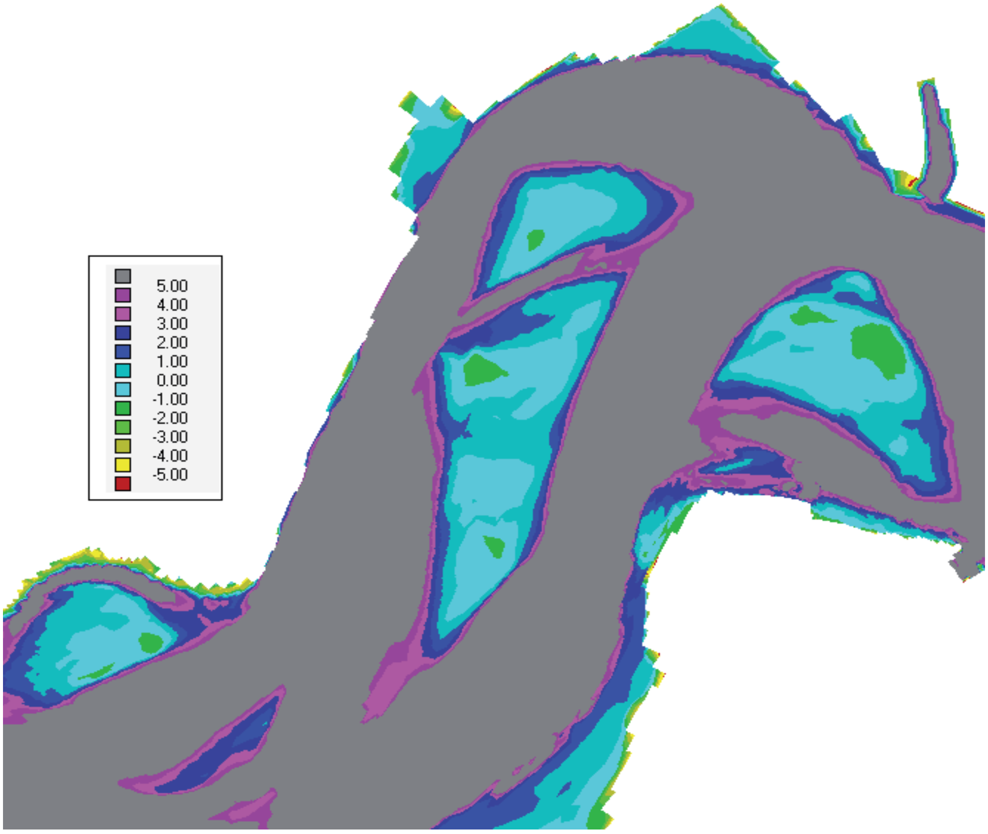


Figure 93 - Bathymetry near the Gat van Ossenisse – Middelgat in 2007 (m NAP)

