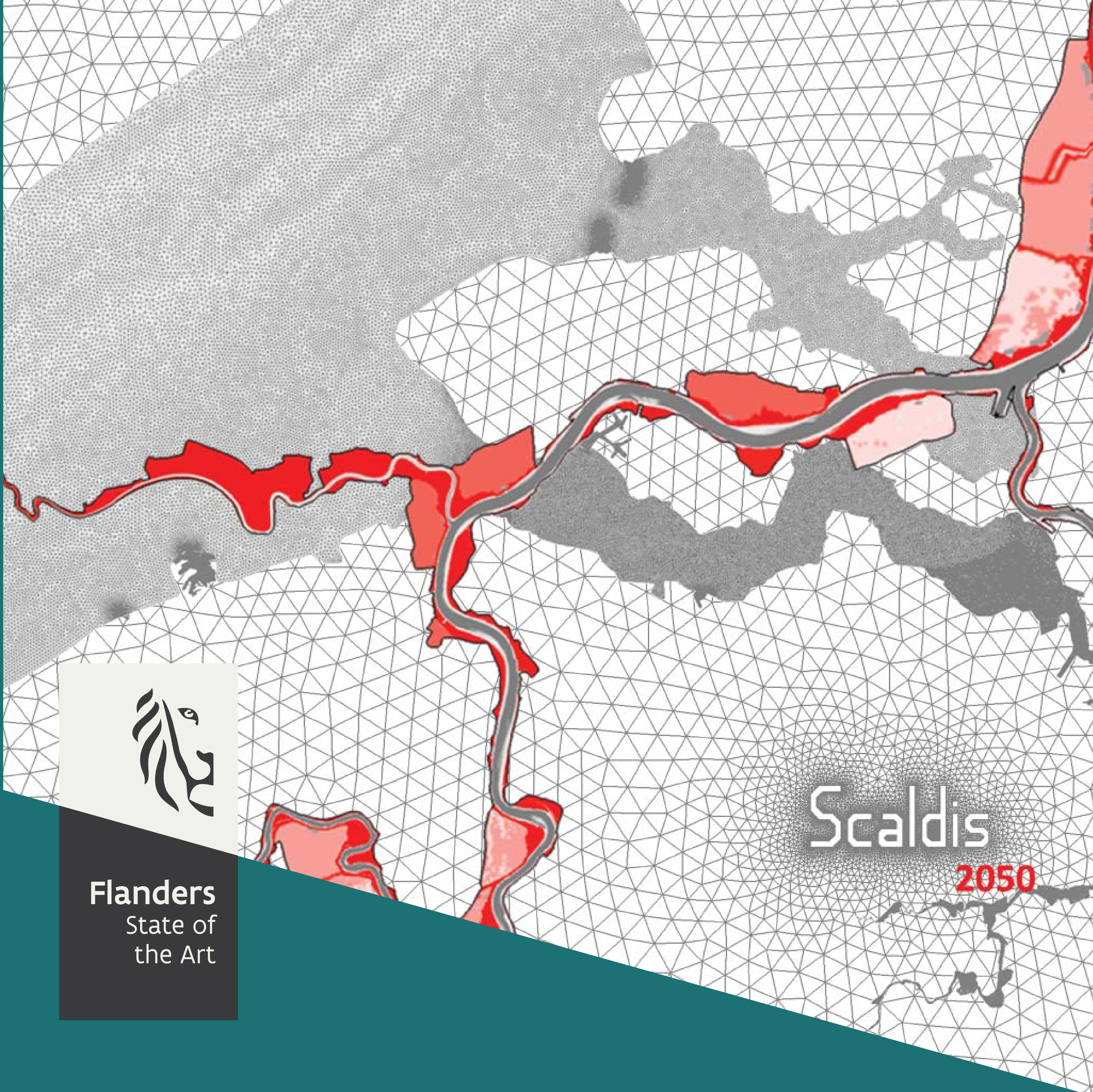

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Deelrapport 5 – Scaldis 2050

Smolders, S.; Maximova, T.; Vandenbruwaene, W.; Coen, L.; Vanlede, J.; Verwaest, T.; Mostaert, F.

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Abstract

In the framework of the projects ‘Integrated plan for the Upper Sea Scheldt’ and ‘Agenda for the Future’, it was necessary to develop a hydrodynamics and sediment transport model that covers the entire tidally influenced zone of the Scheldt Estuary and the mouth area, and that has sufficient resolution in the upstream part.

The SCALDIS model, a new unstructured high resolution model of the tidal Scheldt was developed in TELEMAC 3D for the entire estuary, but with special attention to the upstream parts. The use of an unstructured grid allows to combine a large model extent with a high resolution upstream. The calibrated model will be used to analyze the effects of several scenarios (different morphology of the Scheldt with different ranges of boundary conditions). The setup and calibration of this model are described extensively in a previous report (WL2015R13_131_1_HD_model).

This report describes the updates to Scaldis to make it ready for scenario analysis of the year 2050. An elevation model was developed to estimate the sedimentation in flood control areas with controlled reduced tide by 2050. These estimated new bed levels were implemented in Scaldis. All flood control areas foreseen in the Sigmaplan to work in 2050 were also activated in Scaldis. Every area is described in detail. The whole set of boundary conditions to take into account all possible evolutions by 2050 (like climate change) is described.

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1 Introduction

This report describes the changes that were made to prepare the Scaldis model (described in Smolders et al., 2016) for simulations of the reference situation in the project ‘Integraal Plan Boven-Zeeschelde’. This reference situation is the estuary in the year 2050. The expected (until 2050) changes in the bathymetry were implemented in the model. The bed levels of the de-embanked areas and flood control areas (FCA) with controlled reduced tide (CRT) were updated to account for sedimentation. Furthermore, the full Sigmaplan (as it is known today) is implemented in the Scaldis 2050 model. This means that more FCA and CRT areas have become active and more inlet and outlet constructions of these areas are implemented in the model.

The Scaldis 2050 model will be used to evaluate the effects of different alternatives (morphology of the Scheldt river in a specific state and at a specific time) under different scenarios (a range of boundary conditions that take into account the climate change, sea level rise, increasing or decreasing tidal amplitude, high or low discharge).

In this report we first give an overview of all bathymetry updates that were implemented in the 2013 Scaldis model to make the 2050 model. We describe an elevation model to estimate the increase in average bed level of de-embankments and FCA’s with CRT. Next we give an overview of all Sigma areas in the model and how they were implemented. Then we briefly discuss the computational cost of the extra in- and outlet structures, known as culverts, in the model. Next an overview of the changes in the model grid is given. The model grid had to be adapted so that it can be used for the calculation of the variants with different bathymetries. In the end the boundary conditions and salinity fields used in the scenario runs are described and the list of the scenario simulations is given.

2 Units and reference plane

Time is expressed in CET (Central European Time).

Depth, height and water levels are expressed in meter TAW (Tweede Algemene Waterpassing).

Bathymetry and water levels are positive above the reference plane.

The horizontal coordinate system is RD Parijs.

3 Bathymetry 2050 compared to 2013

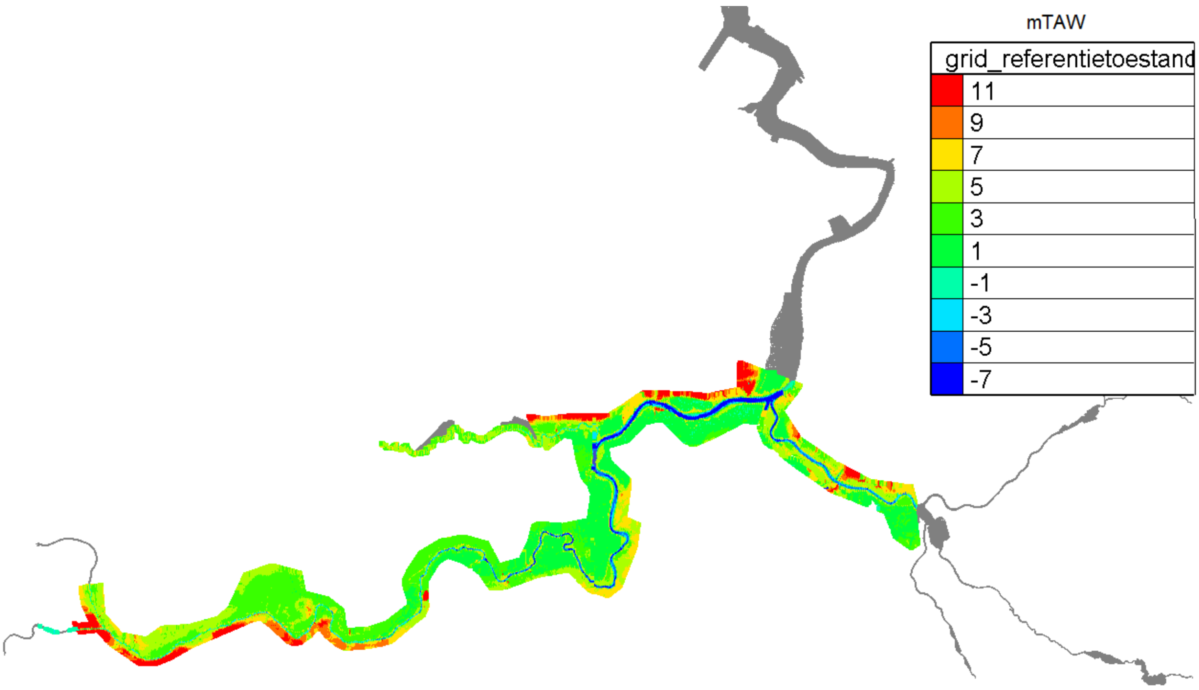
In this chapter we will give an overview of all bathymetry updates that were implemented in the 2013 Scaldis model to make the 2050 model.

3.1 Sustainable bathymetry

The Sustainable Management Plan was developed for a sustainable management of the Upper Sea Scheldt and the Ringvaart. This plan focusses on maintaining the fairway with respect for the tidal nature. The designed bathymetry takes into account the needs for navigation and the characteristics of the river. The impact on the tidal nature is limited to specific areas. The hydrodynamic and morphological processes can develop to the extent that the safety and tidal nature are not endangered. The Management Plan aims to optimize the existing management efforts for navigation and protection of the river banks (IMDC, 2015a).

The sustainable bathymetry is provided by IMDC (Figure 1). The sustainable bathymetry only concerns bathymetry. The de-embanked areas, CRT and FCA, are today's situation based on Lidar 2013. The data set grid_referentie-toestand_LB72_v2.zip was converted to RD Paris : grid_referentietoestand_2050 _RD_TAW_p1.xyz and grid_referentietoestand_2050_RD_TAW_p2.xyz.

Figure 1 – Sustainable bathymetry (mTAW)



Information about the changes implemented in the sustainable bathymetry can be found in IMDC (2015a). In this report we will show some examples (Figure 2, Figure 3).

Figure 2 – Depth difference map of changes implemented in the sustainable bathymetry near Uitbergen (m)

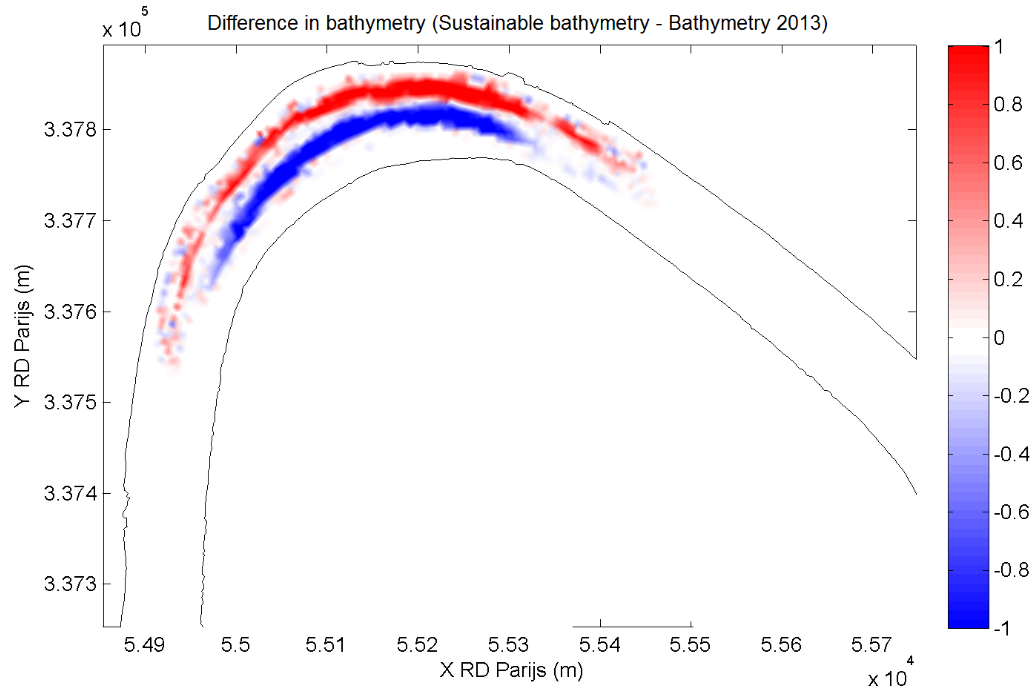
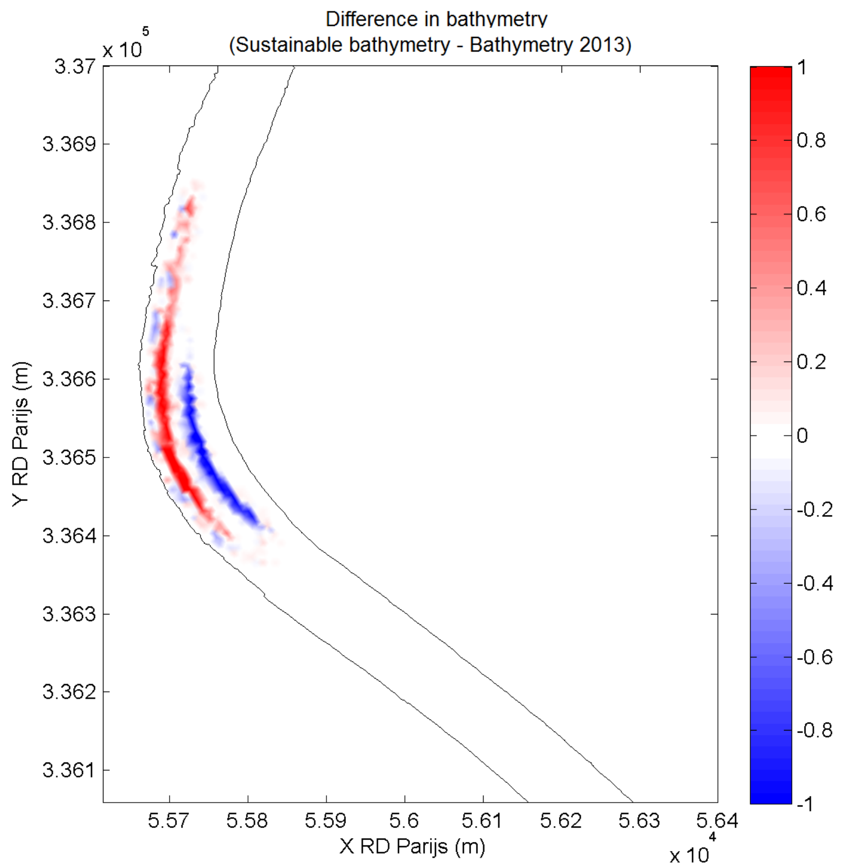


Figure 3 – Depth difference map of changes implemented in the sustainable bathymetry near Wichelen (m)



3.2 Durme and Heusden

A new bathymetry (provided by IMDC) is implemented in the Durme and at Heusden (Figure 4, Figure 5) (Durme_ontwerpprofielIMDC_2050_RD_TAW.xyz and Heusden_ontwerpprofielIMDC_2050_RD_TAW.xyz).

Just north of the de-embankment of Heusden a new sluice will prevent the full tide from penetrating further upstream (see chapter 4.3.31). Like the FCA area with CRT, this sluice will get bypass culverts to allow part of the tide to pass and to encourage the development of fresh water tidal nature upstream in this tidal arm.

Figure 4 – New bathymetry at Durme

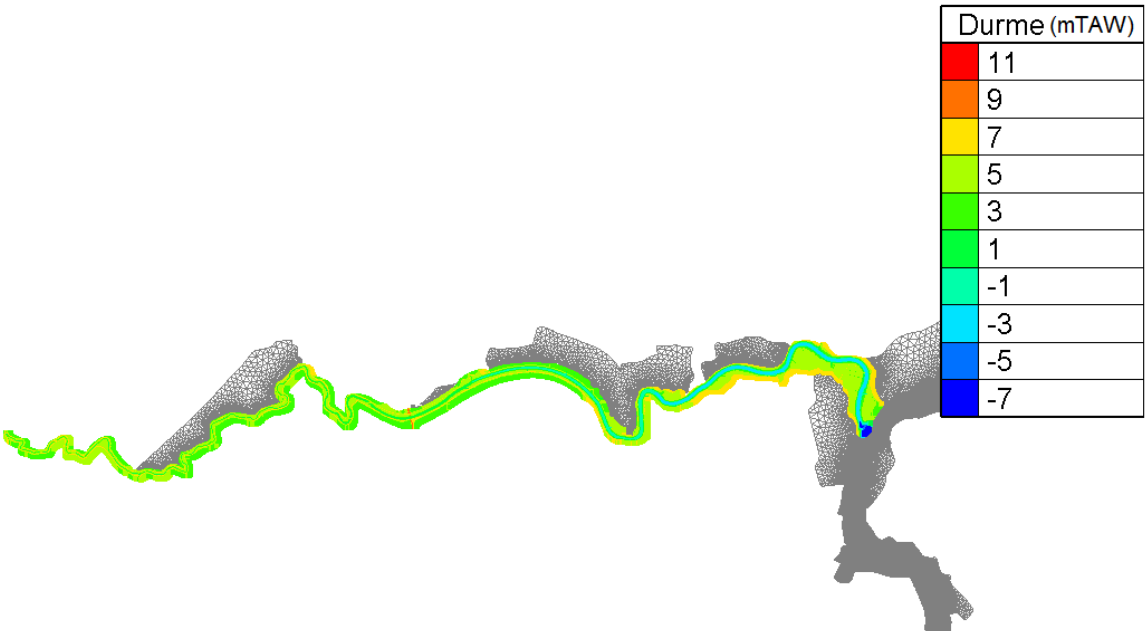
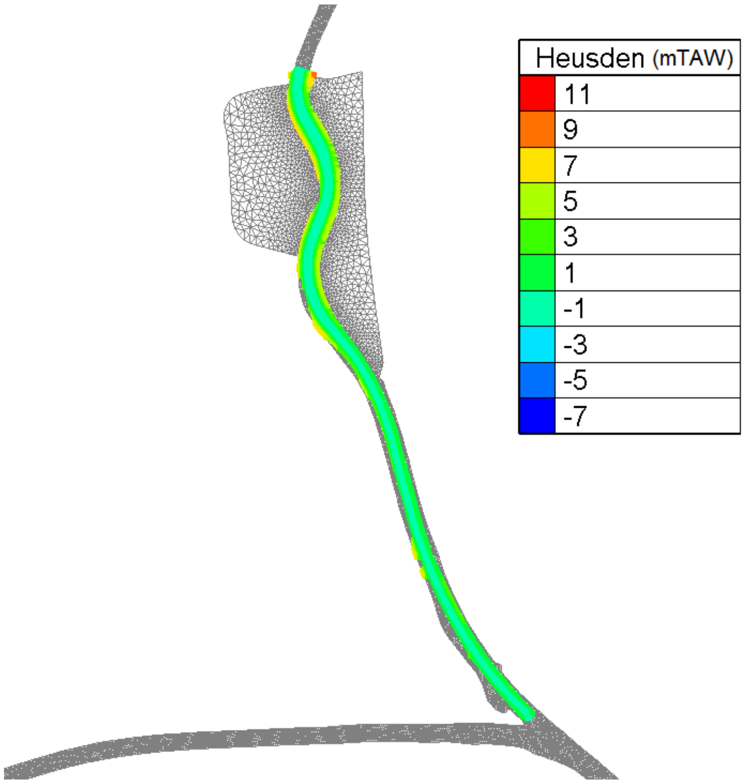


Figure 5 – New bathymetry at Heusden



3.3 Groyne at Fort Sint-Filips

In the coming years, a nature area near Fort Sint-Filips is planned and will be made sustainable with the help of a groyne. The groyne will be constructed at a height of 3.5 m TAW. Sedimentation is expected so that tidal flats and marshes can develop.

The bathymetry of the interest area in Scaldis 2013 and 2050 is presented in Figure 6 and Figure 7. The groyne at Fort Filip is included in Scaldis 2050 based on the samples file c4_9422_zone1_ kribbe+3.50_RD_TAW.xyz provided by Waterwegen & Zeekanaal of the Flemish government. The groyne itself with the expected sedimentation was implemented so a single groyne will not be visible in Figure 7. Different scenarios were tested using the Scaldis model. This bathymetry was chosen for future implementation. For the different scenarios and more information we refer to Maximova et al. (2015b).