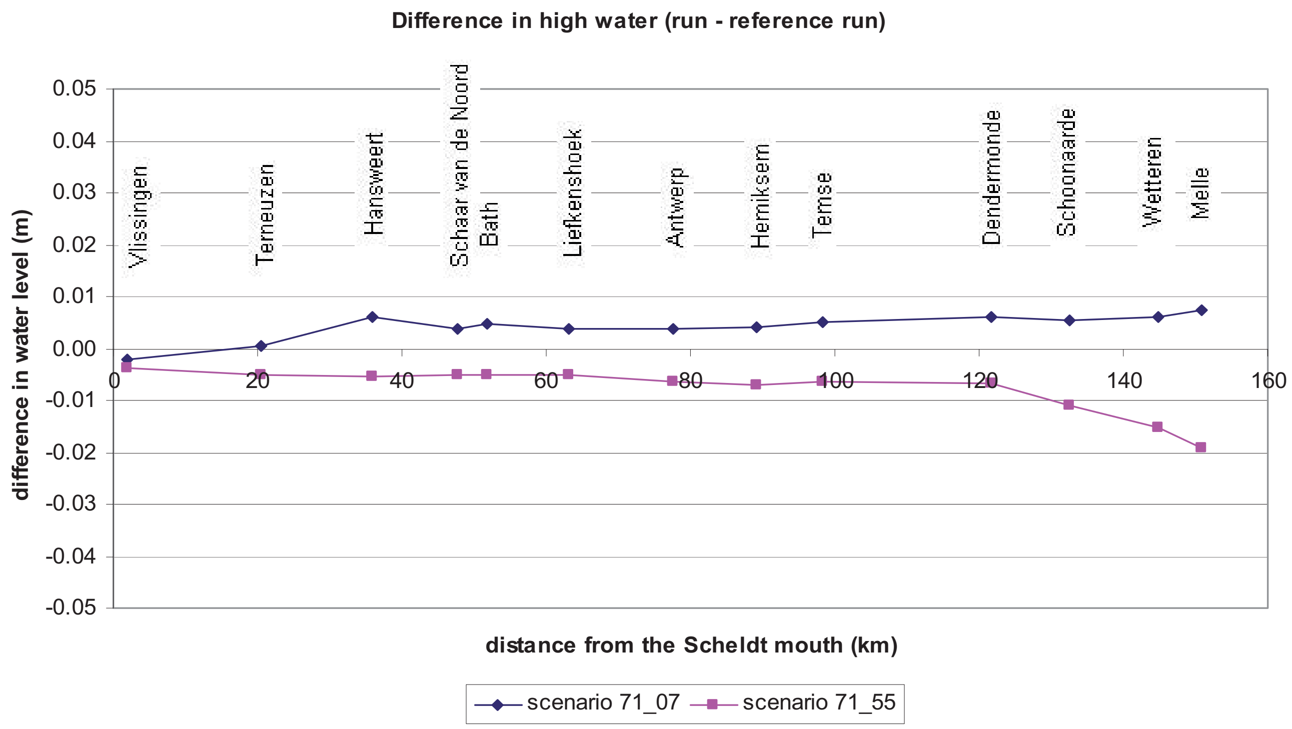


Figure 94 - Difference in high water for the scenarios with bathymetry 1955 and 2007 at the Gat van Ossenisse – Middelgat and the reference situation for 1970 – 1971
(positive value is higher high water compared to the reference simulation)

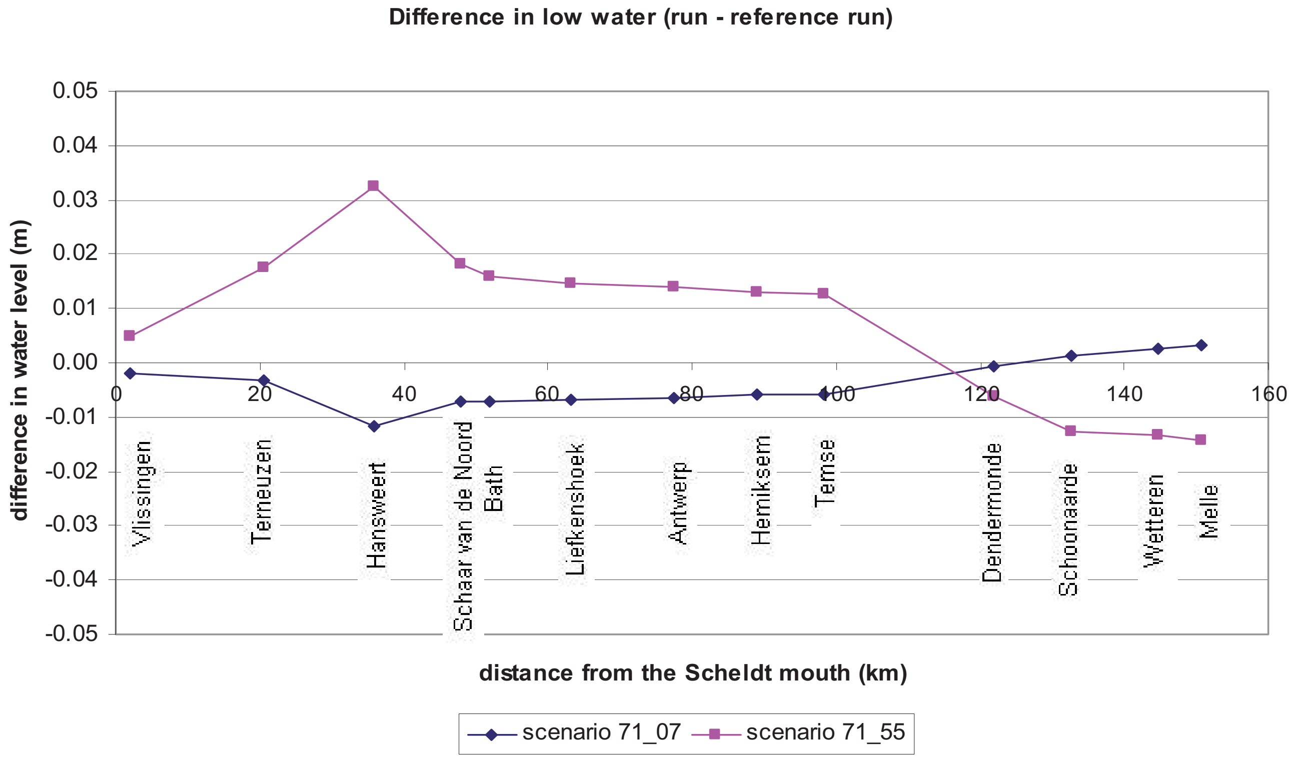


Figure 95 - Difference in low water for the scenarios with bathymetry 1955 and 2007 at the Gat van Ossenisse – Middelgat and the reference situation for 1970 – 1971
(positive value is higher low water compared to the reference simulation)

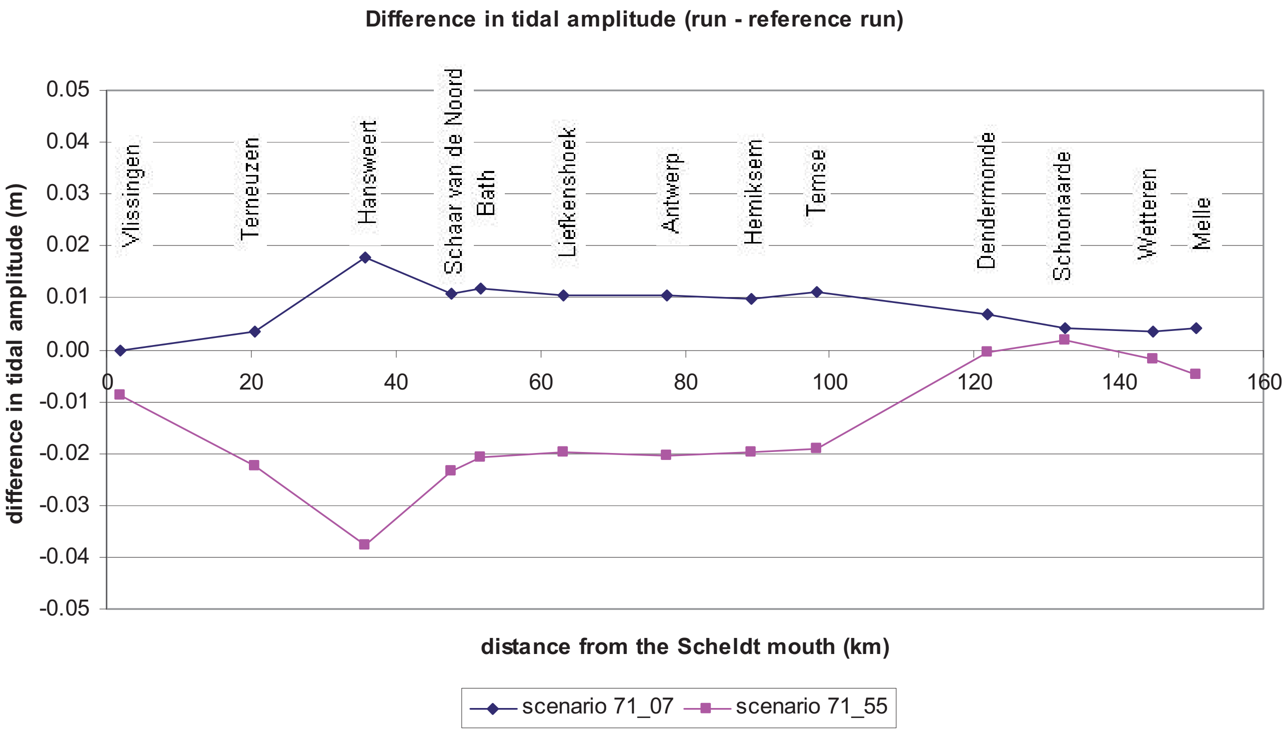


Figure 96 - Difference in tidal amplitude for the scenarios with bathymetry 1955 and 2007 at the Gat van Ossenisse – Middelgat and the reference situation for 1970 – 1971
(positive value is higher amplitude compared to the reference simulation)