Figure 6 – Bathymetry of the interest area in Scaldis 2013 (mTAW)

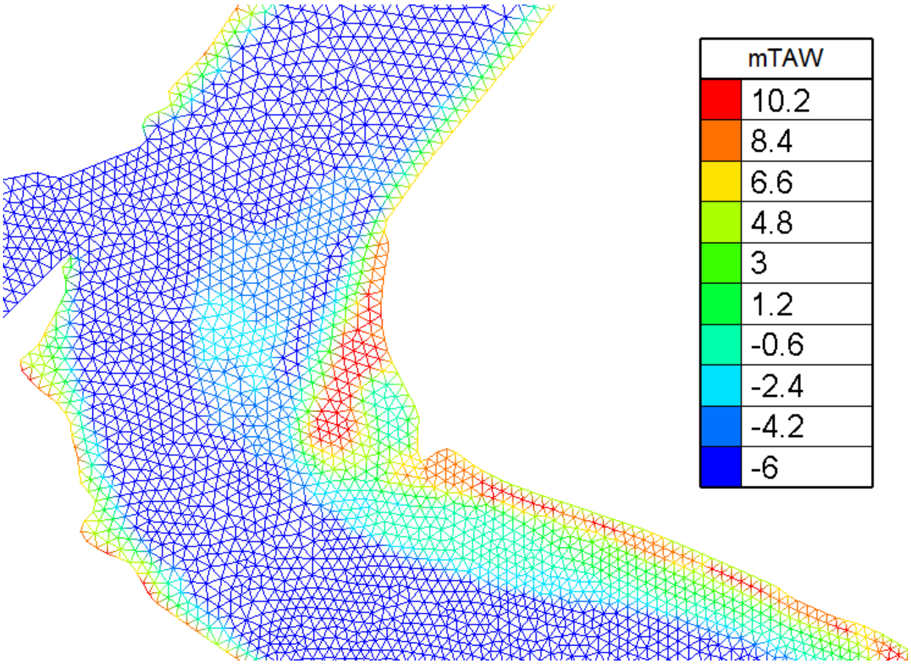
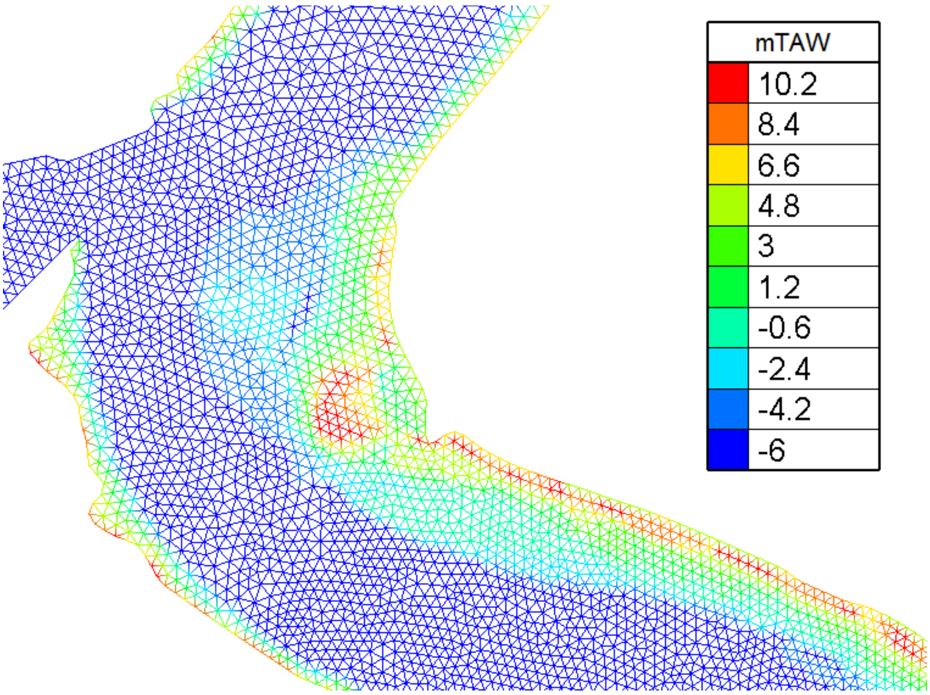


Figure 7 – Bathymetry near the groyne at Fort Filip in Scaldis 2050 (mTAW)



3.4 Sedimentation model for Flood control areas

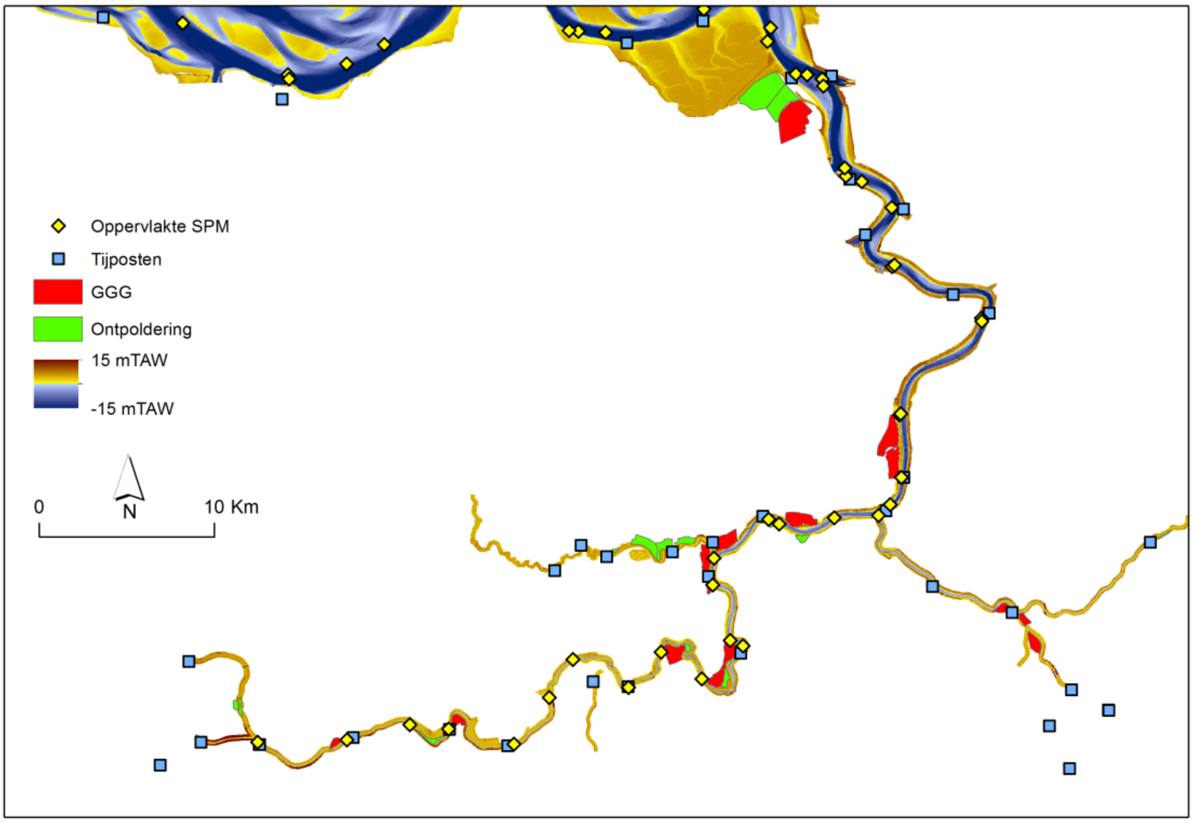
3.4.1 Introduction

The updated Sigmaplan beholds numerous measures to diminish the risk of flooding along the Sea Scheldt and its tidal tributaries. One of these measures is the construction of flood control areas. These areas will buffer water and reduce water levels upstream when extreme high water levels occur. Two types of these flood control areas exist. The first type is the flood control area (FCA) that buffers water when extreme water levels in the river are reached. This area has an outlet structure to release the buffered water when lower water levels are again reached in the tidal river. The second type has the same function as the first one, but has also inlet structures to let water enter these areas at normal tides, creating a reduced tide (CRT = controlled reduced tide) in the area to create tidal nature (Cox et al., 2006; Maris et al., 2007). The FCA with CRT function imports sediments with the water on a daily basis. On the long term this will increase the bed level of the polder.

Next to the flood control areas with and without CRT function, de-embankments are made, giving more space to the river. These de-embankments will also flood daily and tend to trap sediments. The bed level of these areas will also increase on the long term.

Within the project "Navigability of the Upper Sea Scheldt" an estimation has to be made about the increase in bed level of the FCA's with CRT and the de-embankments by the year 2050. Within the project the year 2050 will be taken as a reference situation against which different scenarios will be compared. Figure 8 shows a map of the Sea Scheldt and tidal tributaries with the locations of executed or planned FCA's with CRT function in red and de-embankments in green.

Figure 8 – Map with the executed or planned FCA with CRT (red color) and de-embankments (green color). Tidal gauge stations (blue squares and surface SPM measurements (yellow diamonds)



3.4.2 Available data

Datasets are available for natural intertidal areas, de-embankments and FCA's with CRT. These datasets are measurements of the platform level evolution over time. The results of these measurements give us an indication of the expected speeds of sedimentation on these platforms on the long term. Table 1 gives an overview of the available datasets and areas along the Scheldt estuary.

Table 1 – Overview of available datasets with measurements of platform evolution of natural intertidal areas, de-embankments and FCA's with CRT along the Scheldt estuary (INBO = The Research Institute for Nature and Forest of the Flemisch Government; RWS = Rijkswaterstaat; UA = Antwerp University)

Location	Type	Measurement method	Period	Frequency	execution by
Paardenschor	de-embankment	Sederoplots / Transect / LiDAR	2004-recent	4 month / 5 year / 2 year	INBO
Sieperdaschor	de-embankment	Transect / LiDAR	1990-recent (?)	? / 2 year	RWS
Lippenbroek	FCA with CRT	SET	2006-recent	every 2 months	UA
Westerschelde (Land van Saeftinghe)	Natural intertidal area	Topographic surveys / LiDAR	1930-recent	several decennia / 2 year	RWS
Paulinaschor	Natural intertidal area	SET / LiDAR	2005 (?) - recent	?	UA

3.4.3 Methods

Different methods are available to describe the long term evolution of a platform or bed level. Here we will describe the methods used in this report. We differentiate between de-embankments and FCA's with CRT.

De-embankments

De-embankments are created by breaching an existing dike. The land behind the dike needs to have a bed level that is high enough to get a tidal regime like that of natural intertidal areas. Just after the breaching of the dike, the land will flood frequently and the sedimentation speed and increase in bed level will be high. Eventually this speed will decrease as the bed level rises. The flooding frequency will decrease and the sedimentation rate or the speed at which the bed level increases will decrease. Due to this process the elevation of the platform or bed level over time is asymptotic. This is comparable to the elevation in platform of natural marshes (e.g., Temmerman et al., 2003).
Many types of models can be used to simulate the long term elevation of platform level of marshes (e.g., Temmerman et al., 2004; Vandenbruwaene et al., 2011). We will choose the empiric elevation model of Vandenbruwaene et al. (2011) that was developed to describe the long term elevation of the platform of the FCA with CRT Lippenbroek and nearby situated natural marsh, Scheldeschor. Vandenbruwaene developed this model further within a project on the Hedwige-Prosperpolder to account for natural intertidal areas and de-embankments (not for FCA with CRT). The model was calibrated based on the long term elevation of platform level of the Land of Saeftinghe. This model took into account the suspended matter and could differentiate the elevation speed between vegetated and non-vegetated land (Vandenbruwaene et al., 2015b). This calibrated model is used here to calculate the long term (from 2013 to 2050) elevation of the different de-embankments along the Scheldt estuary. The boundary conditions of the model will be described in one of the next chapters.

FCA's with CRT function

A FCA with CRT function is a flood control area with inlet and outlet structures that allow water to enter the polder in a reduced way (the amount of water coming in is dependent on the size of the inlet structure). So inside the polder the land is flooded with every tide, simulating flooding conditions of natural marshes (e.g., Cox et al., 2006; Maris et al., 2007). In this way estuarine nature can develop inside the polder area. This is the ecological function of such an area (besides its safety function when extreme high water levels occur in the estuary).

Like de-embankments and natural marshes the bed level of these polders will elevate due to sedimentation of suspended particulate matter (SPM) present in the entering tidal water. Such a polder is a closed system which receives a determined amount of water every tide (due to the size of the inlet construction). The sediments trapped inside the polder, will elevate the bed level. As the water volume that enters stays the same and the bed level increases, also the water level inside the polder will increase on the long term. The water level increases together with the bed level and this is different compared to natural marshes or de-embankments (Vandenbruwaene et al., 2011). To estimate the elevation speed we can use the same empirical model developed by Vandenbruwaene et al. (2011) as we do for de-embankments (with the extra calibration there as in Vandenbruwaene al., (2015)), but we need to calibrate this model specifically for FCA's with CRT. This calibration exercise was not done for this project but instead the bed level elevation of CRT areas in 2050 is estimated based on the water volumes and SPM entering these areas. A comparable exercise was already done for CRT Lippenbroek and this was based on detailed monitoring data near the in- and outlet structure of this CRT (Peeters et al., 2009). Here we will follow this approach and make some basic assumptions to estimate the amount of tons of dry matter (TDM) present in the FCA's with CRT by 2050:

$$TDM = V_{sn}\, c_{SPM}\, TE\, m\, n\, 10^{-3} \quad (1)$$

with:

V_{sn}	total volume of water entering the CRT over a spring-neap tidal cylce [m³]
c_{SPM}	Scheldt surface SPM concentration near the CRT area during the last phase of flood tide (representative for average tidal conditions and upstream discharge [kg/m³]
TE	Trapping Efficiency (= TDM deposited / TDM entering) [-]
m	the number of spring neap tidal cycles per annum = 365days / 14.75 days per cycle
n	number of years (from 2013 or future opening of a CRT area until 2050)

Based on the number of TDM, the bulk density and the surface area of the FCA with CRT, the average elevation of the bed level can be calculated suing the following formula:

$$z_{2050} = z_0 + \frac{TDM}{A\,\rho_b} \qquad (2)$$

with:

z_{2050}	Average bed level of CRT in 2050 [m]
z_0	Average bed level of CRT in the year from where we start the calculation [m]
A	Surface area of CRT area [m²]
ρ_b	Bulk density of bottom [kg/m³]

Boundary conditions

Initial elevation

To determine the initial bed level of the de-embankments and the FCA's with CRT the dataset DTM Vlaanderen from 2004 was used (5x5m resolution). This older dataset was chosen over more recent ones because the last years a lot of building activity and excavation has happened in the de-embankment and CRT areas. Some of the CRT areas are already functioning and a recent DTM cannot be used to determine the original polder bed level. Table 2 and Table 3 give an overview of the initial bed level of the de-embankments and CRT areas, respectively.

Year of de-embankment

The year of de-embankment of an area will determine the time it is subjected to tidal flooding and thus possible sedimentation. For this report we need to know the number of years between the de-embankment and 2050 or the number of years that a FCA with CRT is active until 2050. This will be an input for the model (de-embankments) or calculation approach (FCA-CRT). An overview of these input data is given in Table 2 and Table 3 for de-embankments and the FCA-CRT respectively.

Suspended particulate matter

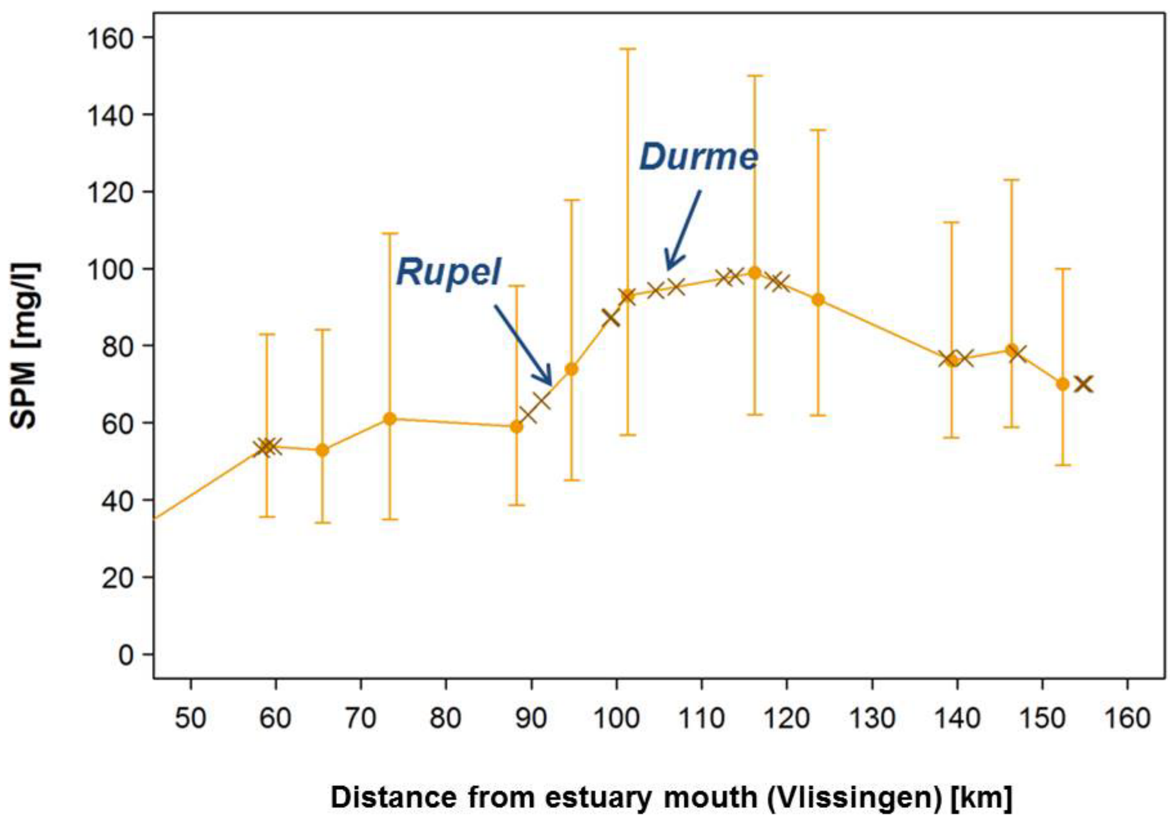
A CRT area or de-embankment will flood during the last phase of the flood tide. To estimate the amount of sediment that enters these areas we need an estimate of the surface SPM concentration of the river at that time. The SPM concentration will depend on the location along the Scheldt estuary. We differentiate between the Scheldt and the tributaries.

Scheldt **–** In another project called "Slibbalans Zeeschelde" (Vandenbruwaene et al., 2015a) the time of high water level was assigned to a dataset containing tide independent surface SPM measurements. This dataset contains measurements performed at different sites along the Scheldt estuary (yellow markers in Figure 8) with a measuring frequency of 3 weeks since 1995.

From this dataset only measurements executed during the last phase of the flood tide were selected (i.e. from 120 minutes before until 60 minutes after high water level). By only selecting these measurements we keep the SPM data representative for the time of flooding of the CRT areas and de-embankments. For every CRT area and de-embankment the distance from the estuary mouth (or Vlissingen) was determined and the locations were subdivided into clusters of 10 km. Per cluster, a median distance from the estuary mouth and the median SPM concentration was calculated. For the SPM this was done for all selected measurements between 1995 until recent. The SPM concentration were linearly interpolated for all clusters as to get a SPM value for all areas (Figure 9). The point location of the different areas was calculated using the middle of the contour polygon of the area.

Tributaries – For the tributaries there are no SPM measurements available. The SPM concentration of the mouth of the tributaries. The location of the mouth of Rupel and Durme is given in Figure 9. We assume that the SPM concentrations stay constant when the water from the Scheldt goes into the tributaries. This assumption does then not take into account the erosion and sedimentation processes in the tributary. The SPM concentration during the last phase of flood near the mouth of the tributary Rupel was 74 mg/L and this value is also taken for the upstream tributaries, Dijle and Nete. The SPM concentration near the mouth of the Durme was 95 mg/L (Figure 9).

Figure 9 – Variation in surface SPM along the Sea Scheldt during the last phase of flood tide. The small brown crosses indicate the locations of the de-embankments and CRT areas.



Hydrodynamics

De-embankments – The empirical elevation model of Vandenbruwaene et al. (2015b) needs a number of hydrodynamics inputs as well: all high water level for a period of one year, the annual average of high water levels at neap tide (GHWD), and, a value to take the sea level rise into account.

For every area the nearest tidal gauge station was selected. For the selected stations all high water levels of 2013 or 2014 (depending on the station) were selected. Further, for every selected tidal gauge station a linear trend for sea level rise was assigned based on calculations made by Levy et al. (2014). They calculated a linear increase in water levels, caused by sea level rise, over the period 1901-2012. This value was used on the one hand to adjust the high water levels of one year for a de-embankment or CRT area that will become active between present and 2050. On the other hand it was used as a boundary condition to predict the future elevation of a de-embankment. The used value taken into account here is only the minimum value for the estimation of sea level rise calculated by Levy et al. (2014). Finally for every de-embankment the annual average high water level at neap tide (GHWD) was determined. Planned de-embankments were taken care of in the same way as before by adjusting the water levels based on the calculated linear trend of sea level rise. The increase in GHWD in the model follows the linear trend of sea level rise calculated by Levy et al. (2014) and this is a small overestimation of the real increase in GHWD. The GHWD was used in the model as a boundary value to determine the platform elevation of a non-vegetated versus a vegetated scenario (Vandenbruwaene et al., 2015b). A study performed on the Land van Saeftinghe shows that the level at which a non-vegetated platform is colonized by vegetation, is approximated by the level of GHWD (Wang and Temmerman, 2013). An overview of the different values for these parameters for the different de-embankment sites is given in Table 2.

Table 2 – Overview of the boundary conditions used to calculate the bed level elevation of the de-embankments

De-embankment	River	X [km]	t_0 [Yr]	z_0 [mTAW]	A [m²]	SPM [mg/l]	SPM factor	ZS	$GHWD_0$
Hedwigepolder	Scheldt	58.3	2019	4.20	3206687	68	1.6	0.76	4.58
Prosperpolder	Scheldt	58.9	2019	3.82	1602812	68	1.6	0.76	4.58
Groot Schoor	Scheldt	99.4	2025	2.98	229957	106	2.5	0.88	5.28
Stort van Hingene	Scheldt	101.2	2030	5	77313	113	2.7	0.88	5.19
Ontpoldering Grote Wal	Scheldt	114	2015	5.09	267033	121	2.9	1.03	5.09
Uiterdijk	Scheldt	118.4	2020	5.09	116912	115	2.7	0.88	4.94
Wijmeers (deel 2)	Scheldt	140.9	2016	4.26	247386	99	2.4	0.78	4.8
Heusden	Scheldt	154.7	2009	4.91	127203	84	2.0	0.64	4.78
Zandput Melle	Scheldt	155	2019	3.5	139606	84	2.0	0.64	4.84
Groot Broek	Durme	n/a	2019	4.84	572424	95	2.3	1.00	5.15
Klein Broek	Durme	n/a	2019	5.11	404971	95	2.3	1.00	5.15
Polder van Waasmunster	Durme	n/a	2025	5.50	105470	95	2.3	1.32	5.33
Potpolder I	Durme	n/a	2025	5.42	823374	95	2.3	1.32	5.33
Anderstadt 1	Nete	n/a	2017	5.34	66054	74	1.8	1.11	5.1

FCA with CRT – To calculate the elevation of the FCA's with CRT according to the calculation method described in the previous chapter, the total volume of water entering these areas is needed. For every single area the total volume entering over a spring neap tidal cycle was taken from a Mike11 (1D) model of the Scheldt estuary (e.g. Coen et al., 2014). KBR (Kruibeekse and Bazelse Polder), Ham and Bovenzanden were the exception, and there the volume was taken for two average tides and the volume was then extrapolated to a spring neap tidal cycle. TDM was then calculated using equation 1. Table 3 gives an overview of all boundary condition values used to calculate the elevation of the FCA's with CRT.

Bulk density

A value for bulk density of the bottom is needed to translate the calculated value of TDM to elevation. We assume that on the long term (decades) all the areas (de-embankments as well as CRT areas) will develop into marshes. So we assume a bulk density of 500 kg/m³, a value representative for the soil of marsh areas (Temmerman et al., 2003; Wang et al., 2014).

Trapping efficiency

The trapping efficiency gives us the amount of TDM that is deposited in the area compared to the total amount of TDM that is entering the area. A value is needed to estimate the sedimentation in the areas. Peeters et al. (2009) calculated an annual trapping efficiency for CRT Lippenbroek of 0,64-0,75 (average conditions). These values were based on the monitoring of SPM in the water entering and leaving this CRT. For this report we will assume a trapping efficiency of 0,75. In reality this value will differ from CRT area to CRT area. The newly constructed Kruibeekse and Bazelse polder for example have an inlet and outlet construction that is specifically designed to have a stronger ebb current. This kind of measures will lower the trapping efficiency. FCA's with CRT function will keep their maximum safety value if they don't accumulate sediments (as to keep a storm water buffer volume as large as possible).