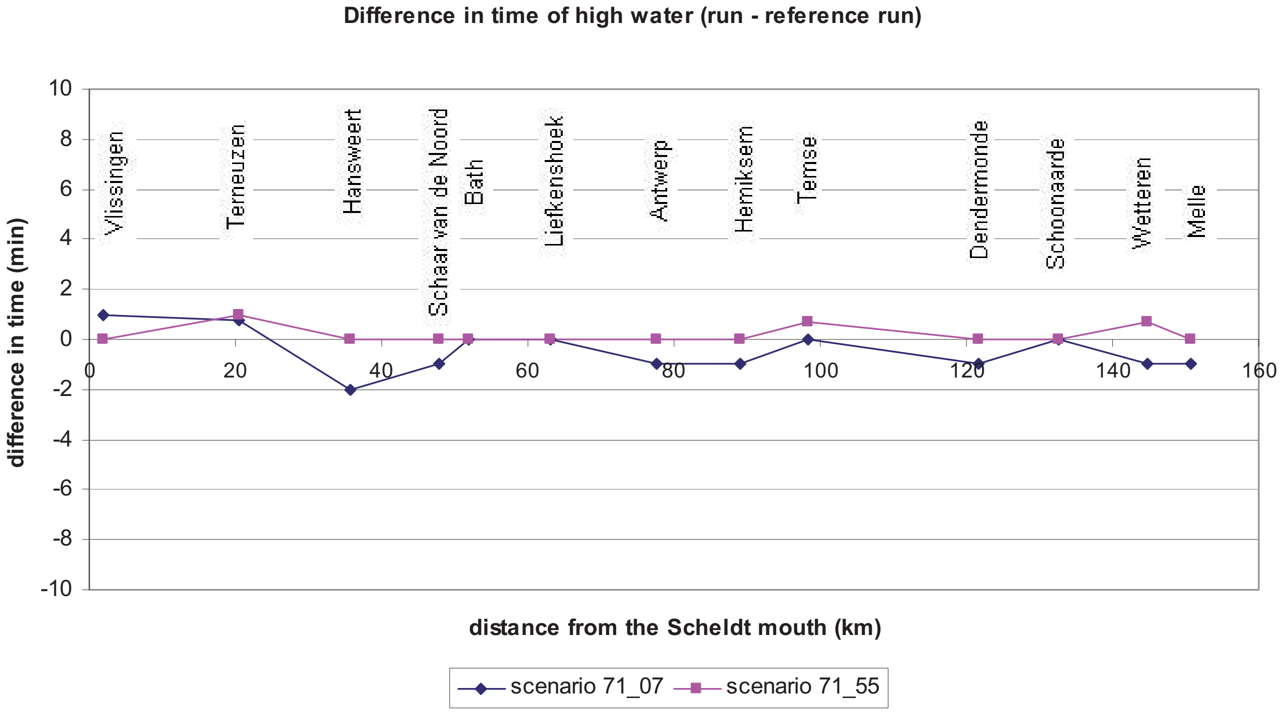


Figure 97 - Difference in phase of high water for the scenarios with bathymetry 1955 and 2007 at the Gat van Ossenisse – Middelgat and the reference situation for 1970 – 1971
(positive value is later compared to the reference simulation)

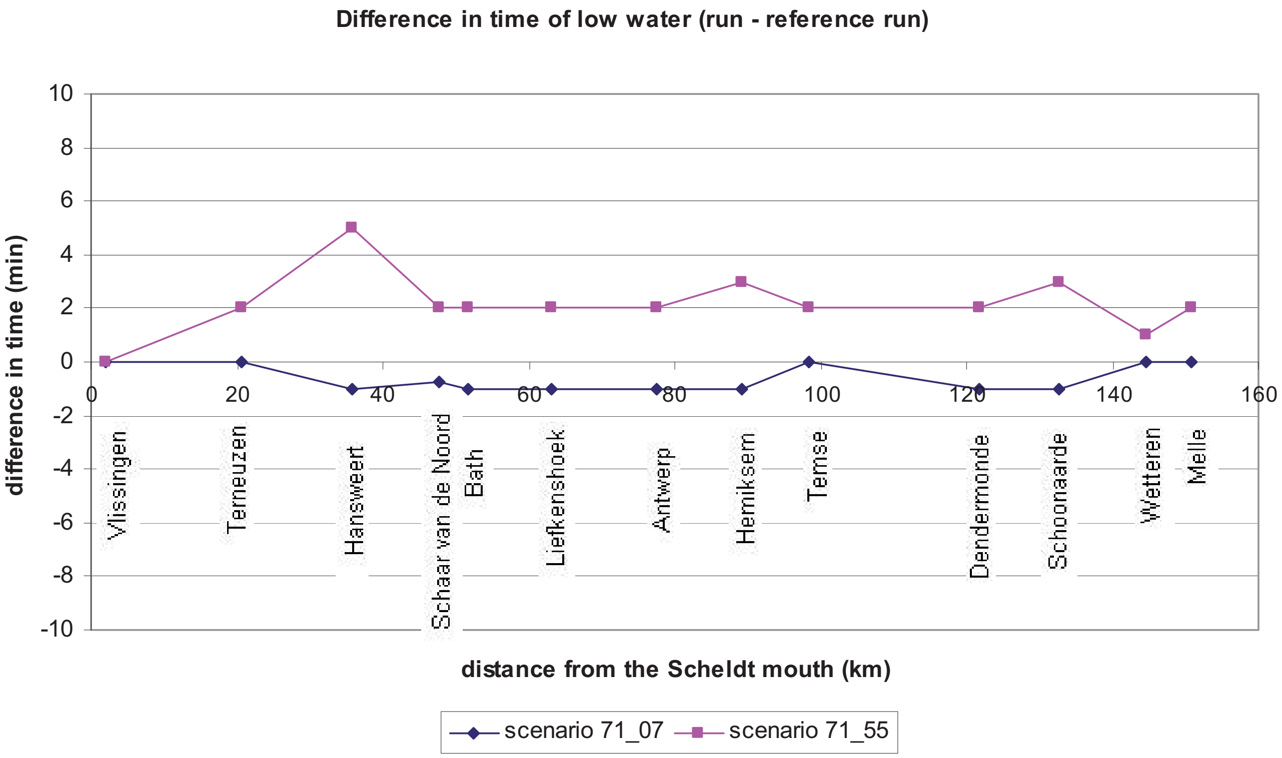


Figure 98 - Difference in phase of low water for the scenarios with bathymetry 1955 and 2007 at the Gat van Ossenisse – Middelgat and the reference situation for 1970 – 1971
(positive value is later compared to the reference simulation)