Table 3 – Overview of the boundary conditions used to calculate the bed level elevation of the CRT areas

FCA with CRT	river	x [km]	t0 [Yr]	z0 [mTAW]	A [m²]	SPM [mg/l]	V_{sd} [m³]
Doelpolder[1]	Scheldt	59.7	2015	3.00	3143278	67.8	22 542 912
KBR-Kruibeekse polder	Scheldt	89.6	2015	1.38	1505069	81.3	1 415 907[2]
KBR-Bazelse polder	Scheldt	91.2	2015	2.04	1051204	83.7	283 495[2]
Schouselbroek	Scheldt	99.3	2019	2.18	1154981	105.6	10 166 347
Tielrodebroek	Scheldt	104.6	2030	2.76	964571	118.2	2 687 882
Lippenbroek	Scheldt	107	2006	2.65	101310	118.9	238 616
Zwijn	Scheldt	112.6	2019	2.39	700575	97.5	3 269 076
Wal	Scheldt	114	2019	2.9	689163	98.1	1 749 652
Vlassenbroekse Polder (northern part)	Scheldt	119.3	2018	2.58	942441	113.9	2 368 472
Bergenmeersen	Scheldt	138.8	2013	4.25	416810	97.2	1 673 429
Ham	Scheldt	147.1	2019	4.28	225926	77.8	134 635[2]
De Bunt	Durme	n/a	2018	3.06	715260	94.6	2 688 362
Bovenzanden	Rupel	n/a	2025	4.44	336868	74.0	183 039[2]
Grote Vijver (northern part)	Dijle	n/a	2018	2.80	280943	74.0	3 061 962
Zennegat - Oude Dijlearm	Dijle	n/a	2016	3.64	554000	74.0	1 630 470

[1] Doelpolder has only a CRT function and is not a FCA.

[2] For CRT areas: Kruibeekse polder, Bazelse polder, Ham and Bovenzanden the total volume entering was calculated based on two average tides, which were extrapolated to a complete spring neap tidal cycle. With the total volume we could calculate the TDM.

3.4.4 Results

De-embankments

Figure 10 – Change in elevation of the de-embanked sites. De-embankments along the Scheldt are given in blue, along the Durme are given in green, and, along the Nete are given in red.

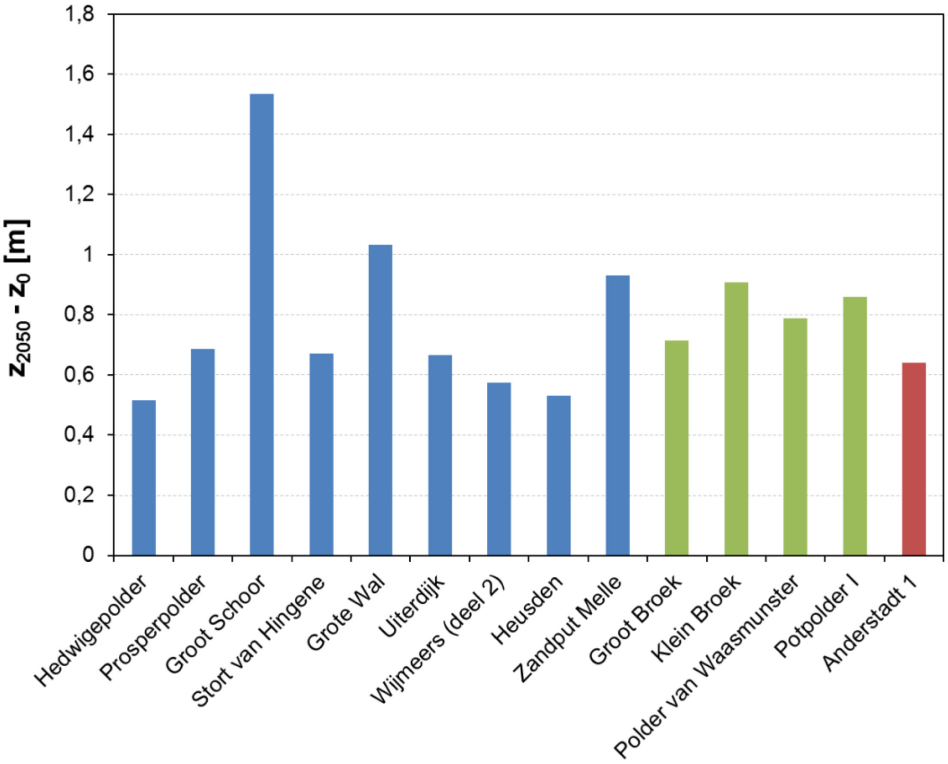


Figure 11 – Tons of dry matter deposited on the de-embankment between the time of de-embankment and 2050. TDM of De-embankments along the Scheldt are given in blue, along the Durme in green and along the Nete in red.

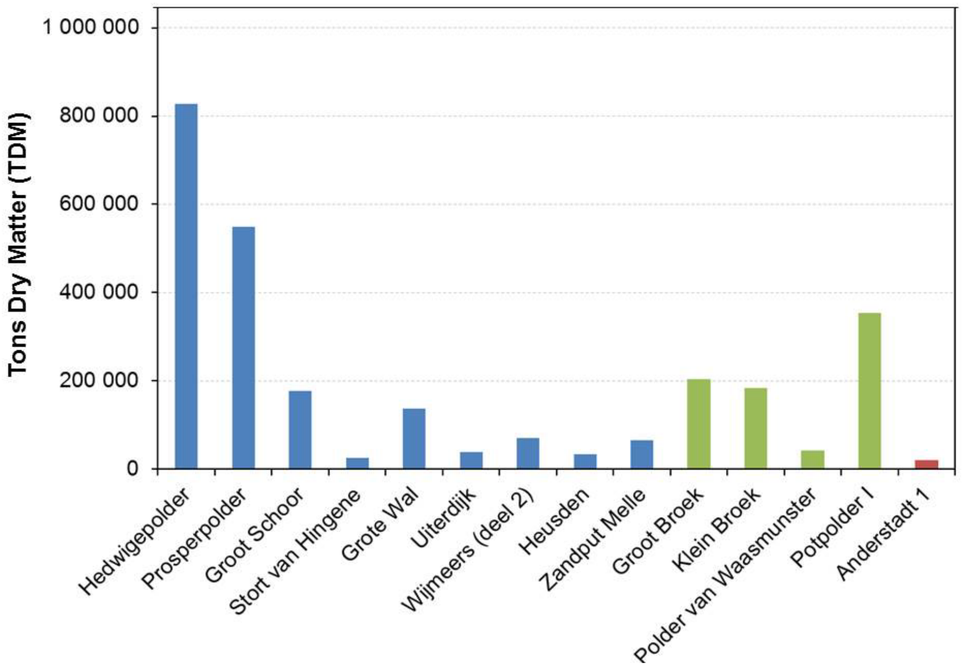


Table 4 – Overview of the average bed level (Z_0) of the de-embankment and the modelled bed level in 2050 (Z_{2050})

De-embankment	Z_0 [m TAW]	Z_{2050} [mTAW]
Hedwigepolder	4.20	4.72
Prosperpolder	3.82	4.51
Groot Schoor	2.98	4.51
Stort van Hingene	5.00	5.67
Grote Wal	5.09	6.12
Uiterdijk	5.09	5.76
Wijmeers (deel 2)	4.26	4.84
Heusden	4.91	5.44
Zandput Melle	3.50	4.43
Groot Broek	4.84	5.55
Klein Broek	5.11	6.02
Polder van Waasmunster	5.50	6.29
Potpolder I	5.42	6.28
Anderstadt 1	5.34	5.98

FCA's with CRT

Figure 12 – Change in bed level of the CRT area between the time the CRT became active and 2050. The results for CRT areas along the Scheldt are given in blue, along the Durme in green and along the Rupel-Dijle in red.

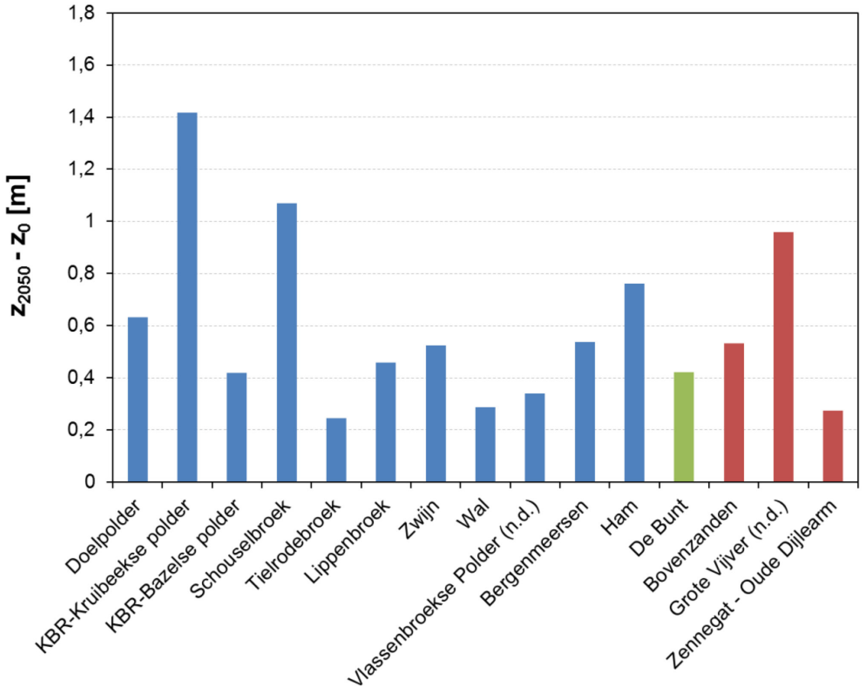


Figure 13 – Tons of dry matter deposited on the CRT area between the time of starting CRT activity and 2050. TDM of CRT areas along the Scheldt are given in blue, along the Durme in green and along the Rupel-Dijle in red.

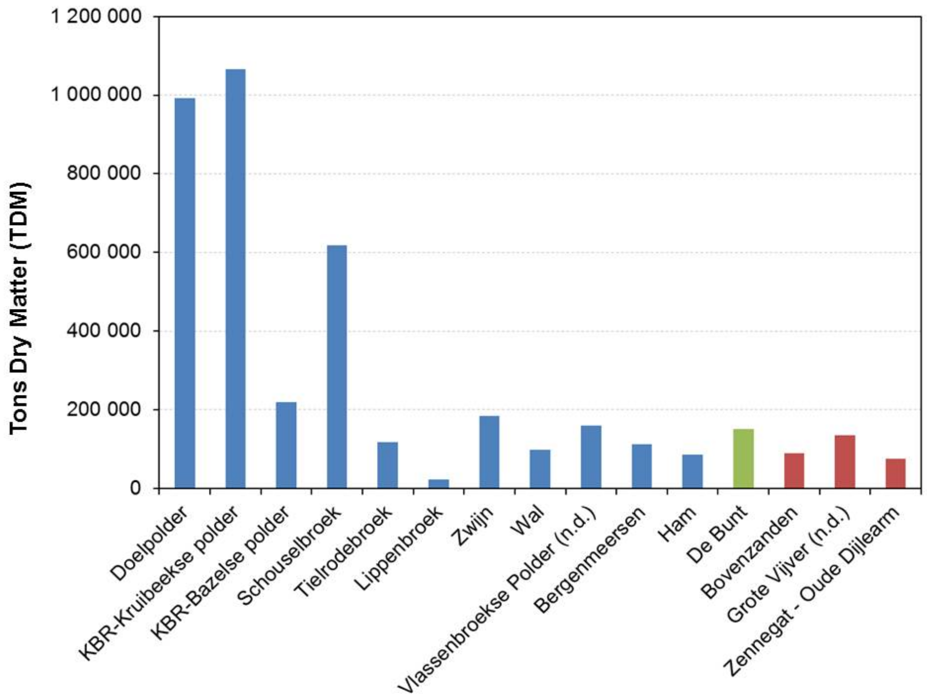


Table 5 – Overview of the average bed level (Z_0) of the CRT areas and the modelled bed level in 2050 (Z_{2050})

CRT areas	Z_0 [mTAW]	Z_{2050} [mTAW]
Doelpolder	3.00	3.64
KBR-Kruibeekse polder	1.38	2.79
KBR-Bazelse polder	2.04	2.46
Schouselbroek	2.18	3.25
Tielrodebroek	2.76	3.00
Lippenbroek	2.65	3.11
Zwijn	2.39	2.91
Wal	2.90	3.19
Vlassenbroekse Polder (n.d.)	2.58	2.92
Bergenmeersen	4.25	4.78
Ham	4.28	5.04
De Bunt	3.06	3.48
Bovenzanden	4.44	4.97
Grote Vijver (n.d.)	2.80	3.75
Zennegat - Oude Dijlearm	3.64	3.91

4 Update and activation of Sigma areas in Scaldis 2050

4.1 Extending the amount of culverts: changes in the TELEMAC code:

In the standard TELEMAC version (V6P3) it is possible to handle 100 sinks and/or sources. This means that we could only use 50 culverts (one sink and one source per culvert). With the implementation of all Sigma areas much more culverts need to be implemented in the model. Therefore the code was changed at two subroutines to handle the extra culverts. The following subroutines were changed:

- ➔ In DECLARATIONS_TELEMAC 3D the keyword MAXSCE=100 (the maximum number of sources) was changed to 1000.
- ➔ In the BIEF folder in the subroutine Allblo.f the parameter Blo%MAXBLOCK was changed from 256 to 2048.

4.2 Short overview of all the culvert parameters

The theoretical background on the culvert equations and how this was implemented in TELEMAC 3D and Scaldis can be found in Smolders et al. (2016). For each culvert the user has to define a number of geographic parameters and head loss coefficients depending on the location and type of construction of the culvert. In the next paragraph we discuss all the Sigma areas and their constructions in more detail. Here we give a short repetition of the meaning of all parameters that have to be defined by the user.

4.2.1 Geographic parameters

For each culvert the X and Y (X_1 and Y_1 for the river side and X_2 and Y_2 for the FCA side) coordinates inside the model and the bottom level Z have to be given.

Important! Because of parallelization of the simulations it is important to give the coordinates with a precision of eight numbers behind the decimal point. This is important for the software to know in which subdomain of the parallelization the culvert is located.

4.2.2 Construction parameters

There are 15 parameters that have to be defined by the user for each culvert. Here follows a short description:

CE1 Inlet head loss coefficient. just called C_1 in the theory. This is the head loss due to contraction of the flow at the entrance of the culvert. The value is usually chosen 0.5 (Smolders et al., 2016) but if the flow at the entrance is split by a pillar the value rises to 0.9.

CE2 this is the same as CE1 but then for the floodplain side. This one is called C_3 in the theory according to Smolders et al. (2016)

CS1 Outlet entrance head loss coefficient at the river side. (=1 according to Smolders et al., 2016)

CS2 Outlet exit head loss coefficient at floodplain side. (=1 according to Smolders et al., 2016)

CV This is the head loss coefficient due to the presence of a valve. (measurements showed the valve to open ¾ giving the head loss coefficient C_v=1 according to Smolders et al., 2016).

C56 This is the constant used to differentiate between flow types 5 and 6. This value is always equal to 10 (Smolders et al. (2016).

CV5 Represents a correction coefficient for the C_1 (present in CE1 and CE2) and to C_V coefficients due to the occurrence of the type 5 flow. This value is equal to zero for inlet culverts and equal to 1.5 for outlet culverts (Smolders et al., 2016).

C5 Has the same function as CV5 but its value is always equal to 6 (Smolders et al., 2016)

CT This is the head loss coefficient due to the presence of trash cscreen or grilles. The value varies between 0.1 and 1 depending on the amount of trash in front of the screen. For inlet culvert the value is usually taken equal to 0.1 and for outlet culverts the value is usually taken equal to 1 (Smolders et al., 2016).

W this is the width of the culvert (the smallest value present in the structure; this is usually the width of the culvert pipe minus the width of a pillar dividing the flow at the entrance)

D1 Height of the culvert at the river side

D2 Height of the culvert at the floodplain side

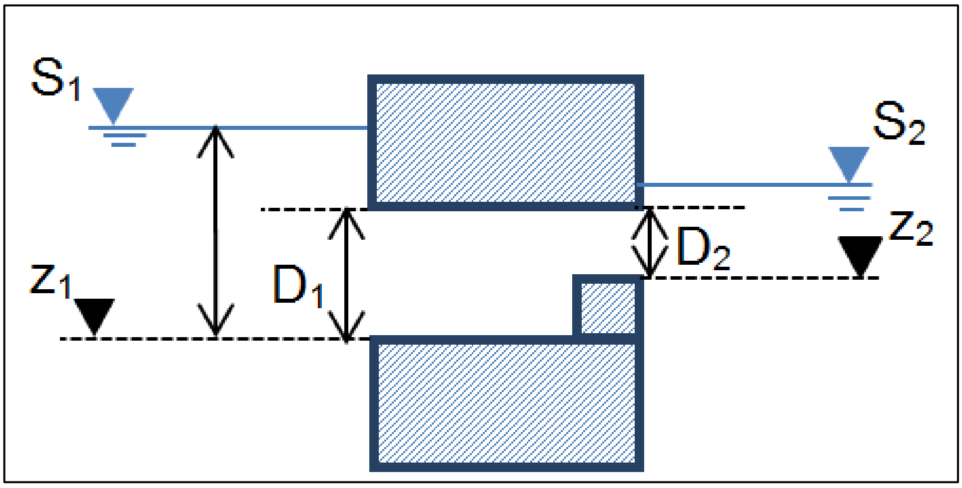
N Manning Strikler’s coefficient for the structure (usually taken 0.015 for smooth concrete according to Smolders et al., 2016)

L Length of the culvert

CLP this number gives the direction of the flow: 0 = flow in both ways (usually taken for the inlet culvert); 1= flow only from the river to the floodplain; 2= flow only from the floodplain to the river (usually taken for the outlet culvert if there is a one-way valve present).

Figure 14 shows how the variables D1 and D2, and Z1 and Z2 have to be interpreted. For every area discussed in the next parapgraph we will give the values we have chosen for these variables.

Figure 14 – Example of some variables to calculate the discharge through a culvert



4.3 Implementation of all de-embankments and FCA areas in Scaldis

Here follows an overview of all de-embankments and FCA areas that will be included in the Scaldis model representing 2050. For each area all possible parameters and information is given to use the culvert subroutine in TELEMAC. All these areas were already included in the mesh of the Scaldis model representing 2013. So no modifications of the mesh had to be made to update the Scaldis model to 2050 to include all Sigma areas. Culverts have to be activated and bathymetry/topography has to be updated to bring the Scaldis model to its 2050 version. Note that the culvert parameters are based on the culvert information of 2013. No remodeling of culvert sizes or the height of inflow has been done. Wooden beams can be placed in front of the inflow culverts to increase the level of inflow or slide valve can be closed to reduce the total discharge through the inflow culvert. If water levels inside the estuary would increase due to the effect of sea level rise, the measures mentioned above can be taken to fine tune the inflow of water in the CRT areas, but no measures were taken at this moment. All culverts work like they would work in 2013.

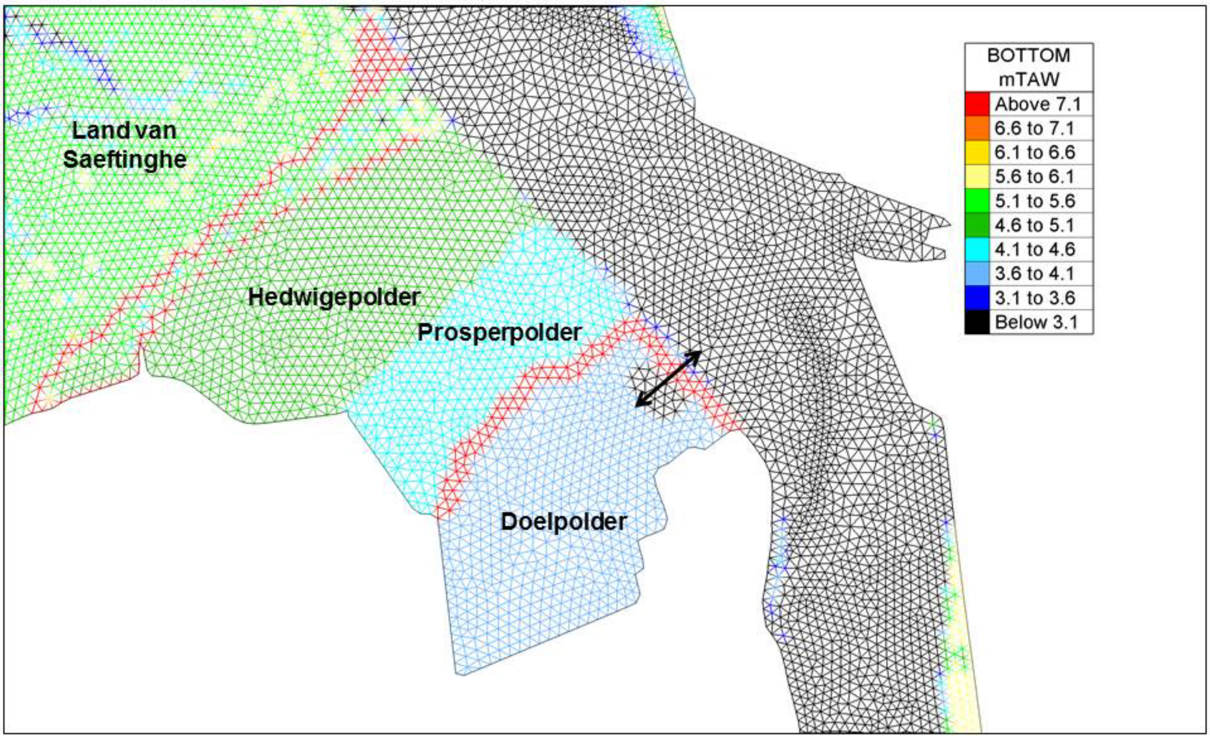
4.3.1 Hedwigepolder

This area will be de-embanked by 2050. The area is included in the Scaldis model 2050 (Figure 15). It is also present in the Scaldis 2013 model, but lies behind a dike.

Current (2013) bed level = 4,20 m TAW

Bed level of the polder at 2050 according to Table 4 = 4,72 m TAW

Figure 15 – Hedwigepolder, Prosperpolder and Doelpolder in the Scaldis model



4.3.2 Prosperpolder

Situated between Hedwigepolder and Doelpolder this area (light blue in Figure 15) is also de-embanked by 2050.

Current (2013) bed level = 3,82 m TAW

Bed level of the polder at 2050 according to Table 4 = 4,51 m TAW

4.3.3 Doelpolder

Situation 2013: the area is included in the model but accessible for water

Situation 2050: Doelpolder will only have a controlled reduced tide and will not operate as a flood control area. This means that the dike between Doelpolder and the estuary will be at Sigma level (11 m TAW) (blue area behind the red dike in Figure 15).

Overflow dike: no overflow dike – no FCA function

Water inflow: - 11 culverts: bottom level = 4,2 m TAW

dimensions = 3 m wide x 2,2 m high

length = 18 m

height of weir = 0 m

trash screen present

Water outflow: - 11 culverts: bottom level = 2,7 m TAW
dimensions = 3 m wide x 2,2 m high
length = 18 m
non return valves present
trash screen present

Current (2013) bed level = 3,00 m TAW

Bed level of polder at 2050 according to Table 5 = 3,64 m TAW

Figure 16 shows the different values for the parameters needed by the culvert subroutine in TELEMAC 3D for the Doelpolder inlet and outlet structure. Since the exact construction of this structure is not yet known at this moment, estimates are based on the structure of Bergenmeersen.

Figure 16 – Variables for the Doelpolder inlet and outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Doelpolder CRT in	76553,398	372417,25	4,2	75946,766	372165,344	4,2	0,9	0,5	1	1	0	10	0	6	0,1	2,6	1,8	2,2	0,015	10	1
Doelpolder CRT in	76493,281	372472,563	4,2	75924,164	372247,563	4,2	0,9	0,5	1	1	0	10	0	6	0,1	2,6	1,8	2,2	0,015	10	1
Doelpolder CRT in	76435,742	372533,906	4,2	75864,953	372291,75	4,2	0,9	0,5	1	1	0	10	0	6	0,1	2,6	1,8	2,2	0,015	10	1
Doelpolder CRT in	76377,813	372596,313	4,2	75861,68	372210,813	4,2	0,9	0,5	1	1	0	10	0	6	0,1	2,6	1,8	2,2	0,015	10	1
Doelpolder CRT in	76320,203	372661,406	4,2	75790,922	372258,063	4,2	0,9	0,5	1	1	0	10	0	6	0,1	2,6	1,8	2,2	0,015	10	1
Doelpolder CRT in	76272,578	372728	4,2	75795,758	372343,281	4,2	0,9	0,5	1	1	0	10	0	6	0,1	2,6	1,8	2,2	0,015	10	1
Doelpolder CRT in	76250,367	372841,594	4,2	75718,766	372304,625	4,2	0,9	0,5	1	1	0	10	0	6	0,1	2,6	1,8	2,2	0,015	10	1
Doelpolder CRT in	76189,828	372883,844	4,2	75714,672	372401,719	4,2	0,9	0,5	1	1	0	10	0	6	0,1	2,6	1,8	2,2	0,015	10	1
Doelpolder CRT in	76124,547	372926,25	4,2	75641,711	372339,563	4,2	0,9	0,5	1	1	0	10	0	6	0,1	2,6	1,8	2,2	0,015	10	1
Doelpolder CRT in	76058,219	372969,469	4,2	75671,734	372490,281	4,2	0,9	0,5	1	1	0	10	0	6	0,1	2,6	1,8	2,2	0,015	10	1
Doelpolder CRT in	75992,102	373013,5	4,2	75616,789	372421,156	4,2	0,9	0,5	1	1	0	10	0	6	0,1	2,6	1,8	2,2	0,015	10	1
Doelpolder CRT out	76553,398	372417,25	2,7	75946,766	372165,344	2,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	10	2
Doelpolder CRT out	76493,281	372472,563	2,7	75924,164	372247,563	2,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,1	2,2	0,015	18	2
Doelpolder CRT out	76435,742	372533,906	2,7	75864,953	372291,75	2,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,1	2,2	0,015	18	2
Doelpolder CRT out	76377,813	372596,313	2,7	75861,68	372210,813	2,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,1	2,2	0,015	18	2
Doelpolder CRT out	76320,203	372661,406	2,7	75790,922	372258,063	2,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,1	2,2	0,015	18	2
Doelpolder CRT out	76272,578	372728	2,7	75795,758	372343,281	2,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,1	2,2	0,015	18	2
Doelpolder CRT out	76250,367	372841,594	2,7	75718,766	372304,625	2,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,1	2,2	0,015	18	2
Doelpolder CRT out	76189,828	372883,844	2,7	75714,672	372401,719	2,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,1	2,2	0,015	18	2
Doelpolder CRT out	76124,547	372926,25	2,7	75641,711	372339,563	2,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,1	2,2	0,015	18	2
Doelpolder CRT out	76058,219	372969,469	2,7	75671,734	372490,281	2,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,1	2,2	0,015	18	2
Doelpolder CRT out	75992,102	373013,5	2,7	75616,789	372421,156	2,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,1	2,2	0,015	18	2

4.3.4 Fort Sint-Filips

At this location the dike is moved and a small area is added to the estuary.

It is planned to develop a nature area near Fort Sint-Filips with the help of a groyne. The bathymetry of the Scaldis 2050 model was adapted in this area. More information is given in chapter 3.3.

4.3.5 Burchtse Weel: connected

<u>Situation 2013:</u> in the model and connected

<u>Situation 2050:</u> same as in 2013.

Because Burchtse Weel has no FCA function and the culverts that connect this small area with the Scheldt are very large, this area was added to the model and connected with the Scheldt, rather than using culverts for this. A direct connection with the river in the model has the advantage of increased computational speed. The characteristics of the culverts are given below although they are not used in the model.

2 Inlet/outlet culverts:

width = 3,45 m per culvert and each culvert is separated in two by a pillar to hold valve that can close the culvert. These valves are open in normal circumstances.

height = 3,30 m of which 0,3 m is filled with rubbles, leaving 3 m effective space for the flow to pass

total length = 70 m

$Z_1 = Z_2 = 0$ m TAW already taking the 0,3 m layer of rubbles into account.

Width of pillar in every culvert = 0,6 m; the effective width for flow to enter is 3 m per culvert.

Figure 17 – Frontal view on culverts in Burchtse Weel. Viewpoint from the floodplain. Four sliding valves are present to close two culverts (source: W&Z).

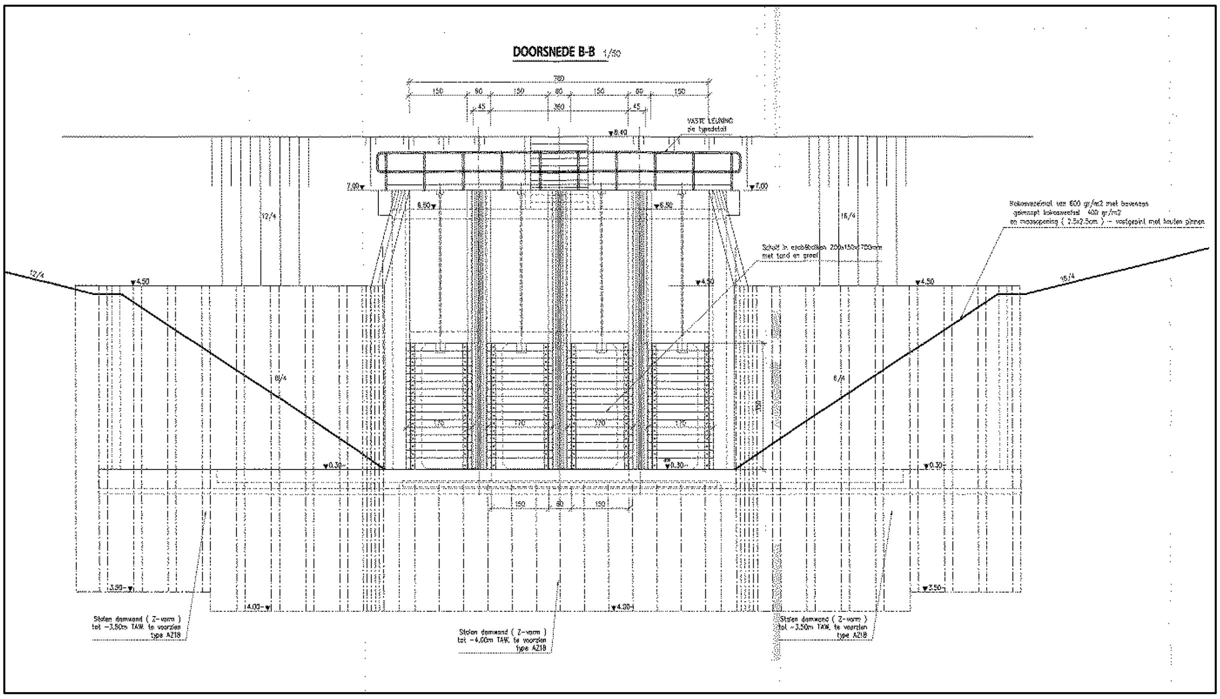


Figure 18 – Top view of inlet/outlet structure Burchtse Weel at floodplain side (source: W&Z)

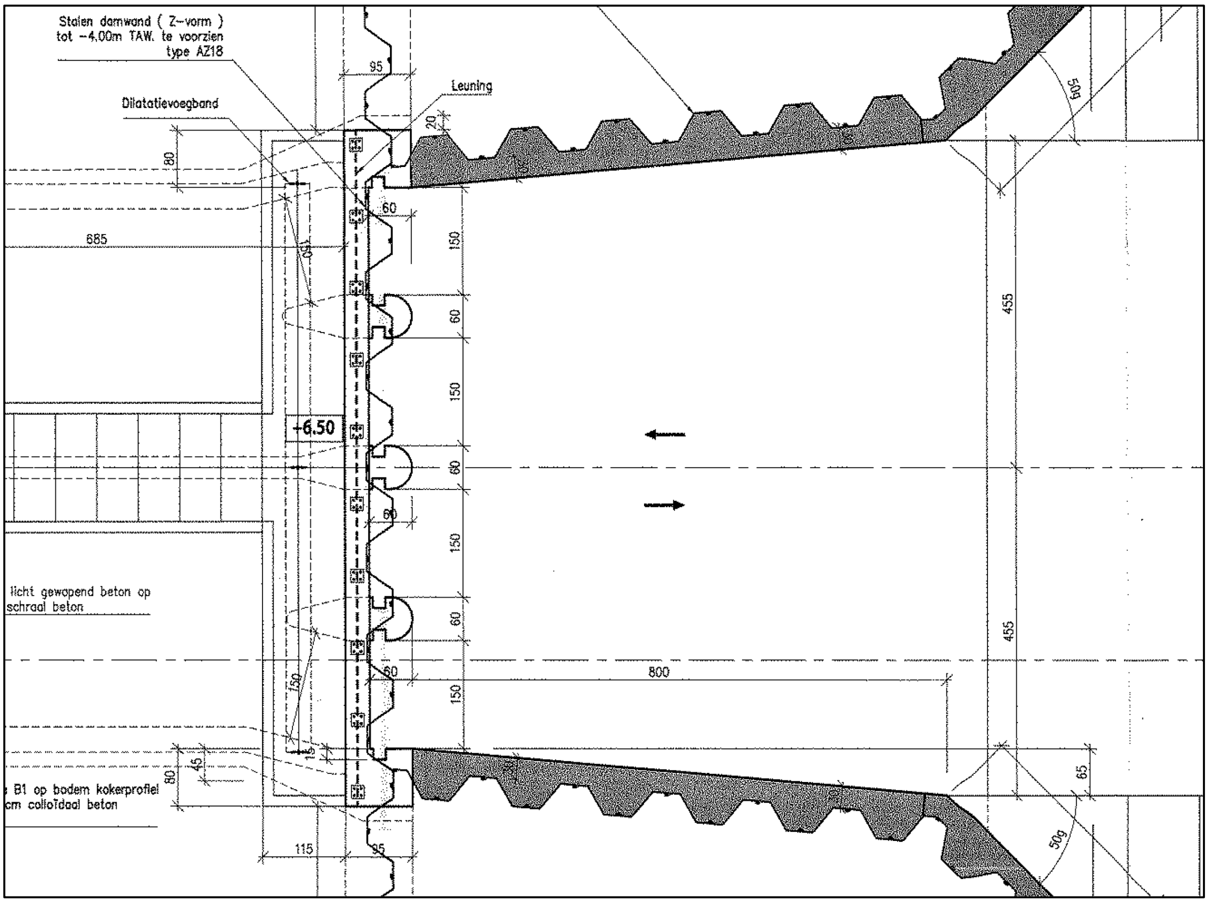


Figure 19 – Cross section of culverts of Burchtse Weel (source: W&Z)

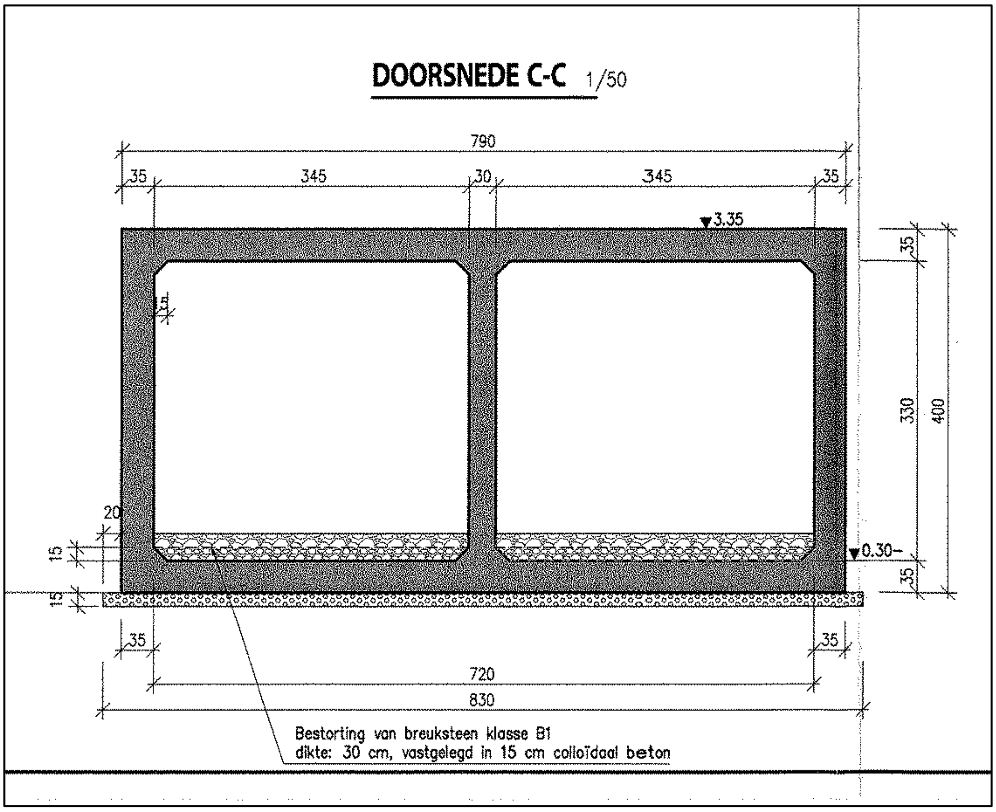
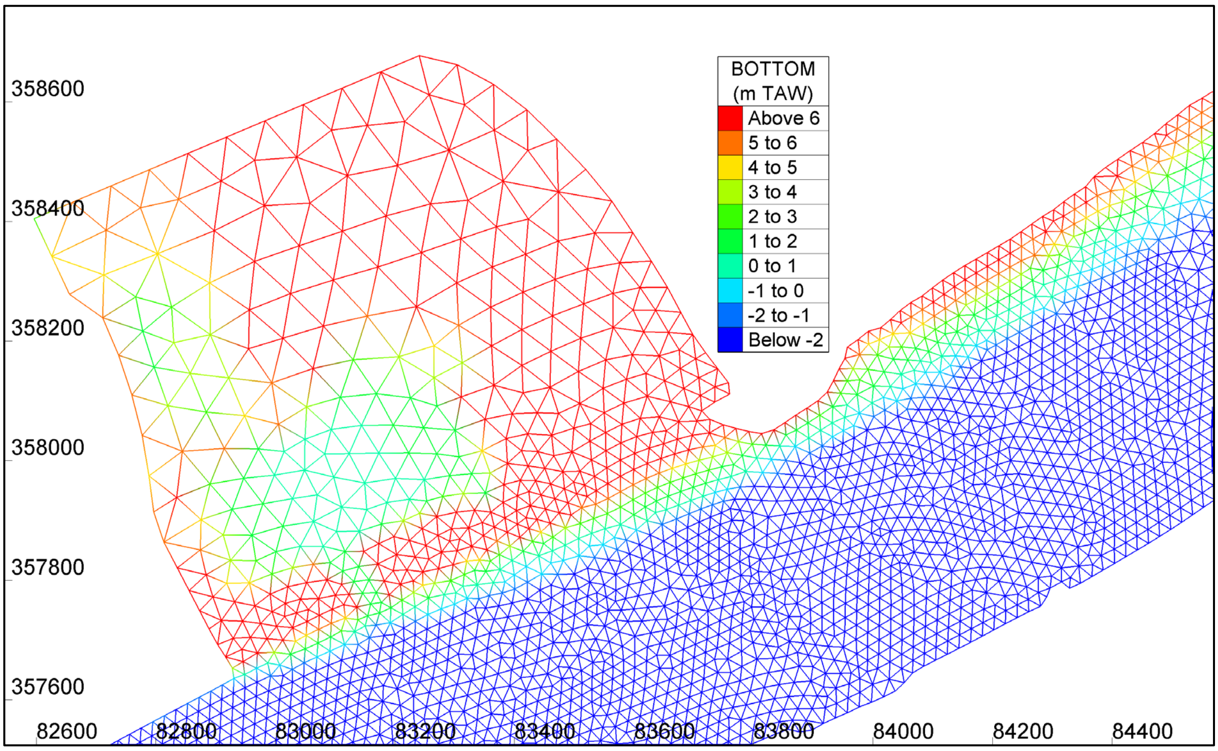


Figure 20 – Burchtse Weel in Scaldis 2050



4.3.6 KBR – CRT Kruibeekse Polder

situation 2013: present in the model, not active.

situation 2050: FCA with CRT function.

Overflow dike: - 1300 m long
- crest level: 6,8 m TAW

Water inflow: - 15 culverts: bottom level = 4,2 m TAW
dimensions = 3 m wide x 2,2 m high
length = 18 m
height of weir = 0 m

Water outflow: - 15 culverts: bottom level = 0,5 m TAW
dimensions = 3 m wide x 2,2 m high
length = 18 m
non return valves present
grille present

- 4 culverts: bottom level = -0,25 m TAW
dimensions: 0,8 m diameter pipes
length = ?

Bed level of FCA-CRT at 2050 according to Table 5 = 2,79 m TAW

Current (2013) bed level = 1,38 m TAW

Figure 25 shows the implementation of the Kruibeekse polder into the Scaldis mesh. The blue areas on the polder are the locations of the in- and outlet structures in the model. These don't have to coincide with the actual location of the structures, but we tried to follow reality as much as possible.

Figure 21 shows the side and top view of one of the inlet culverts. We can see that the width of the culvert is 3 m inside, but that the width at the valves is only 2,6 m in total. Because this smaller width will limit the amount of water entering the culvert this value was given to the parameter LARG for the culvert calculation. The same approach is made for the height of the culvert at the entrance and exit.

Figure 21 – Schematization of the KBR inflow construction.

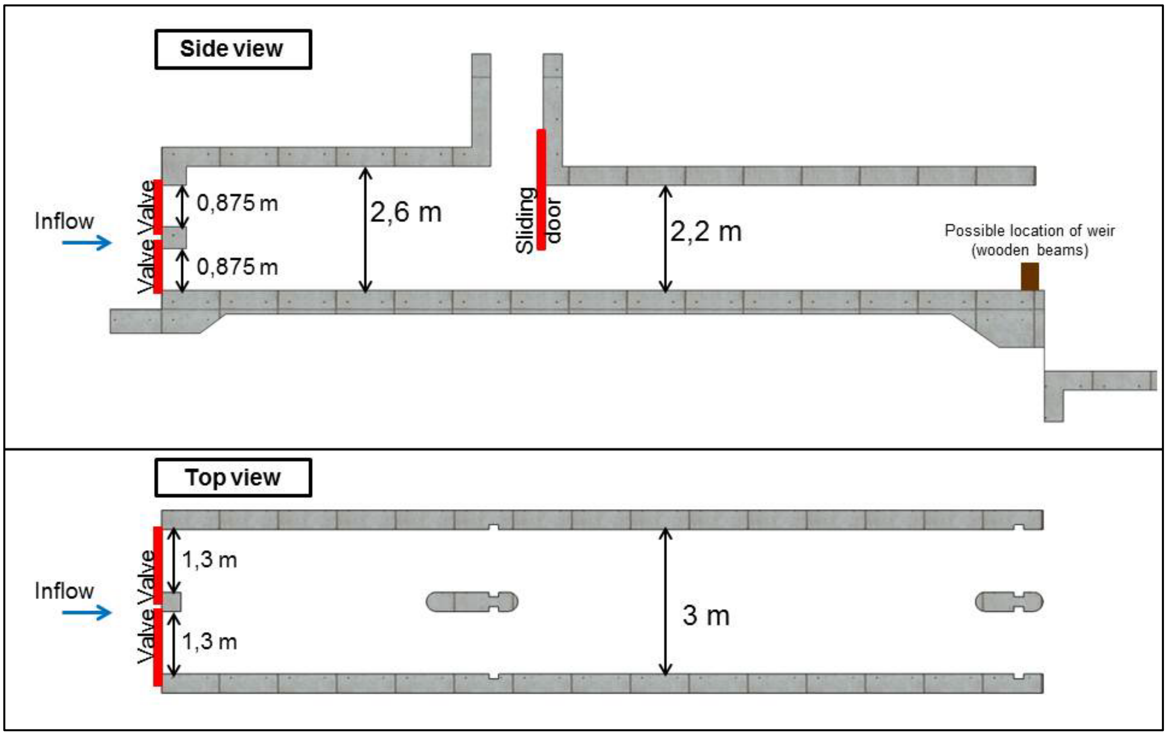


Figure 22 – Variables for the Kruibeekse polder inlet/outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
CRT Kruibeekse polder in	80808,73	354161,6	4,2	80593,84	354098	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80825,83	354145,8	4,2	80600,48	354074,8	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80818,87	354067,1	4,2	80622,99	354064,6	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80816,45	354046,5	4,2	80626,91	354040,5	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80803,07	353994,5	4,2	80634,49	354018,5	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80811,21	353980,6	4,2	80642,59	353999	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80802,11	353965,8	4,2	80649,63	353979,5	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80810,91	353950	4,2	80655,59	353958,1	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80802,94	353932,7	4,2	80664,73	353938,7	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80819,27	353921,2	4,2	80657,91	353918,3	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80818,94	353899,1	4,2	80656,53	353895,5	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80815,36	353876,6	4,2	80658,23	353873,4	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80829,09	353862,6	4,2	80662,45	353852,3	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80823,45	353845	4,2	80667,53	353829,5	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder in	80817,57	353828	4,2	80663,47	353809,5	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Kruibeekse polder out	80808,73	354161,6	0,5	80652,11	353797,6	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80825,83	354145,8	0,5	80642,2	353816,3	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80818,87	354067,1	0,5	80646,14	353838,5	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80816,45	354046,5	0,5	80639,05	353858	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80803,07	353994,5	0,5	80635,05	353881,8	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80811,21	353980,6	0,5	80633,87	353907,1	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80802,11	353965,8	0,5	80636,49	353936,3	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80810,91	353950	0,5	80630,16	353964,3	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80802,94	353932,7	0,5	80629,31	353984,5	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80819,27	353921,2	0,5	80619,58	354000,9	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80818,94	353899,1	0,5	80609,09	354021,7	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80815,36	353876,6	0,5	80595,89	354048,1	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80829,09	353862,6	0,5	80568,09	354073,7	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80823,45	353845	0,5	80531,01	354052,6	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80817,57	353828	0,5	80528,84	354091,2	0,5	0,9	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Kruibeekse polder out	80836,27	353600,7	-0	80686,52	353601,1	-0	0,5	0,5	1	1	1	10	1,5	6	1	0,8	0,6	0,6	0,015	18	2
CRT Kruibeekse polder out	80835,96	353582,7	-0	80686,73	353581,4	-0	0,5	0,5	1	1	1	10	1,5	6	1	0,8	0,6	0,6	0,015	18	2
CRT Kruibeekse polder out	80845,59	353560,2	-0	80690,16	353563,9	-0	0,5	0,5	1	1	1	10	1,5	6	1	0,8	0,6	0,6	0,015	18	2
CRT Kruibeekse polder out	80846,02	353537,3	-0	80683,62	353543,7	-0	0,5	0,5	1	1	1	10	1,5	6	1	0,8	0,6	0,6	0,015	18	2

Figure 23 – Pictures of the in- and outlet structure under construction of the Kruibeekse polder.