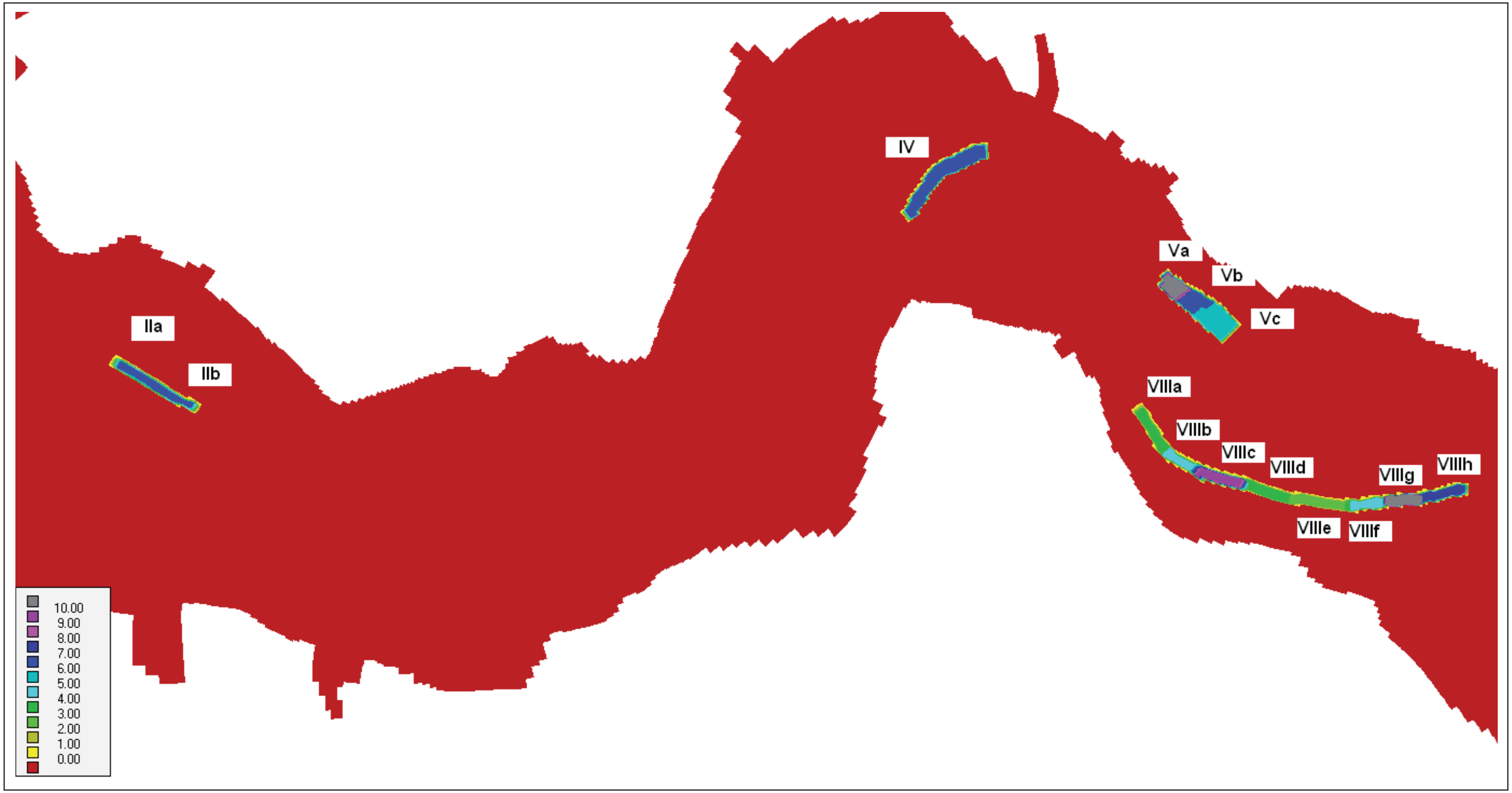


Figure 99 - Difference in bathymetry between the scenario with sand mining for 10 years and the reference situation