4.3.7 KBR: CRT Bazelse Polder

situation 2013: present in the model, but not active.

situation 2050:This area is designated to become FCA with CRT.

The structure is similar like the one of the Kruibeekse polder.

Overflow dike: - 1500 m long
- crest level: 6,8 m TAW

Water inflow:	- 3 culverts:	bottom level = 4,2 m TAW
	(1+ 2)	dimensions = 3 m wide x 2,2 m high
		length = 18 m
		height of weir = 0 m
		trash screen present

Water outflow: - 12 culverts: bottom level = 0,5 m TAW

(5+5+2) dimensions = 3 m wide x 2,2 m high

length = 18 m

non return valves present

trash screen present

Bed level of FCA-CRT at 2050 according to Table 5 = 2,46 m TAW

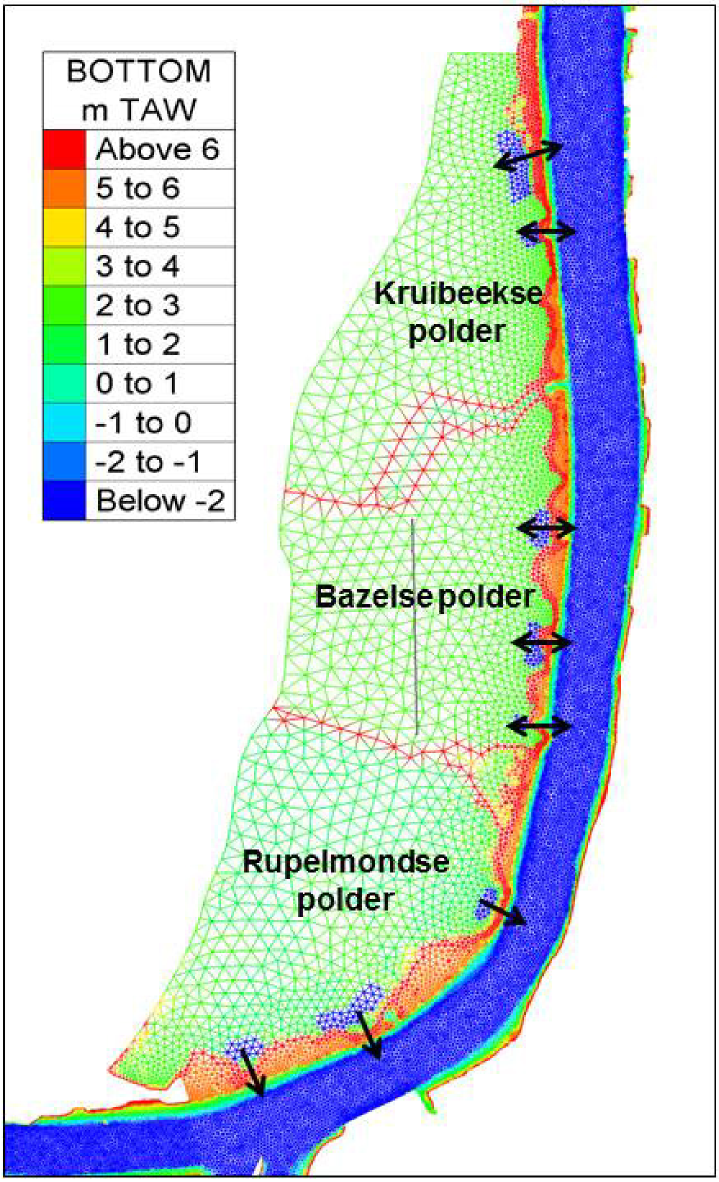
Current (2013) bed level = 2,04 m TAW

A dike separates the CRT part from the FCA part behind it. This dike has a design elevation of 2 m TAW at the time of construction, but as the bed level in this area will be 2,46 m TAW in 2050 (according to Table 5) the whole area is given a bottom elevation of 2,46 m TAW (Figure 25).

Figure 24 – Variables for the Bazelse polder inlet and outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Bazelse polder GGG uit	80968,7	352103	0,5	80733,28	352114,8	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG uit	80981,83	352067,8	0,5	80724,87	352087,9	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG uit	80967,91	352026,3	0,5	80731,27	352054,7	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG uit	80953,16	351997,1	0,5	80736,94	352024,8	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG uit	80962,73	351977,8	0,5	80733,29	351999,7	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG uit	80915,88	351486	0,5	80711,76	351432,6	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG uit	80910,37	351468,1	0,5	80702,03	351454,5	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG uit	80912,51	351448,3	0,5	80695,4	351481	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG uit	80896,81	351435,3	0,5	80703,45	351503,5	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG uit	80888,18	351414	0,5	80700,43	351526,1	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG uit	80866,54	351062,3	0,5	80635,02	351027,7	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG uit	80859,25	351025,9	0,5	80629,2	351051,9	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Bazelse polder GGG in	80947,23	351946,2	4,2	80718	351981,8	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
Bazelse polder GGG in	80896,52	351374,9	4,2	80693,82	351387,1	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
Bazelse polder GGG in	80864,58	351352,4	4,2	80703,74	351360,6	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0

Figure 25 – Overview of Kruibeekse polder (above), Bazelse polder (middle) and Rupelmondse polder (below) in Scaldis. The grey line indicates the location of a dike (2 m TAW) to divide the Bazelse polder in two parts. The blue fields in the polder area indicate the locations of the in- and outflow structures.



4.3.8 KBR: FCA Rupelmondse Polder

<u>situation 2013:</u> present in the model, but not active.

<u>situation 2050:</u> This area is designated to become FCA.

Overflow dike: - 1800 m long

- crest level: 6,8 m TAW

Water outflow: - 18 culverts: bottom level = 0,8; 0,9; 1,0 m TAW
(6+9+3) dimensions = 3 m wide x 2,2 m high
length = 18 m
non return valves present
trash screen present

Figure 25 shows the location and implementation of the Rupelmondse polder into the Scaldis mesh. The blue areas on the polder side give the locations of the outlet structures.

Figure 26 – Variables for the Rupelmondse polder outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
FCA Rupelmondse polder uit	80603,88	349979,4	0,8	80437,39	350039,6	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	80624,29	349990	0,8	80452,31	350058,4	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	80636,95	350007,9	0,8	80460,21	350085,7	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	80649,58	350023,4	0,8	80472,45	350107,3	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	80662,73	350037,8	0,8	80488,88	350124,9	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	80680,34	350063,4	0,8	80487,34	350148,3	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	79885,22	349250,8	0,9	79702,47	349483	0,9	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	79903,07	349257,3	0,9	79739,42	349492,4	0,9	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	79919,45	349261,7	0,9	79774,82	349482,8	0,9	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	79941,77	349281,4	0,9	79801,52	349498,6	0,9	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	79975,64	349289	0,9	79831,11	349505,2	0,9	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	80017,63	349310,7	0,9	79844,01	349533,4	0,9	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	80047,46	349332,3	0,9	79864,32	349559,9	0,9	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	80077,5	349345	0,9	79896,4	349584,9	0,9	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	80104,79	349370,9	0,9	79924,54	349622,6	0,9	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	79400,83	349031,8	1	79274,48	349329,2	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	79433,45	349043,4	1	79310,96	349337,8	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Rupelmondse polder uit	79474,21	349064,4	1	79348,21	349346,4	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2

4.3.9 FCA Schellandpolder/Oudbroekpolder

situation 2013: present in the model, but not active.

situation 2050: This FCA has to be designed so no data are available. The dimensions will be estimated based on the Rupelmondse polder (downstream). According to INBO (personal communication) the crest level of the overflow dike will be put 5 cm higher than over FCA in the area to decrease the flooding frequency to accomplish better the ecological goals of this area.

This area is designated to become FCA with CRT.

Overflow dike: - 1800 m long
- crest level FCA Rupelmondse Polder = 6,8 m TAW
⇨ so crest level here will be 6,85 m TAW

The area is roughly 2/3 of the Bazelse Polder. Based on that we take 2/3 outlet culverts

Water outflow: - 8 culverts: bottom level = 1.0 m TAW (like Rupelmondse polder upstream)

(8) dimensions = 3 m wide x 2,2 m high (standard dimensions)

length = 18 m

non return valves present

trash screen present

Figure 28 shows the implementation of the FCA in the Scaldis mesh. The blue areas inside the polder give the locations of the culverts. All culverts are located on the downstream part of the polder.

Figure 27 – Variables for the Schellandpolder outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Schellandpolder out	76450,48	348204	1	76717,19	347962,6	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Schellandpolder out	76460,04	348228,2	1	76756,69	347979	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Schellandpolder out	76494,04	348259,3	1	76791,34	348001,4	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Schellandpolder out	76542	348281,7	1	76824,34	348028,6	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Schellandpolder out	77766	348745	1	77778,54	348510,5	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Schellandpolder out	77812,14	348766,1	1	77808,36	348510,5	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Schellandpolder out	77850,6	348778,8	1	77836,98	348511,4	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Schellandpolder out	77901	348780,9	1	77862,84	348515	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2

4.3.10 FCA/CRT Schouselbroek

<u>situation 2013:</u> present in the model, but not active.

<u>situation 2050:</u> This FCA/CRT has to be designed so no data is available. The dimensions will be estimated based on the average between data from Tielrodebroek (upstream) and Bazelse polder (downstream).

Overflow dike: - 1800 m long (900+900)

- crest level FCA Tielrodebroek = 6,85 m TAW

crest level FCA Bazelse Polder = 6,8 m TAW

⇨ so crest level here will be 6,8 m TAW

The area is roughly 2/3 of the Bazelse Polder. Based on that we take 2/3 outlet culverts

Water outflow: - 8 culverts: bottom level = 1.0 m TAW (like Rupelmondse polder upstream)

(4+4) dimensions = 3 m wide x 2,2 m high (standard dimensions)

length = 18 m

non return valves present

trash screen present

Water inflow: - 2 culverts: bottom level = 4,2 m TAW

(1+1) dimensions = 3 m wide x 2,2 m high

length = 18 m

height of weir = 0 m

trash screen present

Bed level of FCA-CRT at 2050 according to Table 5 = 3,25 m TAW

Current (2013) bed level = 2,18 m TAW

Figure 28 – FCA Schellandpolder on the right and FCA with CRT area Schouselbroek on the left. Blue dots inside FCA give the location of the culverts. The de-embankment of Groot Schoor is shown on the left bottom, i.e. the red colored area and the de-embankment area Stort van Hingene is located at the bottom in the middle, i.e. the yellow colored area.

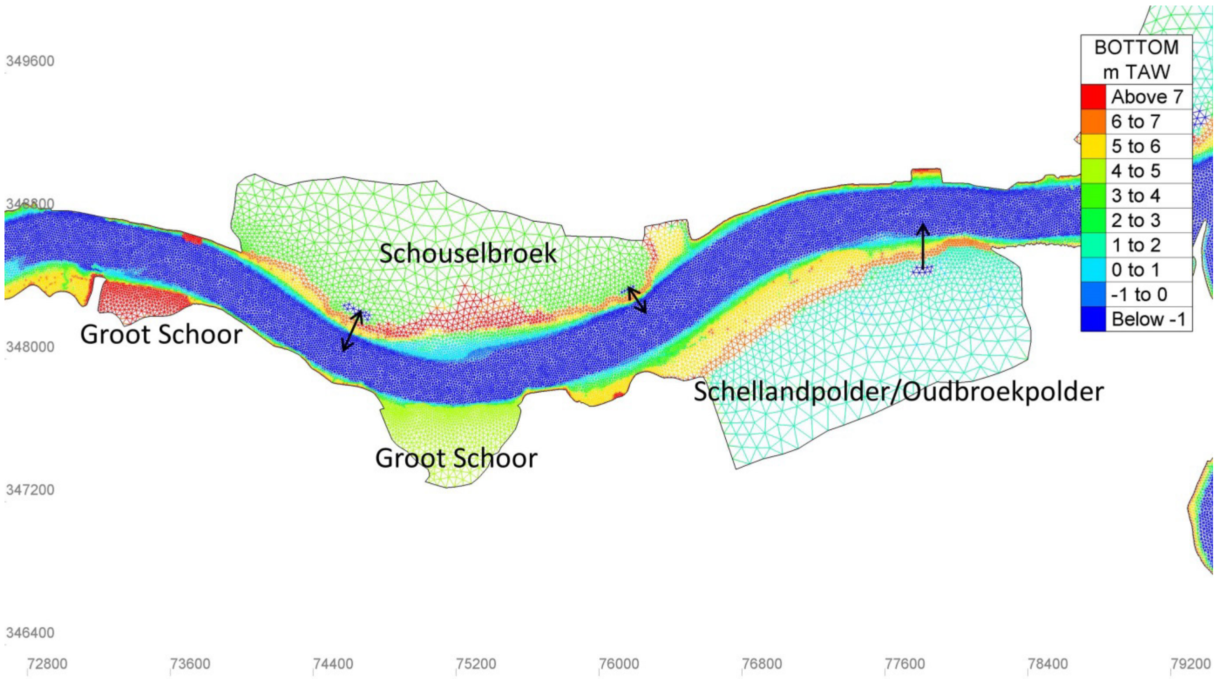


Figure 29 – Variables for CRT Schouselbroek in- and outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
CRT Schousselbroek out	76182,2	348240,8	1	76128,18	348371,6	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Schousselbroek out	76204,38	348252,3	1	76144,15	348380,2	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Schousselbroek out	76237,17	348260,3	1	76159,19	348388	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Schousselbroek out	76261,12	348269	1	76174,81	348,396	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Schousselbroek out	74651,42	348008,7	1	74705,01	348219,9	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Schousselbroek out	74627,38	348023,9	1	74688,84	348239,8	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Schousselbroek out	74628,81	348039,4	1	74661,5	348241,2	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Schousselbroek out	74627,77	348055,2	1	74636,34	348252,8	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Schousselbroek in	76312,52	348280	4,2	76192,17	348403,9	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Schousselbroek in	74513,88	348085,3	4,2	74601,96	348304,8	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0

4.3.11 De-embankment Groot Schoor

Situation 2013: present in the mesh but behind a dike, not active

Situation 2050: the dike was removed and the elevation was set to 4,51 m TAW according to Table 4. The average bed level in 2013 was 2,98 m TAW (Figure 28).

4.3.12 De-embankment Stort van Hingene

Situation 2013: present in the mesh but behind a dike, not active

Situation 2050: the dike was removed and the elevation was set to 5,67 m TAW according to Table 4. The average bed level in 2013 was 5,00 m TAW (Figure 28).

4.3.13 FCA Tielrodebroek

situation 2013: present in the model and active as FCA.

Overflow dike: - 800 m long

- crest level = 6,75-6,95 m TAW (crest level in Scaldis according to measured crest levels)

Water outflow: - 4 culverts: bottom level =0.5 + 2.78 m TAW

(2+2) dimensions = 3 m wide x 2,2 m high (standard dimensions)

length = 30 m

non return valves present

trash screen present

situation 2050: This area is designated to become FCA with CRT. But the inflow culverts are not designed yet. The standard sigma culvert will be used and the dimensions will be adapted from the inflow structure of the nearby FCA with CRT area De Bunt.

Water inflow: - 2 culverts: bottom level = 4,2 m TAW

(1+1) dimensions = 3 m wide x 2,2 m high

length = 18 m

height of weir = 0,2 m

Trash screen present

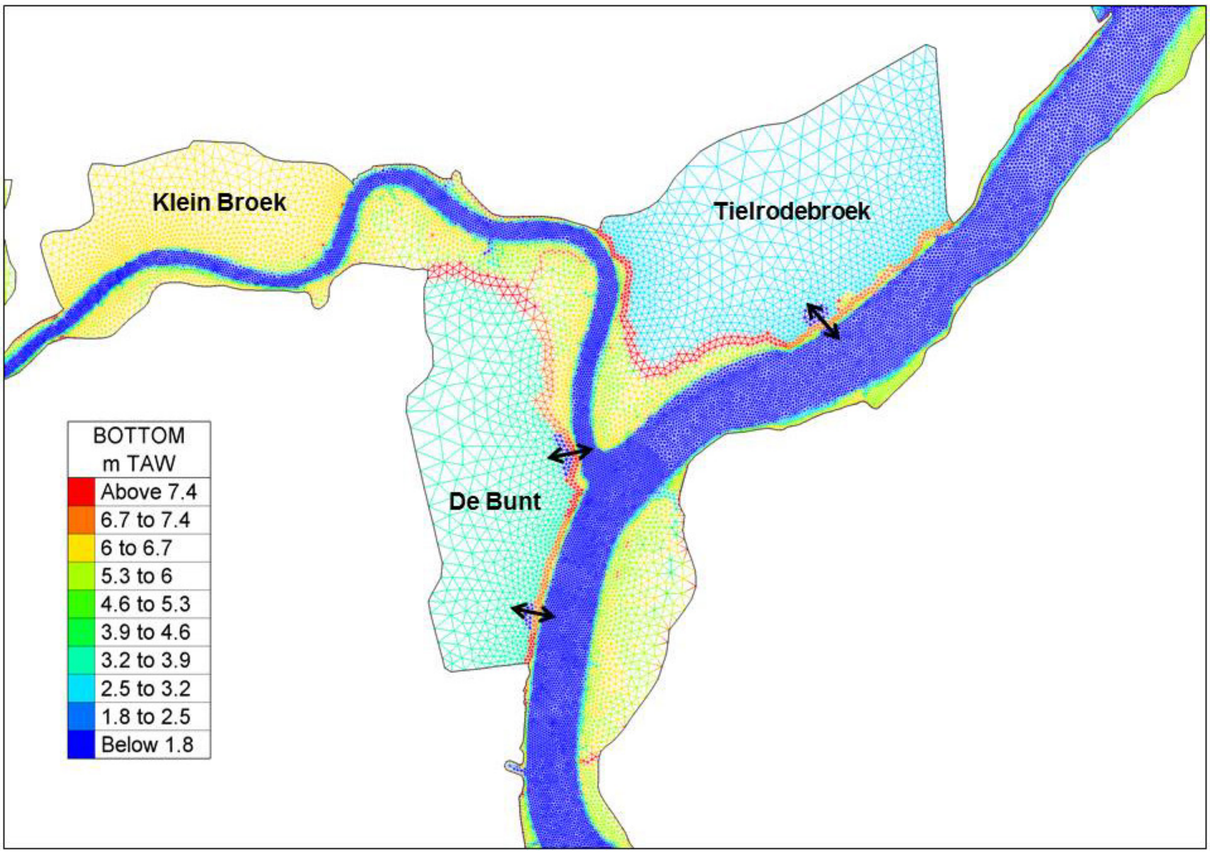
Bed level of FCA-CRT at 2050 according to Table 5 = 3,00 m TAW

Current (2013) bed level = 2,76 m TAW

Figure 30 – Variables for Tielrodebroek in- and outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Tielrodebroek FCA out	70965,91	346065,2	0,5	70939,57	347088,2	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	30	2
Tielrodebroek FCA out	70978,27	346972,5	0,5	70905	347069,4	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	30	2
Tielrodebroek FCA out	71005,75	346974,6	2,8	70954,66	347099,6	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	30	2
Tielrodebroek FCA out	70973,55	347000,3	2,8	70922,47	347079	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	30	2
Tielrodebroek FCA/CRT in	71017,48	346994,9	4,4	70940,67	347067,9	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,6	2,2	0,015	18	0
Tielrodebroek FCA/CRT in	71037,57	347005,3	4,4	70957,86	347078,8	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,6	2,2	0,015	18	0

Figure 31 – FCA/CRT Tielrodebroek in the upper right corner, FCA/CRT De Bunt in the middle of the figure and the de-embankment of Klein Broek in the upper left corner (yellow area). The overflow dikes can be recognized by the orange color. The location of the culverts inside the areas is given by the dark blue dots.



4.3.14 FCA/ CRT De Bunt

situation 2013: present in the model but not active.

situation 2050: This area is designated to become FCA with CRT.