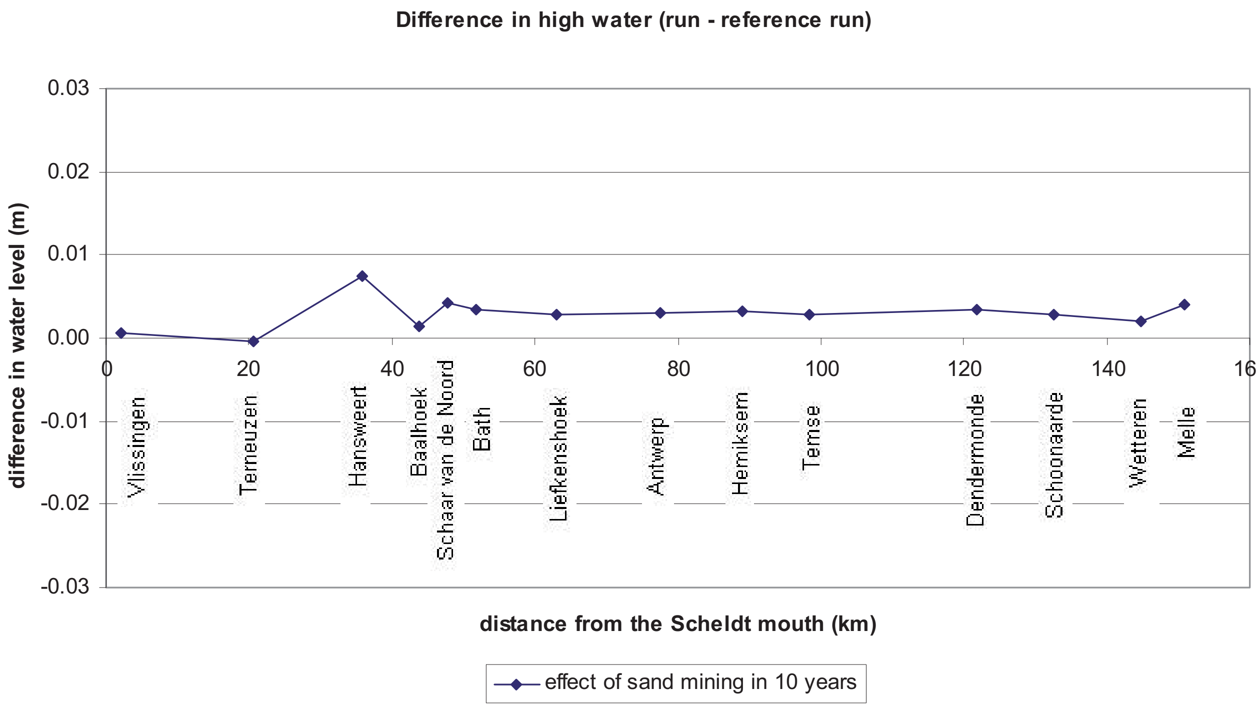


Figure 100 - Difference in high water for the scenario with sand mining in 10 years and reference run (positive value is higher high water compared to the reference simulation)

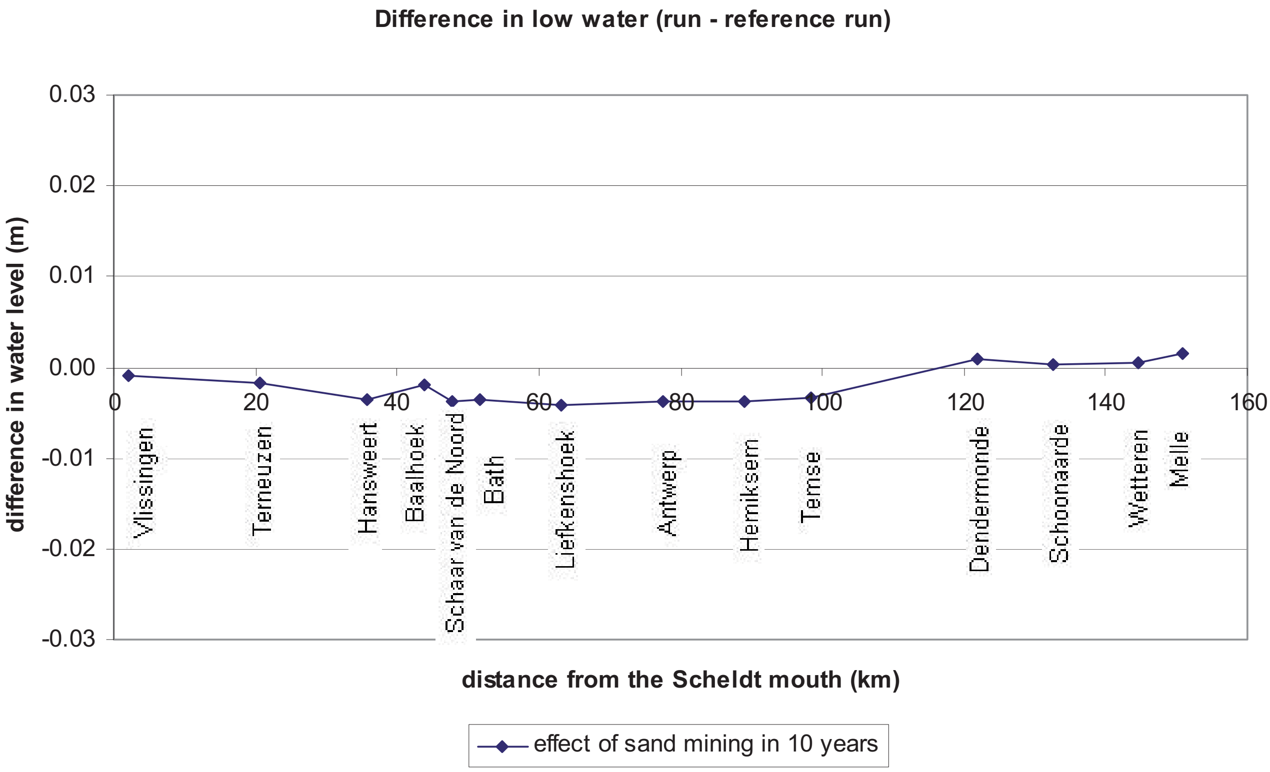


Figure 101 - Difference in low water for the scenario with sand mining in 10 years and reference run (positive value is higher low water compared to the reference simulation)

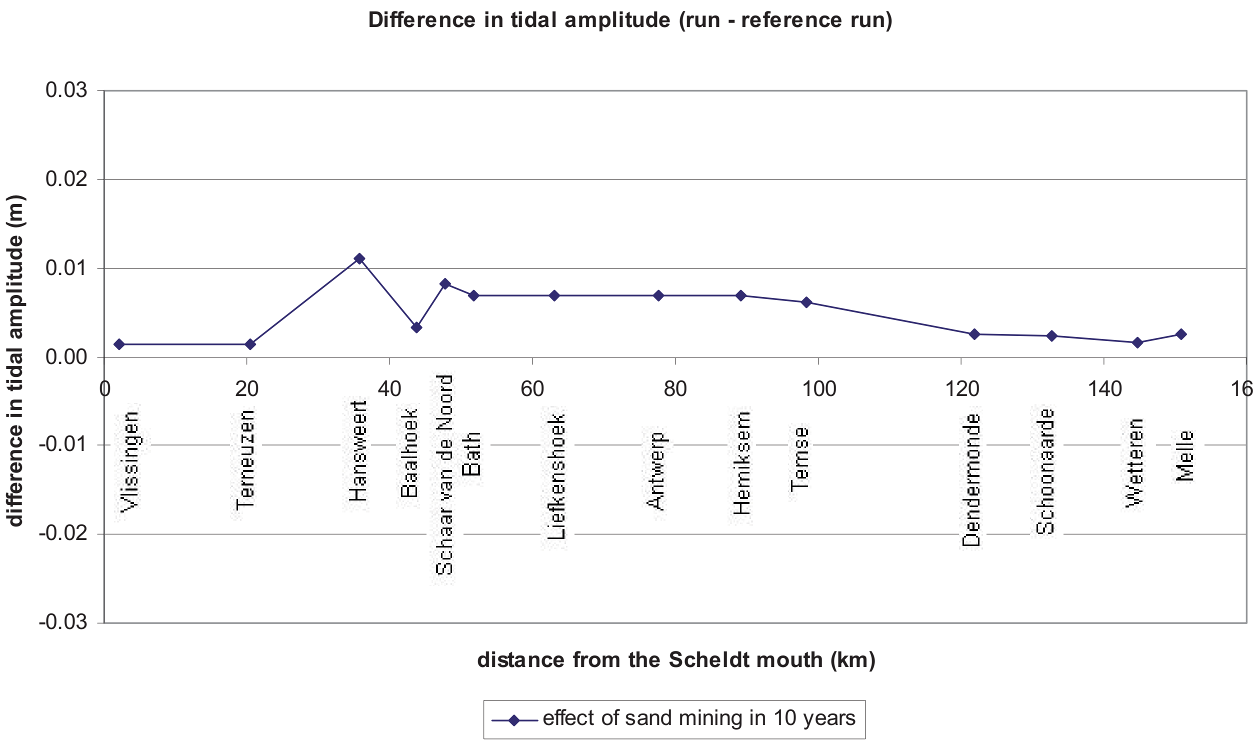


Figure 102 - Difference in tidal amplitude for the scenario with sand mining in 10 years and reference run (positive value is higher amplitude compared to the reference simulation)

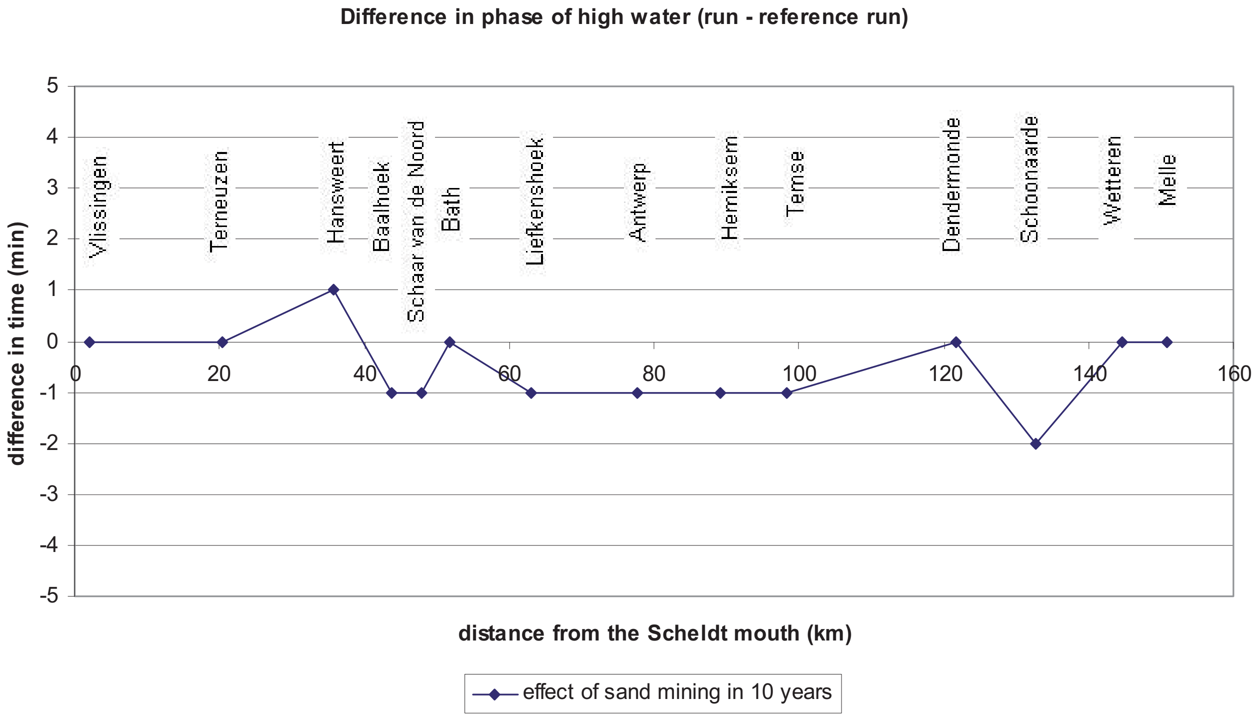


Figure 103 - Difference in phase of high water for the scenario with sand mining in 10 years and reference run (positive value is later compared to the reference simulation)