Overflow dike: - 920 m long (in two sections see Figure 33)
- crest level = 6,8 m TAW

Water outflow: - 8 culverts: (6+2)
bottom level =0,5 + 2,78 m TAW
dimensions = 3 m wide x 2,2 m high (standard dimensions)
length = 18 m
non return valves present
trash screen present

Water inflow: - 5 culverts: (3+2)
bottom level = 4,2 m TAW
dimensions = 3 m wide x 2,2 m high
length = 18 m
height of weir = 0,2 + 0,4 m
trash screen present

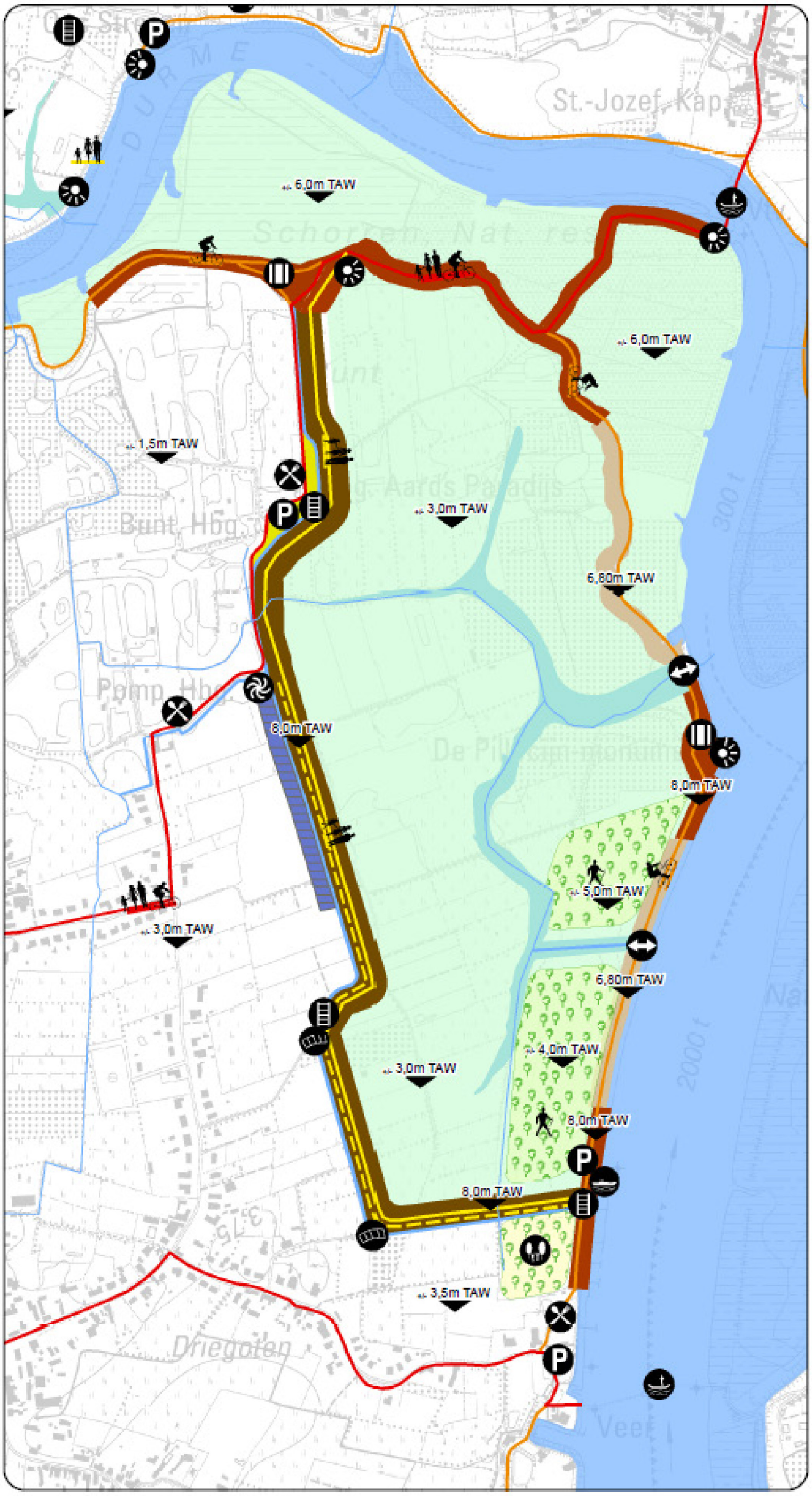
Bed level of FCA-CRT at 2050 according to Table 5 = 3,48 m TAW

Current (2013) bed level = 3,06 m TAW

Figure 32 – Variables for De Bunt in- and outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
CRT De Bunt out	70021,85	346558,3	0,8	69960,65	346541,3	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT De Bunt out	70020,59	346548,8	0,8	69950,95	346556,1	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT De Bunt out	70067,49	346482,6	0,8	69923,28	346609,7	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT De Bunt out	70095,27	346483,8	0,8	69915,93	346629,3	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT De Bunt out	70022,7	346567,8	0,8	69950,71	346511,6	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT De Bunt out	70031,39	346561,8	0,8	69948,09	346498,1	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT De Bunt out	69876,02	345954	0,8	69797,2	345922	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT De Bunt out	69886,23	345971,4	0,8	69797,52	345940,6	0,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT De Bunt in	70060,41	346498,4	4,4	69943,8	346574,8	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,6	2,2	0,015	18	0
CRT De Bunt in	70079,52	346505,5	4,4	69932,11	346592,3	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,6	2,2	0,015	18	0
CRT De Bunt in	70068,66	345492,3	4,4	69955,06	346526,4	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,6	2,2	0,015	18	0
CRT De Bunt in	69875,85	345935,8	4,6	69800,4	345959,6	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,4	2,2	0,015	18	0
CRT De Bunt in	69875,47	345917,6	4,6	69806,12	345974,6	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,4	2,2	0,015	18	0

Figure 33 – Design of May 2008 of the FCA/CRT De Bunt. (Map taken from: Rivierherstelproject Durmevallei Stapsgewijze realisatie van het GGG De Bunt: Schetsontwerp. versie Mei 2008)

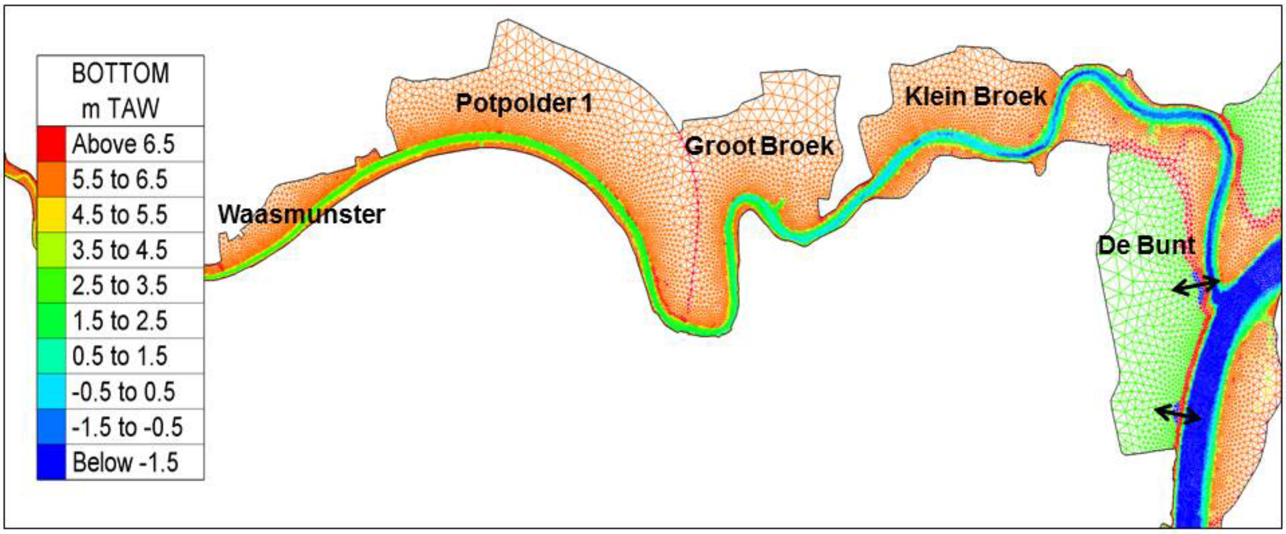


4.3.15 De-embankment Klein Broek and Groot Broek

Situation in 2013: Both areas were already included in the mesh, but were not yet de-embanked. Not active.

Situation in 2050: Both areas are de-embanked and connected to the Durme. The mean bed level in 2013 was 4,84 m TAW and 5,11 m TAW for Groot and Klein Broek, respectively. In the 2050 Scaldis model the mean bed level was raised to 5,55 m TAW and 6,02 m TAW for Groot and Klein Broek, respectively according to Table 4.

Figure 34 – From left to right: Polder van Waasmunster, Potpolder I, Groot Broek, Klein Broek, De Bunt



4.3.16 Potpolder I

Situation in 2013: Potpolder I was active as FCA in Scaldis 2013.

Situation in 2050: Potpolder I gets de-embanked. The mean bed level of this area in the Scaldis 2050 model will be 6,28 m TAW.

Overflow dike: - 2200 m long in Scaldis 2013 model

- crest level = 6,8 m TAW in Scaldis 2013 model

Water outflow: - 6 culverts: bottom level =1,6 +1,6+1,9+2+2+2,5 m TAW

dimensions = various dimensions see Figure 35

length = 30 m

non return valves present

trash screen present

Figure 35 – Variables for Potpolder I outlet structure for the culvert subroutine of TELEMAC 3D for Scaldis 2013

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Potpolder I	66416,93	346955,3	1,9	66457,03	347034,5	1,9	0,5	0,5	1	1	1	10	1,5	6	1	2,4	1	1	0,015	30	2
Potpolder I	66409,61	346960,1	2	66471,91	347020,4	2	0,5	0,5	1	1	1	10	1,5	6	1	2,3	2,3	2,3	0,015	30	2
Potpolder I	66402,19	346964,7	2	66485,86	347005,3	2	0,5	0,5	1	1	1	10	1,5	6	1	1,94	1,95	1,95	0,015	30	2
Potpolder I	66394,86	346969,3	1,6	66500,39	346986,6	1,6	0,5	0,5	1	1	1	10	1,5	6	1	1,7	1,5	1,5	0,015	30	2
Potpolder I	66395,17	346977,9	1,6	66504,58	346962,5	1,6	0,5	0,5	1	1	1	10	1,5	6	1	1,7	1,5	1,5	0,015	30	2
Potpolder I	66387,79	346982,4	2,5	66438,55	347049,2	2,5	0,5	0,5	1	1	1	10	1,5	6	1	2,25	0,86	0,86	0,015	30	2

4.3.17 Polder van Waasmunster

Situation in 2013: This area was already included in the mesh, but was not yet de-embanked. Not active.

Situation in 2050: The area is de-embanked and connected to the Durme. The mean bed level in 2013 was 5,50 m TAW. In the 2050 Scaldis model the mean bed level was raised to 6,29 m TAW according to Table 4.

4.3.18 Potpolder IV

Situation in 2013: This area is FCA but the culverts were not implemented in the model. No water reaches this far upstream in the Durme.

Situation in 2050: This area stays FCA. Culverts will be added to the model if their dimensions are known.

Overflow dike: - 3300 m long

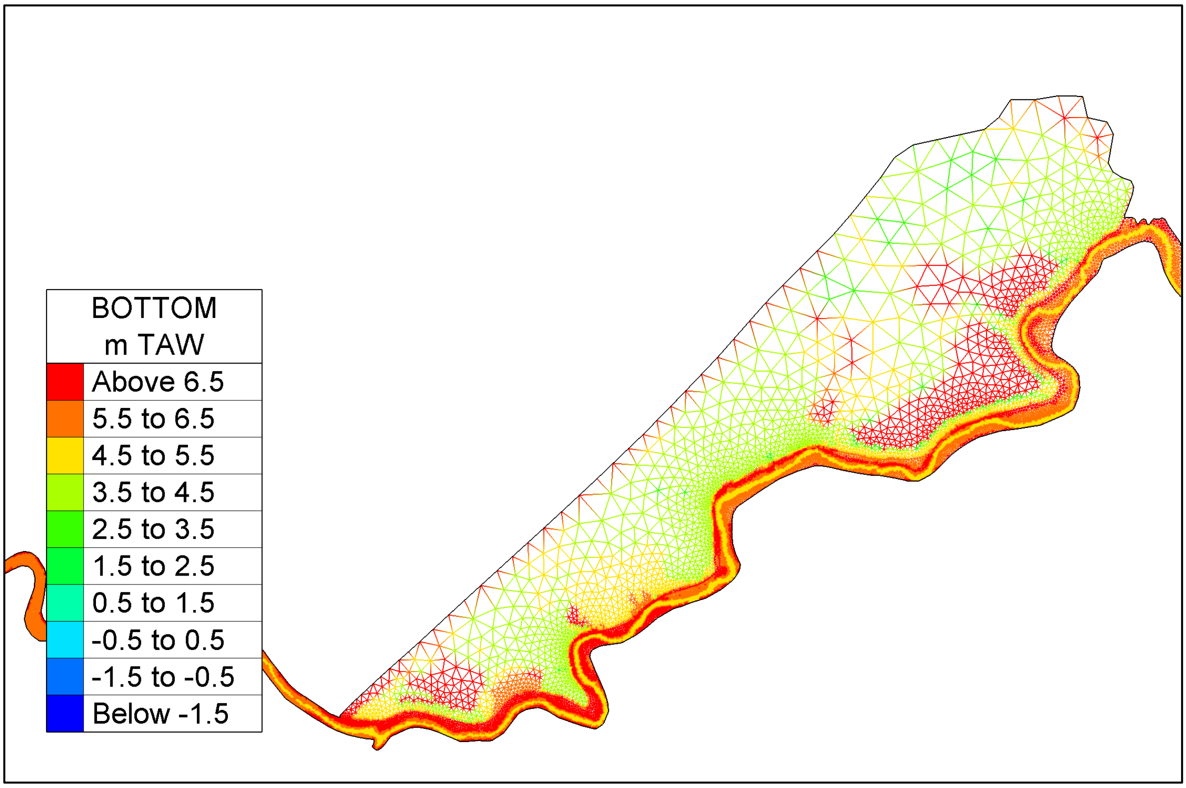
- crest level = 6,8-7,5 m TAW (6,8 m TAW for 1000 m; 1000 m at 7,1 m TAW and 1300 m at 7,5 m TAW in Scaldis model)

Water outflow: - 6 culverts: bottom level =5 m TAW

dimensions = 3 x 2,2 m

length = 4 m

Figure 36 – FCA Potpolder IV far upstream Durme



4.3.19 FCA/CRT Lippenbroek

situation 2013: present in the model and active as CRT.

Overflow dike: - 50 m long

- crest level = 6,8 m TAW

Water outflow: - 1 culvert: bottom level =1,6 m TAW

dimensions = 1,5 m wide x 1,5 m high

length = 40 m

non return valves present

trash screen present

Water inflow: - 3 culverts: bottom level = 4,7 m TAW

dimensions = 1 m wide x 1,9 m high

length = 13 m

height of weir = 0,0 m + 0,2 + 0,4 m

trash screen present

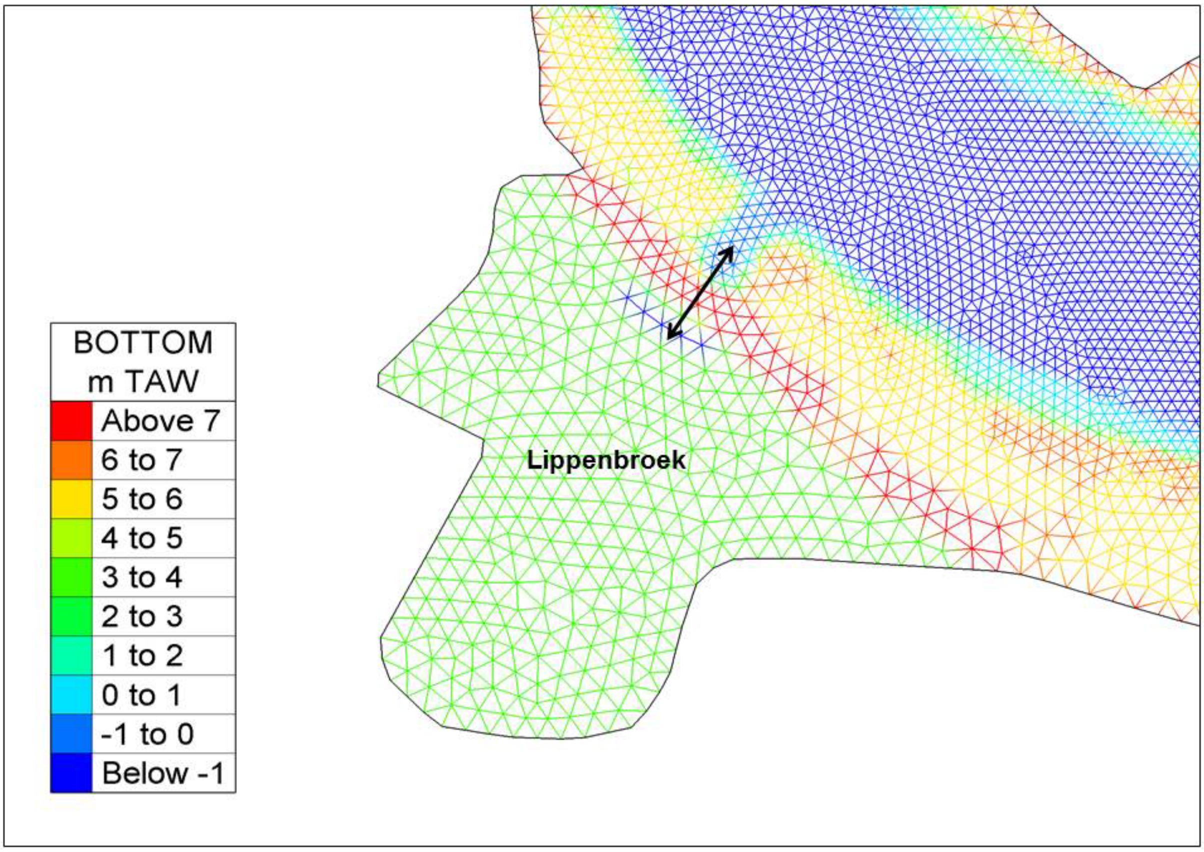
<u>Situation in 2050:</u> Mean bed level of FCA-CRT at 2050 according to Table 5 = 3,11m TAW

Current (2013) bed level = 2,65 m TAW.

Figure 37 – Variables for Lippenbroek in- and outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Lippenbroek in	69949,41	344869,8	4	69918,16	344788,2	5,3	0,5	0,5	1	1	0	10	0	6	0,8	1	1,9	0,6	0,015	13	0
Lippenbroek in	69942,69	344878,5	4	69900,8	344796,3	5	0,5	0,5	1	1	0	10	0	6	0,8	1	1,9	0,9	0,015	13	0
Lippenbroek in	69931,87	344876,6	4	69884,73	344805,9	4,7	0,5	0,5	1	1	0	10	0	6	0,8	1	1,9	1,2	0,015	13	0
Lippenbroek out	69928,47	344866,5	1,6	69869,91	344817,2	1,6	0,5	0,5	1	1	1	10	1,5	6	0,1	1,5	1,5	1,5	0,015	40	2

Figure 38 – FCA/CRT Lippenboek in the Scaldis 2050



4.3.20 FCA Zwijn

<u>situation 2013:</u> present in the model but not active.

<u>situation in 2050:</u> the area becomes FCA

Overflow dike: - 1050 m long with crest level 6,7 m TAW (See Figure 39 for location details)

- 800 m long with crest level = 6,9 m TAW (See Figure 39 for location details)

Water outflow: - 6 culverts: bottom level =1,5 m TAW

dimensions = 3 m wide x 2,2 m high

length = 18 m

non return valves present

trash screen present

Figure 39 – Implementation plan from 2005 for FCA Zwijn. (Map taken from: Zone 2:Vlassenbroek, Wal-Zwijn & Groot schoor Voorkeurscenario Inrichtingsplan Wal-Zwijn & Groot Schoor. versie Juni 2009).

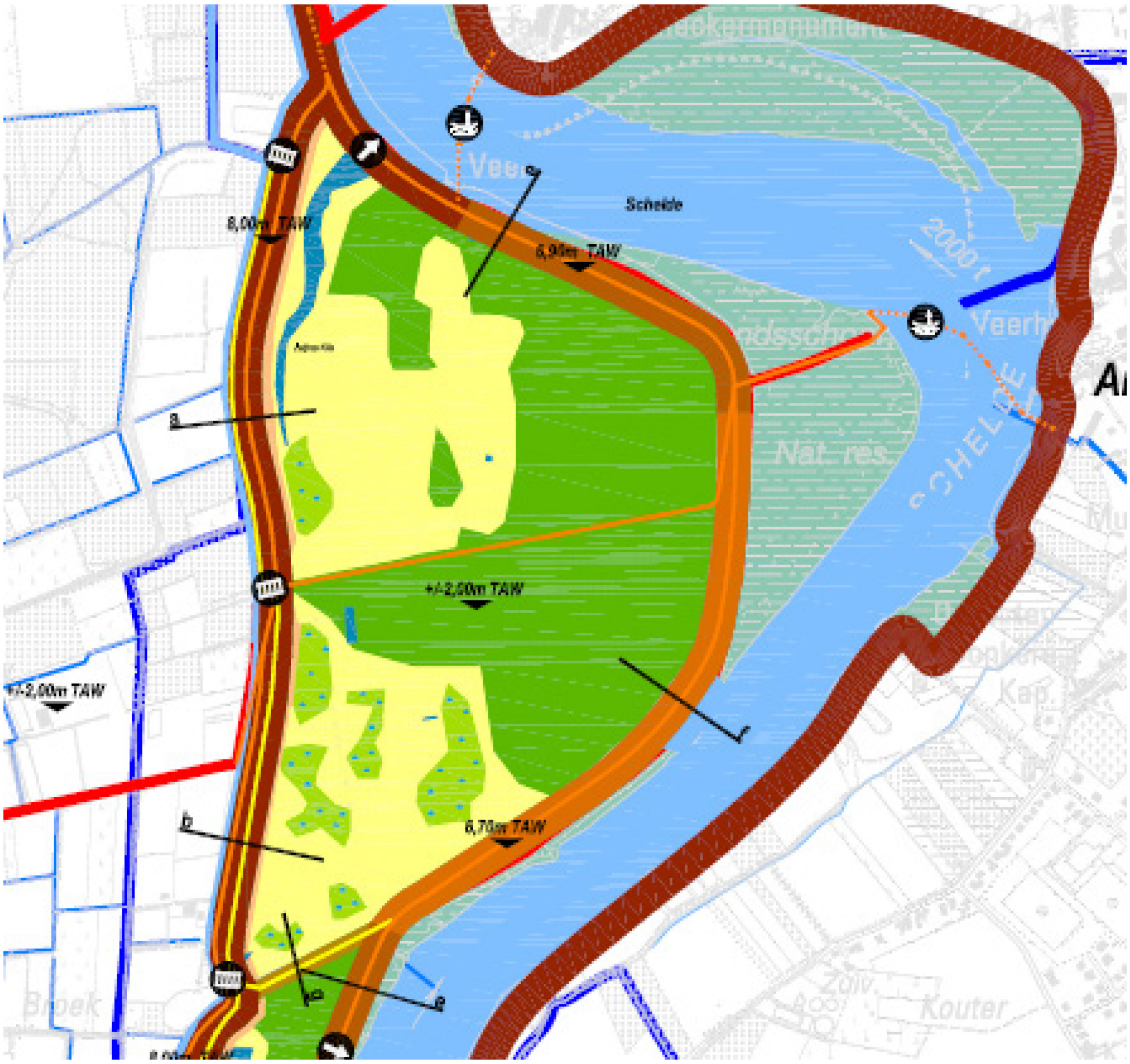


Figure 40 – Variables for FCA Zwijn outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
FCA Zwijn out	70935,57	341725,3	1,5	70762,4	341708,3	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Zwijn out	70917,23	341734,9	1,5	70778,52	341692,8	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Zwijn out	70905,27	341754,9	1,5	70796,78	341681	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Zwijn out	70887,8	341776,7	1,5	70816,09	341674,3	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Zwijn out	70874,46	341789,5	1,5	70823,21	341657,7	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Zwijn out	70843,87	341819,9	1,5	70833,76	341641,6	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2

4.3.21 FCA Grote Wal and Kleine Wal

<u>situation 2013:</u> present in the model and active, but not with the destination that it will have by 2050. Grote Wal was active as FCA in 2013, but was located in front of the current Grote Wal area. This area is de-embanked in 2050.