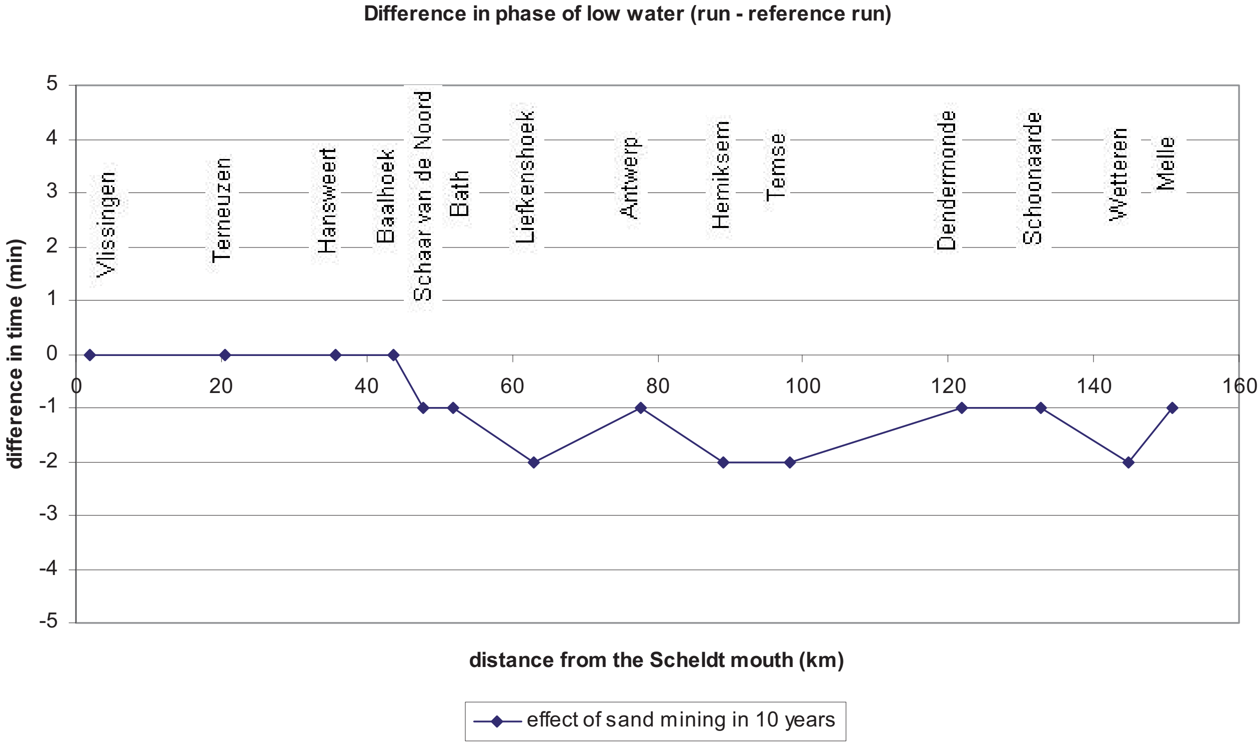


Figure 104 - Difference in phase of low water for the scenario with sand mining in 10 years and reference run (positive value is later compared to the reference simulation)

Appendix A. The effect of the use of 10 minute time series

The time and magnitude of the low and high water levels were found using a Matlab script, based on the sign of the first derivative of the water level time series. 10 minute time series of the water levels were used for the analysis. We studied the effect of this time interval on the calculated magnitude and phase of high and low waters for some scenarios (Table B-1). The results of the analysis of 1 minute versus 10 minute time series were compared. The analysis shows that the differences between the use of the 1 minute and 10 minute time series are small. The differences in high and low water magnitude are zero for most stations, a maximal difference of 3 cm is observed at Melle. The differences in the phase are 1 to 2 minutes.

Table B-1. Comparison of the high and low water magnitude and phase calculated from 1 min and 10 min time series

Station	**Difference in magnitude (run - reference run) (cm)**								**Difference in phase (run - reference run) (min)**							
	Sea level rise in 2100				**4 polders together**				**Sea level rise in 2100**				**4 polders together**			
	HW		LW		HW		LW		HW		LW		HW		LW	
	10min	1min	10min	1min	10min	1min	10min	1min	10min	1min	10min	1min	10min	1min	10min	1min
Antwerp	57	57	56	56	-8	-8	2	2	-2	-1	-6	-6	5	7	2	2
Wetteren	58	59	38	36	-2	-2	5	5	5	5	-20	-18	12	12	3	4
Melle	64	64	39	36	1	0	4	3	1	1	-25	-25	11	11	4	6
Boom	56	56	53	53	-11	-11	3	3	-1	-1	-9	-8	7	7	2	3
Walem	56	56	46	46	-12	-12	2	2	-1	-2	-12	-12	8	7	3	3

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