<u>situation in 2050:</u> Both FCA's will be active. FCA Grote Wal will lose its water via FCA Kleine Wal.

Overflow dike: - 1050 m long with crest level 6,7 m TAW (Grote Wal) (location details in Figure 43)

- 800 m long with crest level 6,9 m TAW (Grote Wal) (location details in Figure 43)
- 450 m long with crest level 6,9 m TAW (Kleine Wal) (location details in Figure 43)

Water outflow: - 6 culverts: bottom level =1,5 m TAW

(Kleine Wal) dimensions = 3 m wide x 2,2 m high

length = 18 m

non return valves present

trash screen present

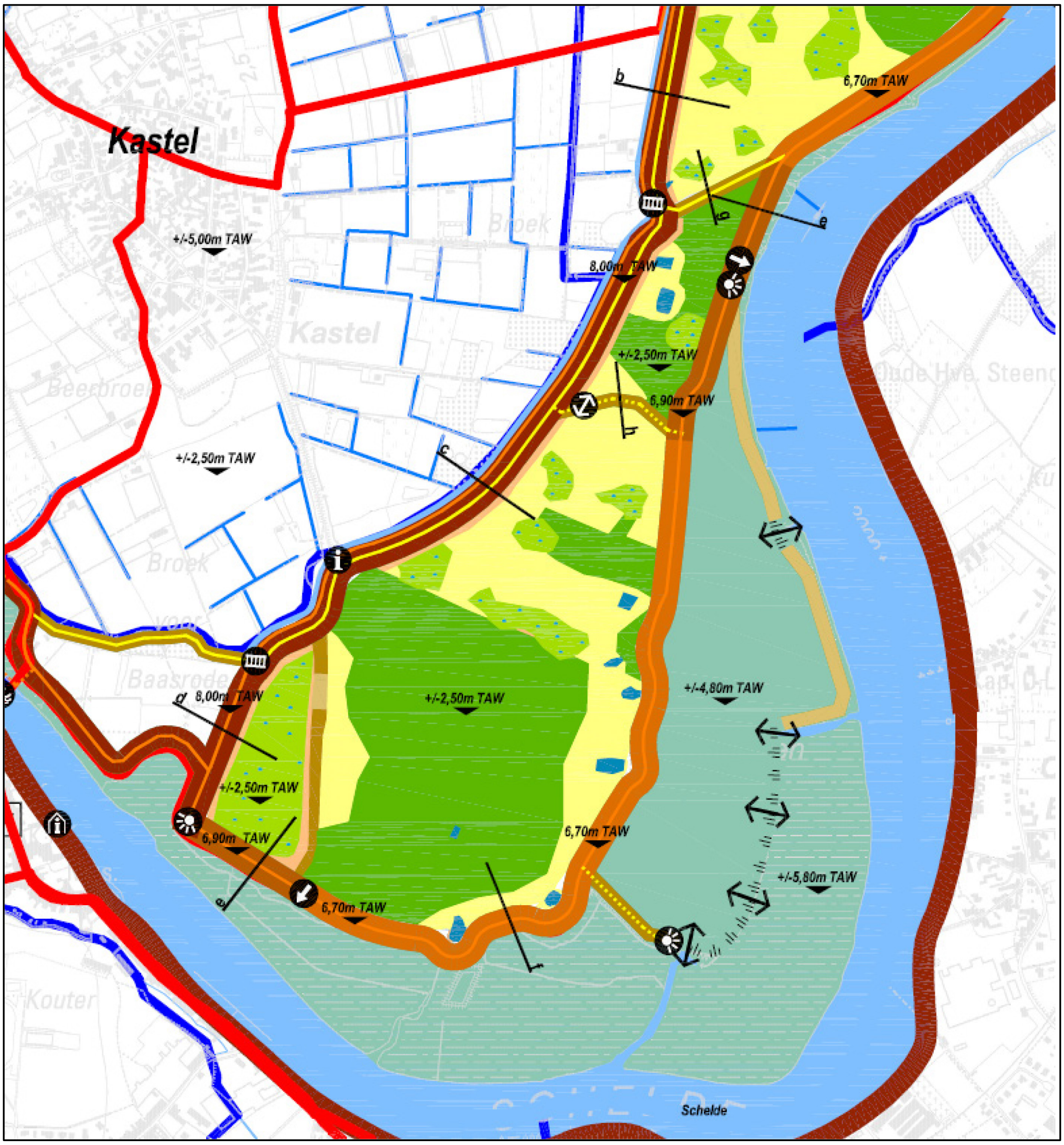
Figure 41 – Variables for FCA Grote Wal in 2013 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Grote Wal	70958,9	339528,9	1,3	70729,55	339493,4	1,3	0,5	0,5	1	1	1	10	1,5	6	0,1	1,5	1,5	1,5	0,015	30	2

Figure 42 – Variables for FCA Kleine Wal in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
FCA Kleine Wal out	70773,23	340222,8	1,5	70647,29	340241,6	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Kleine Wal out	70772,2	340238,7	1,5	70655,86	340259,2	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Kleine Wal out	70779,32	340257,5	1,5	70653,59	340277,2	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Kleine Wal out	70776,39	340275,8	1,5	70653,37	340300,7	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Kleine Wal out	70783,47	340295,7	1,5	70668,98	340319,4	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Kleine Wal out	70790,6	340313,9	1,5	70678,3	340340	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2

Figure 43 – Implementation plan from 2005 for FCA Grote Wal and Kleine Wal in Sigmaplan. (Map taken from: Zone 2:Vlassenbroek, Wal-Zwijn & Groot schoor Voorkeurscenario Inrichtingsplan Wal-Zwijn & Groot Schoor. versie Juni 2009).



4.3.22 FCA/CRT Vlassenbroek Noord

situation 2013: present in the model but not active.

situation in 2050: active as CRT area. Bed level at 2050 according to Table 5 = 2,92 m TAW

Current (2013) bed level = 2,58 m TAW

Overflow dike: - 1700 m long with crest level 6,5 m TAW (location details in Figure 44)

- 700 m long with crest level = 6,9 m TAW (location details in Figure 44)

Water outflow: - 8 culverts: bottom level =0,5 m TAW

dimensions = 3m wide x 2,2 m high

length = 18 m

non return valves present

trash screen present

Inflow culverts are not designed yet. We make assumptions based on CRT Bergenmeersen.

Water inflow: - 6 culverts: bottom level = 4,2 m TAW

dimensions = 3 m wide x 2,2 m high

length = 18 m

height of weir = 0,0 m

trash screen present

Figure 44 – Vlassenbroek Noord CRT implementation plan from 2012

Figure 45 – Variables for CRT Vlassenbroek Noord in 2050 in- and outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
CRT Vlassenbroek N out	67900,79	341472,4	0,5	67714,66	341392,1	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Vlassenbroek N out	67884,9	341473,8	0,5	67736,16	341387,1	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Vlassenbroek N out	67869,21	341473,6	0,5	67753,06	341377,3	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Vlassenbroek N out	67853,18	341475,1	0,5	67769,47	341381,3	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Vlassenbroek N out	67764,02	341498,4	0,5	67724,39	341423,4	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Vlassenbroek N out	67748,93	341503,3	0,5	67708,95	341429,2	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Vlassenbroek N out	67733,67	341508,8	0,5	67693,8	341436,6	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Vlassenbroek N out	67718,72	341514,2	0,5	67680	341447,6	0,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Vlassenbroek N in	67853,18	341475,1	4,2	67722,19	341347,2	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Vlassenbroek N in	67866,07	341479,9	4,2	67744,91	341339,7	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Vlassenbroek N in	67880,8	341480,6	4,2	67768,63	341333	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Vlassenbroek N in	67809,25	341491,3	4,2	67767,52	341409,4	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Vlassenbroek N in	67794,42	341499,2	4,2	67753,84	341413,5	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0
CRT Vlassenbroek N in	67778,71	341501,3	4,2	67739,74	341418,8	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	18	0

4.3.23 FCA Vlassenbroek Zuid

situation 2013: present in the model but not active.

situation in 2050: Area is FCA. This area is separated from Vlassenbroek Noord by a dike with crest level at 6,5 m TAW.

Overflow dike: - 850 m long with crest level 6,9 m TAW (location details see Figure 46)

Water outflow: - 10 culverts: bottom level =1,7 m TAW

dimensions = 3m wide x 2,2 m high

length = 18 m

non return valves present

trash screen present

Figure 46 – Vlassenbroek Zuid FCA implementation plan from 2012.

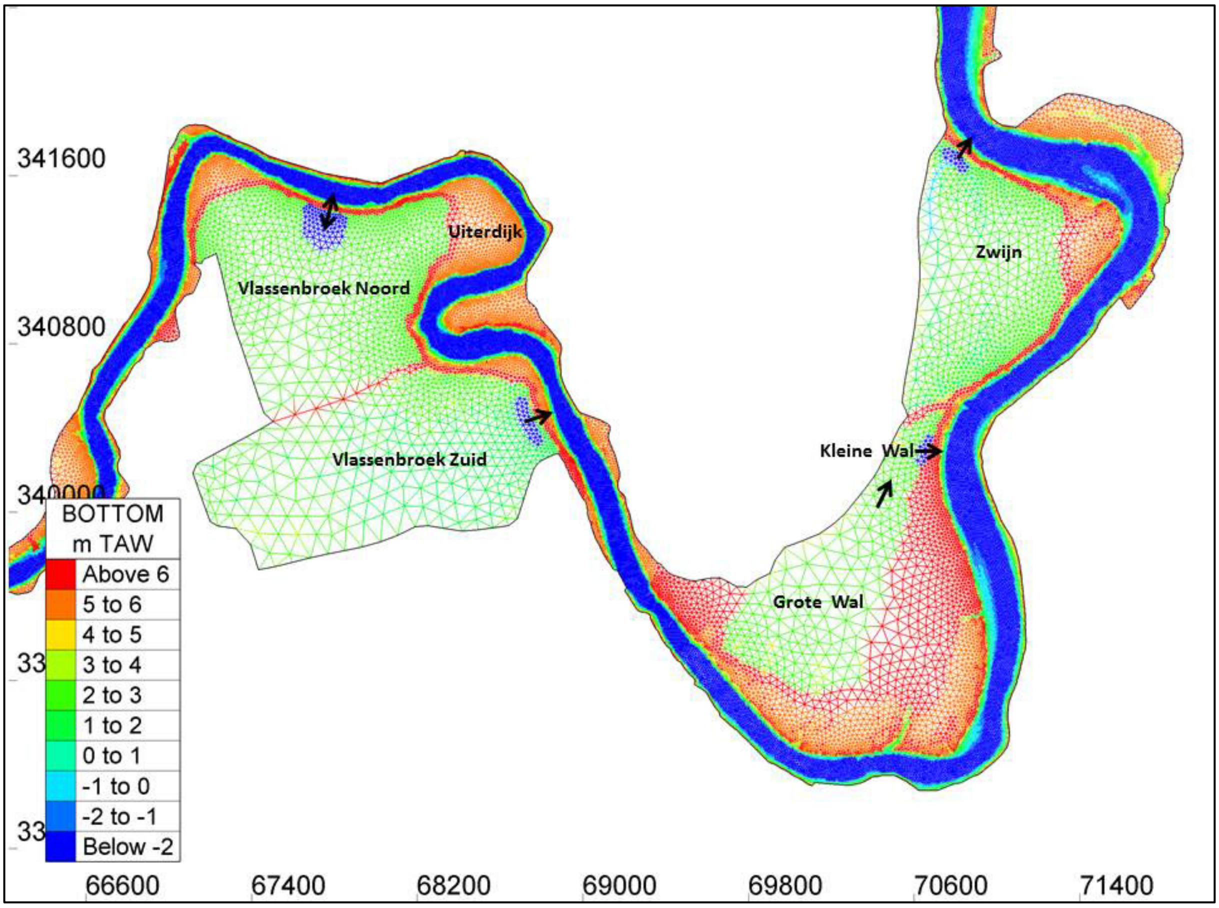
Figure 47 – Variables for FCA Vlassenbroek Zuid in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
FCA Vlassenbroek out	68919,87	340374,9	1,7	68782,23	340342,2	1,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Vlassenbroek out	68915,45	340390	1,7	68770,43	340355,7	1,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Vlassenbroek out	68912,17	340411,5	1,7	68759,84	340373,1	1,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Vlassenbroek out	68900,12	340430,8	1,7	68750,85	340393	1,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Vlassenbroek out	68890,09	340448,2	1,7	68740,88	340415,9	1,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Vlassenbroek out	68880,77	340467,5	1,7	68726,06	340436,6	1,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Vlassenbroek out	68878,8	340484	1,7	68716,34	340457,7	1,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Vlassenbroek out	68869,22	340503,1	1,7	68709,91	340479,6	1,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Vlassenbroek out	68867,52	340519,5	1,7	68706,44	340502,7	1,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Vlassenbroek out	68858,95	340530,8	1,7	68705,58	340522,8	1,7	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2

4.3.24 De-embankment Uiterdijk

This area was FCA in 2013 but without outlet structure. This area will be de-embanked by 2050. The dike will be removed completely and the bed level will increase from 5,09 m TAW to 5,76 m TAW according to Table 4.

Figure 48 – Vlassenbroek Noord and Vlassenbroek Zuid, Uiterdijk, Grote Wal, Kleine Wal and Zwijn implemented in Scaldis 2050.



4.3.25 FCA Scheldebroek

<u>situation 2013:</u> existing FCA (1981) present and active.

Overflow dike: - 1000 m long with crest level 6,4-6,6 m TAW (6,4 m TAW in Scaldis model)

Water outflow: - 2 culverts: bottom level =2,45 and 3,5 m TAW

dimensions = 2 m wide x 1,5 m high

length = 30 m

non return valves present

trash screen present

<u>Situation 2050:</u> the same as in 2013.

Figure 49 – FCA Scheldebroek in the Scaldis model.

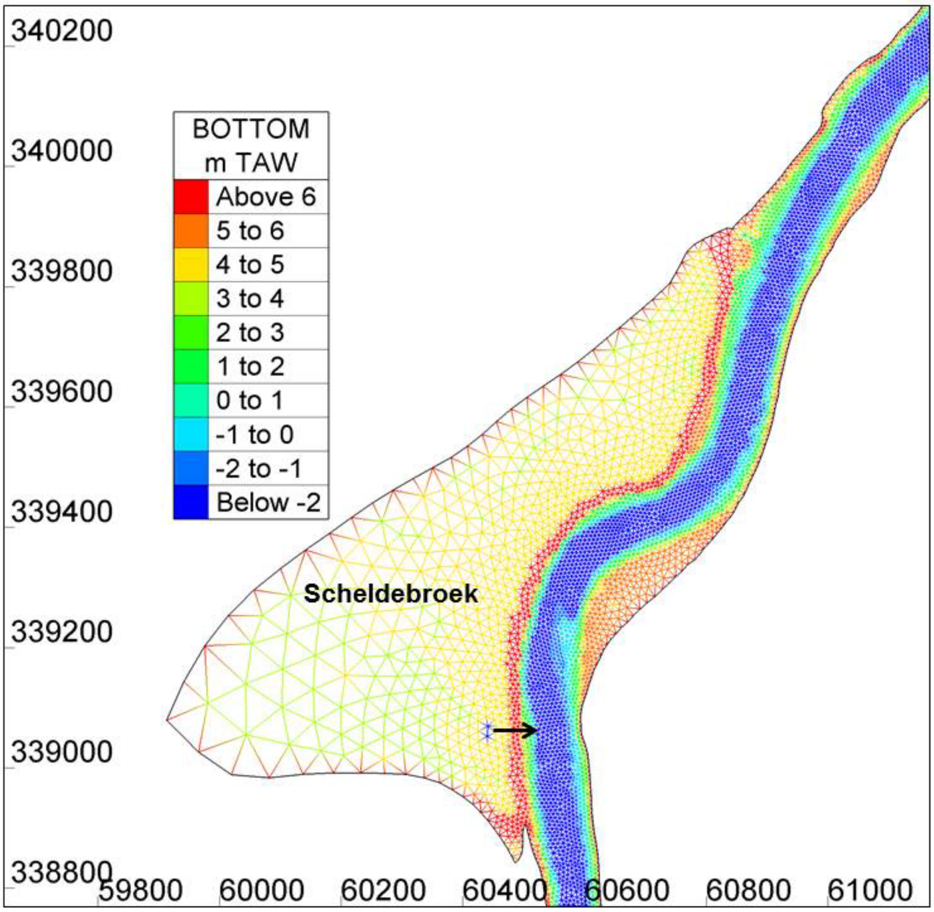


Figure 50 – Variables for FCA Scheldebroek in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Scheldebroek	60522,32	339078	3,5	60441,08	339069,1	3,5	0,5	0,5	1	1	1	10	1,5	6	1	3	2,2	2,2	0,015	30	2
Scheldebroek	60522,91	339056	2,5	60439,87	339052,6	2,5	0,5	0,5	1	1	1	10	1,5	6	1	2	1,5	1,5	0,015	30	2

4.3.26 FCA Paardeweide

situation 2013: existing FCA (2013) present and active.

Overflow dike: - 2700 m long with crest level 6,2-6,3 m TAW (6,2 m TAW in Scaldis model)

Water outflow: - 5 culverts: bottom level =2,5 (3) and 3 (2) m TAW

dimensions = 1,5 m wide x 1,5 m high

length = 30 m

non return valves present

trash screen present

Situation 2050: this area stays the same as in 2013. Two extra outlet culverts will be added to this area.

Water outflow: - 2 culverts: bottom level =2,5 m TAW
dimensions = 3 m wide x 2,2 m high
length = 15 m
non return valves present
trash screen present

Figure 51 – Variables for FCA Paardeweide in 2013 and 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Paardeweide	55720,87	336526,1	2,5	55817,85	336535,2	2,5	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,5	1,5	0,015	30	2
Paardeweide	55731,15	336505,6	2,5	55817,11	336516	2,5	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,5	1,5	0,015	30	2
Paardeweide	55739,92	336483,7	2,5	55825,32	336496,4	2,5	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,5	1,5	0,015	30	2
Paardeweide	55752,16	336472,6	3	55832,98	336488,3	3	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,5	1,5	0,015	30	2
Paardeweide	55755,18	336465,2	3	55822,55	336506,1	3	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,5	1,5	0,015	30	2

Figure 52 – Variables for 2 extra outlet culverts in 2050 for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Paardeweide out 2050	56698,99	335795	2,5	56715,82	335892,6	2,5	0,5	0,5	1	1	1	10	1,5	6	1	2,7	1,8	2,2	0,015	15	2
Paardeweide out 2050	56685,23	335796,4	2,5	56702,97	335893,4	2,5	0,5	0,5	1	1	1	10	1,5	6	1	2,7	1,8	2,2	0,015	15	2

4.3.27 FCA/CRT Bergenmeersen

situation 2013: present in model and active.

Overflow dike: - 2000 m long with crest level 6,3-6,4 m TAW (6,35 m TAW in Scaldis model)
Water outflow: - 9 culverts: bottom level =2,5 (2); 2,7 (6) and 3,0 (1) m TAW
(6+3) dimensions = 1,35 m wide x 1,1 m high (6)
dimensions = 1,5 m x 1,5 m (3)
length = 18 m
non return valves present
trash screen present
Water inflow: - 6 culverts: bottom level = 4,2 m TAW
dimensions = 3 m wide x 2,2 m high
length = 9,5 m
height of weir = 0,0 (3); 0,17 (1) and 0,33 (2) m
trash screen present

<u>Situation 2050:</u> The culverts stay the same, but because of the CRT function the bed level will increase from 4,25 m TAW in 2013 to 4,78 m TAW in 2050 according to Table 5. In the Scaldis model 2050 the bed level was increased, but the main channel inside the area was kept (Figure 57).

Figure 53 – Variables for CRT Bergenmeersen in 2013 and 2050 in- and outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
CRT Bergenmeersen in	55578,89	337632,8	4,4	55497,54	337560	4,2	0,9	0,5	1	1	0	10	0	6	1	2,7	1,45	2,25	0,015	9,5	0
CRT Bergenmeersen in	55600,28	337623,5	4,5	55501,88	337555,2	4,2	0,9	0,5	1	1	0	10	0	6	1	2,7	1,3	2,25	0,015	9,5	0
CRT Bergenmeersen in	55605,4	337619,2	4,5	55506,45	337550,3	4,2	0,9	0,5	1	1	0	10	0	6	1	2,7	1,3	2,25	0,015	9,5	0
CRT Bergenmeersen in	55610,55	337614,8	4,2	55511	337545,3	4,2	0,9	0,5	1	1	0	10	0	6	1	2,7	1,6	2,25	0,015	9,5	0
CRT Bergenmeersen in	55615,71	337610,5	4,2	55516,26	337539,9	4,2	0,9	0,5	1	1	0	10	0	6	1	2,7	1,6	2,25	0,015	9,5	0
CRT Bergenmeersen in	55620,95	337606,2	4,2	55513,42	337552,5	4,2	0,9	0,5	1	1	0	10	0	6	1	2,7	1,6	2,25	0,015	9,5	0
CRT Bergenmeersen out	55547,4	337592,6	2,7	55490,5	337558,3	2,2	0,5	0,5	1	1	1	10	1,5	6	1	3	1,1	2,25	0,015	18,5	2
CRT Bergenmeersen out	55554,25	337587,2	2,7	55494,86	337553,1	2,2	0,5	0,5	1	1	1	10	1,5	6	1	3	1,1	2,25	0,015	18,5	2
CRT Bergenmeersen out	55540,63	337589,8	2,7	55499,5	337548,1	2,2	0,5	0,5	1	1	1	10	1,5	6	1	3	1,1	2,25	0,015	18,5	2
CRT Bergenmeersen out	55533,98	337587,8	3,1	55504,15	337543,2	3,1	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,8	2,6	0,015	20	2
CRT Bergenmeersen out	55546,21	337585,1	3	55508,7	337538,3	3	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,8	2,6	0,015	20	2
CRT Bergenmeersen out	55539,36	337582,9	2,9	55512,23	337533,7	2,9	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,8	2,6	0,015	20	2
CRT Bergenmeersen out	54922,13	337305,5	2,5	54978,72	337332,5	2,5	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,5	1,5	0,015	30	2
CRT Bergenmeersen out	54921,57	337331,6	2,5	54978,75	337339	2,5	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,5	1,5	0,015	30	2
CRT Bergenmeersen out	54922	337345,2	3	54978,97	337345,4	2,5	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,5	1,5	0,015	30	2

4.3.28 FCA Wijmeers

<u>situation 2013:</u> present in the model but not active.

<u>situation 2050:</u> one part will be de-embanked. The bed level of this area will increase from 4,26 m TAW in 2013 to 4,84 m TAW in 2050 according to Table 4. The part behind this de-embanked area will function as FCA area. This is the larger area and this FCA is separated in half by a dike with crest level at 5,5 m TAW. There are two outlet structures to release the water back to the Scheldt river after a flooding (Figure 57).

Overflow dike: - 1700 m long with crest level 6,8 m TAW (Eastern part)

- 800 m long with crest level 7,1 m TAW (Western part)

Water outflow: - 12 culverts: bottom level = 2,75 m TAW

dimensions = 3 m wide x 2,2 m high

length = 18 m

non return valves present

trash screen present

Figure 54 – Variables for FCA Wijmeers deel 1 in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
FCA Wijmeers out	54596,2	336626,7	2,8	54543,56	336651,5	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Wijmeers out	54597,76	336639,7	2,8	54546,48	336662,6	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Wijmeers out	54604,99	336648,5	2,8	54550,92	336673,6	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Wijmeers out	54611,71	336658,5	2,8	54558,18	336684,8	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Wijmeers out	54611,38	336671,3	2,8	54562,63	336697,8	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Wijmeers out	54618,68	336683,7	2,8	54567,87	336708,7	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Wijmeers out	52989,27	336832,6	2,8	53026	336884,8	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Wijmeers out	52980,34	336838,8	2,8	53015,81	336892,8	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Wijmeers out	52967,39	336845,8	2,8	53004,64	336899,5	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Wijmeers out	52959	336856,5	2,8	52993,46	336905,7	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Wijmeers out	52946,22	336863,8	2,8	52982,87	336911,5	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Wijmeers out	52937,48	336875,6	2,8	52971,94	336916,8	2,8	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2

Figure 55 – Cross section of Wijmeers outlet construction (source: W&Z)

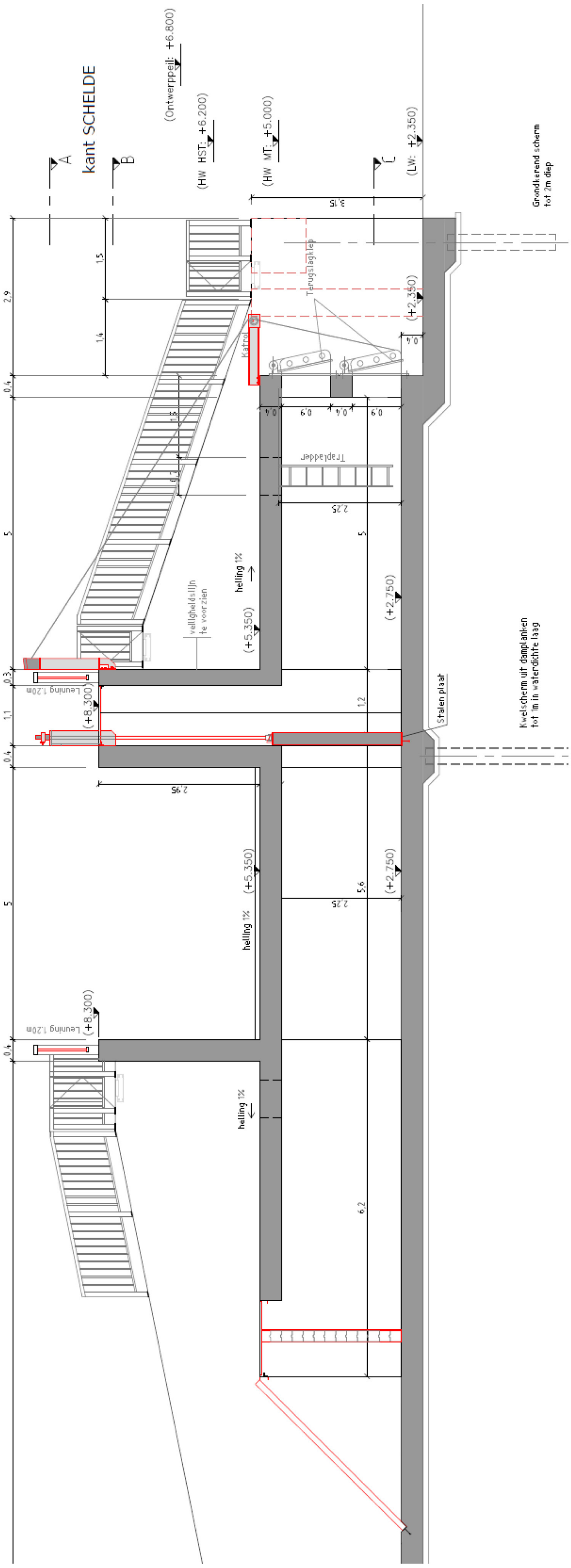


Figure 56 – View from river side on outlet construction of Wijmeers (source: W&Z)

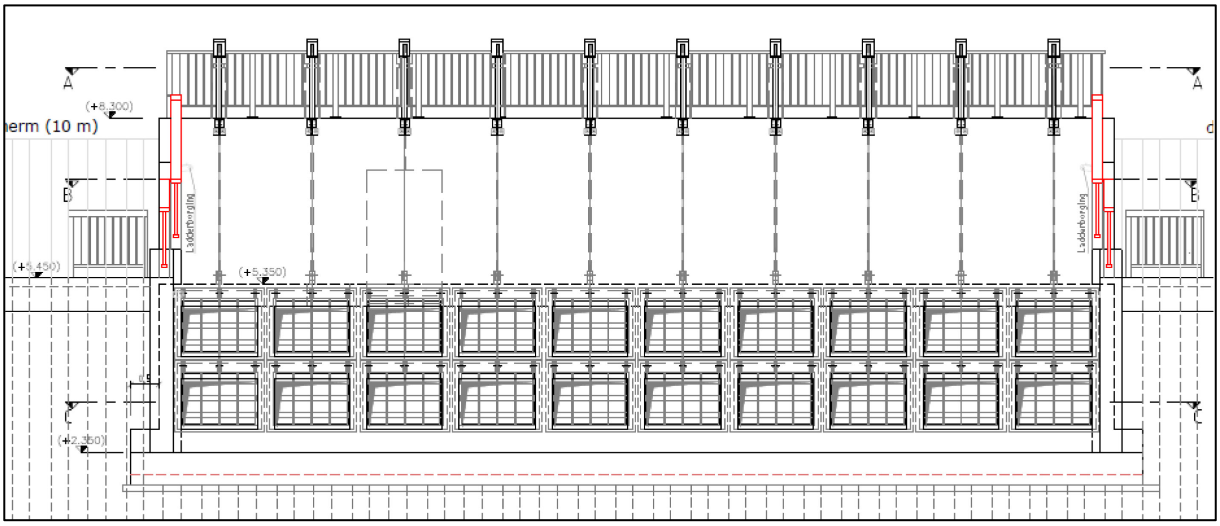
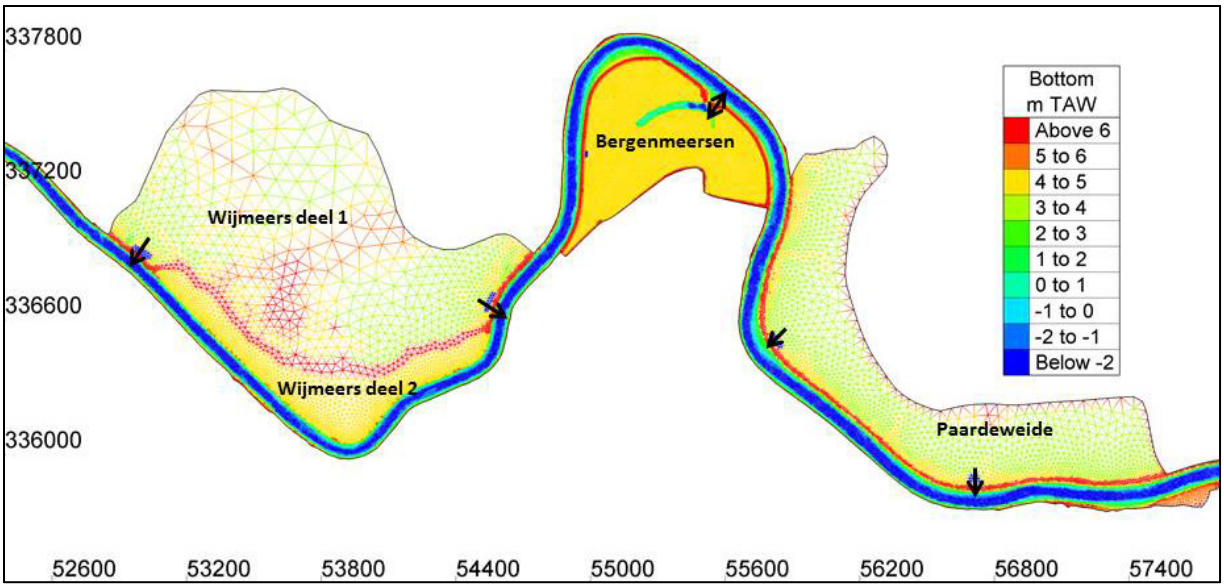


Figure 57 – Wijmeers, Bergenmeersen and Paardeweide implementation into Scaldis 2050



4.3.29 FCA/CRT Ham

<u>situation 2013:</u> present in the mesh but not active.

<u>situation 2050:</u> this is a FCA/CRT area with a mean bed level of 4,28 m TAW in 2013 and this will increase to 5,04 m TAW in 2050 according to Table 5.

Overflow dike: - 830 m long with crest level 6,0 m TAW

Water inflow: - 3 culverts: bottom level =4,05 m TAW

dimensions = 3 m wide x 2,4 m high

length = 9,5 m

trash screen present

Water outflow: - 3 culverts: bottom level = 4,4 m TAW

dimensions = 2,6 m wide x 0,75 m high

length = 18 m

trash screen present

non return valves present

Figure 58 – Variables for CRT Ham in 2050 in- and outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
CRT Ham out	48474,13	336099,7	2,6	48431,97	336131,1	2,6	0,5	0,5	1	1	1	10	1,5	6	1	2,4	1,1	2,4	0,015	13,35	2
CRT Ham out	48476,24	336106,2	2,6	48438,65	336139,1	2,6	0,5	0,5	1	1	1	10	1,5	6	1	2,4	1,1	2,4	0,015	13,35	2
CRT Ham out	48485,88	336113,7	2,6	48446,76	336146,2	2,6	0,5	0,5	1	1	1	10	1,5	6	1	2,4	1,1	2,4	0,015	13,35	2
CRT Ham in	48497,34	336122,2	4,1	48456,07	336152,5	4,1	0,9	0,5	1	1	0	10	0	6	1	2,4	0,5	2,4	0,015	9,5	0
CRT Ham in	48508,36	336130,5	4,1	48465,53	336158,3	4,1	0,9	0,5	1	1	0	10	0	6	1	2,4	0,5	2,4	0,015	9,5	0
CRT Ham in	48520,01	336138,1	4,1	48475,16	336162,4	4,1	0,9	0,5	1	1	0	10	0	6	1	2,4	0,5	2,4	0,015	9,5	0

Figure 59 – Top view of in- and outlet construction CRT Ham (source: W&Z)

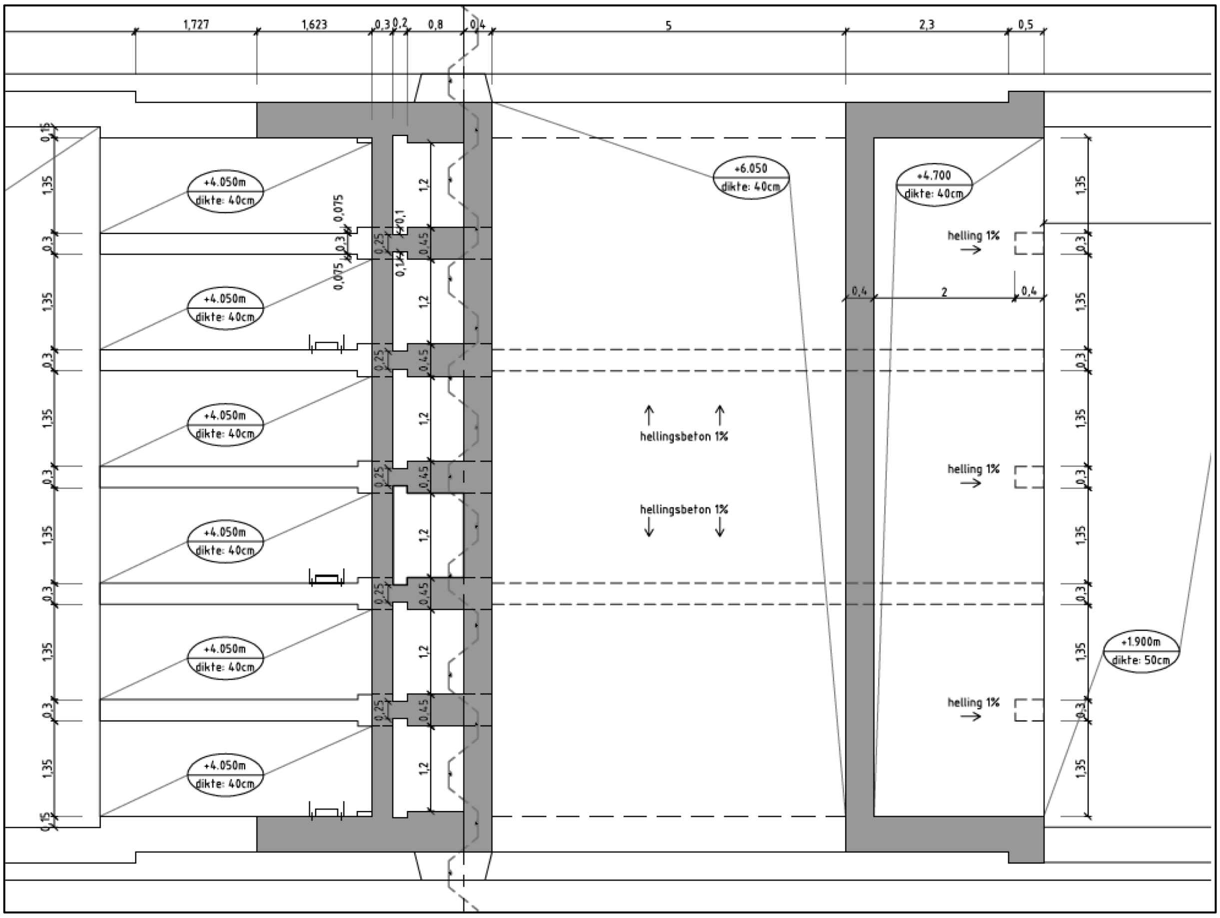
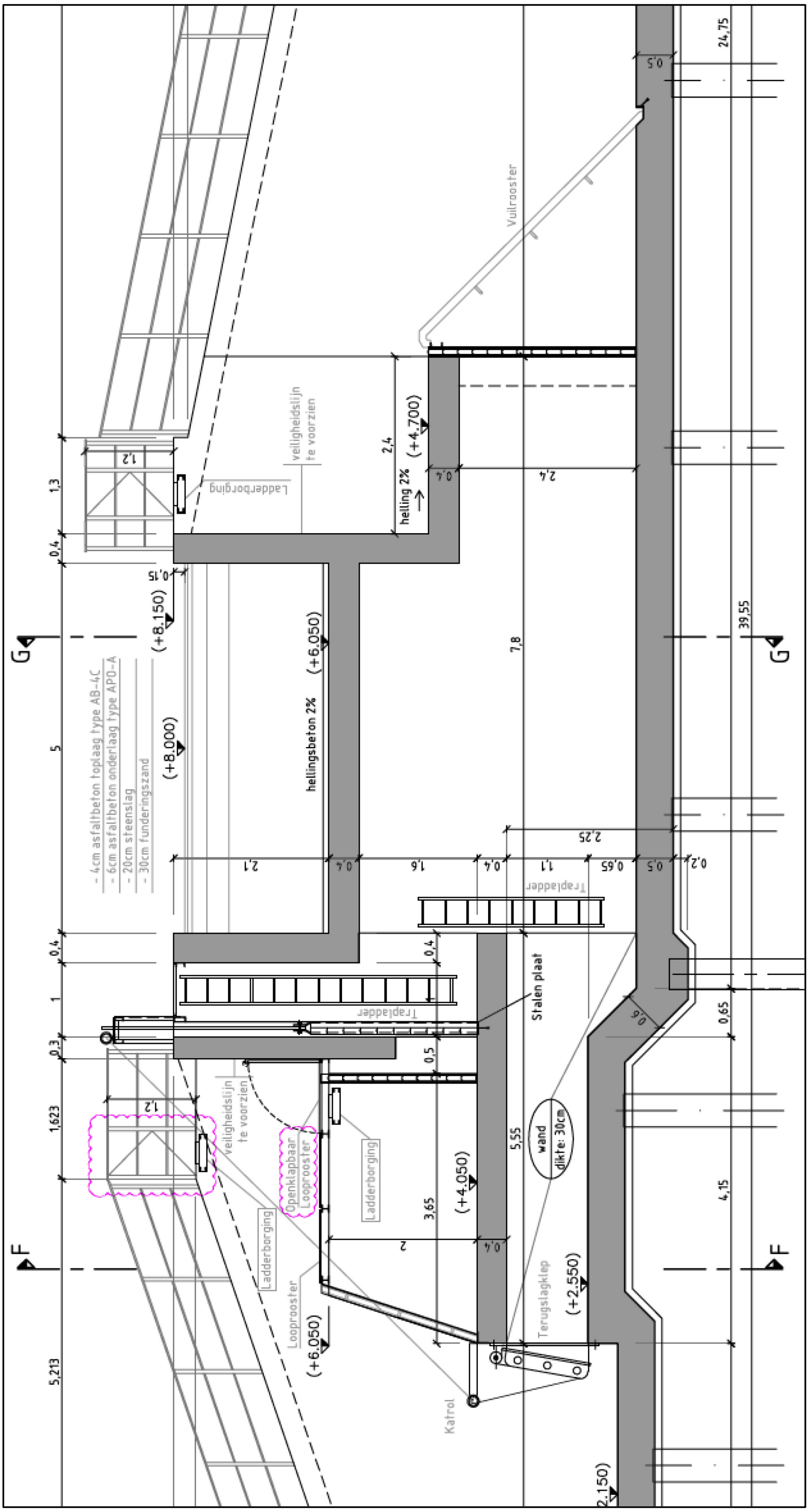


Figure 60 – Cross section of in- and outlet structure of CRT Ham (source: W&Z)



4.3.30 FCA Bastenakkers

situation 2013: present in the mesh but not active.

situation 2050: FCA area with two time 3 outlet culverts

Overflow dike: - 2120 m long with crest level 7,0 m TAW

Water outflow: - 6 culverts: bottom level =2,55 m TAW

(2 x 3) dimensions = 3 m wide x 2,2 m high

length = 18 m

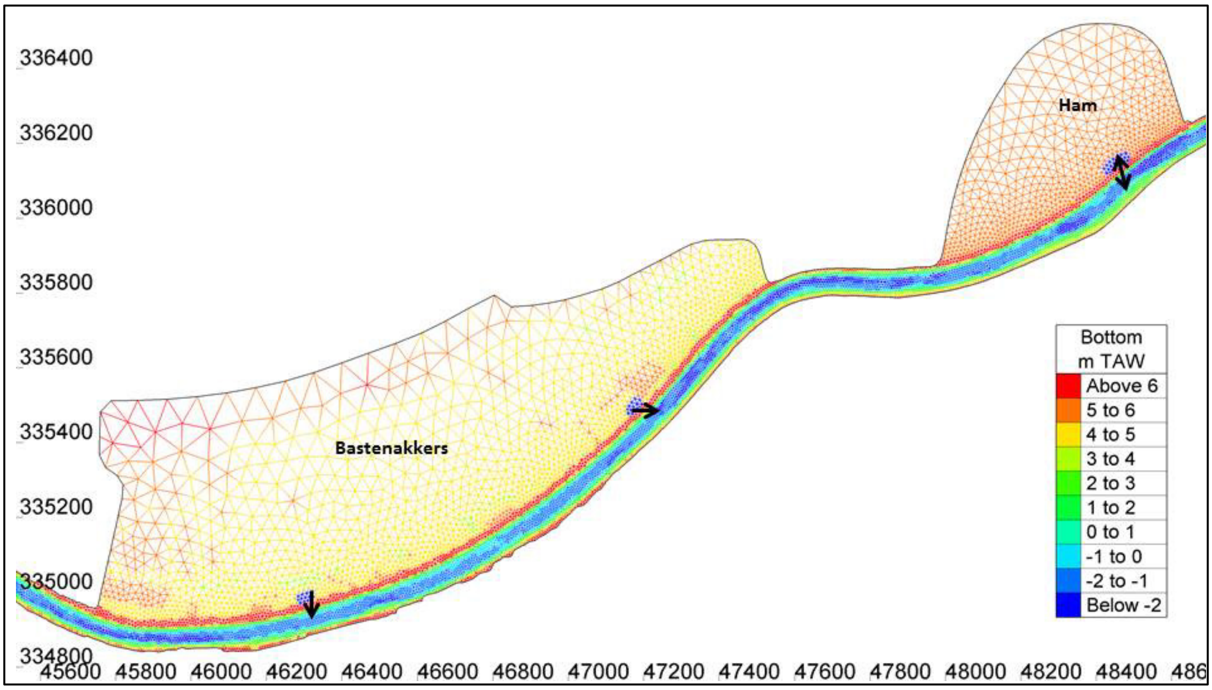
non return valves present

trash screen present

Figure 61 – Variables for FCA Bastenakkers in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
FCA Bastenakkers out	47215,37	335455,8	2,6	47165,87	335487,3	2,6	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Bastenakkers out	47225,34	335464,9	2,6	47172,72	335495,6	2,6	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Bastenakkers out	47234,8	335473,9	2,6	47182,14	335503,7	2,6	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Bastenakkers out	46306,9	334928	2,6	46292,52	334982,7	2,6	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Bastenakkers out	46320,32	334932,2	2,6	46303	334986,1	2,6	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Bastenakkers out	46333,13	334935,1	2,6	46314,01	334988,3	2,6	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2

Figure 62 – FCA Bastenakkers and CRT Ham implementation in Scaldis 2050



4.3.31 New sluice at de-embankment Heusden and Zandput Melle

Just north of the de-embankment of Heusden a new sluice will prevent the tide from attenuating further upstream in this tidal arm. Next to the sluice 2 culverts will let some of the water through like a CRT area. These culverts will be implemented as inflow culverts since these culverts also allow outflow. At storm conditions with water levels above 5,5 m TAW these culverts will be closed. In the model they will not be closed. This would require further code development. The sluice itself is implemented as a dike with crest level of 8 m TAW.

Water inflow: - 2 culverts: bottom level =4,35 m TAW (0,5 m wide) and 4,65 m TAW (5,5 m wide)

dimensions = 2,2 m high

length = 10 m

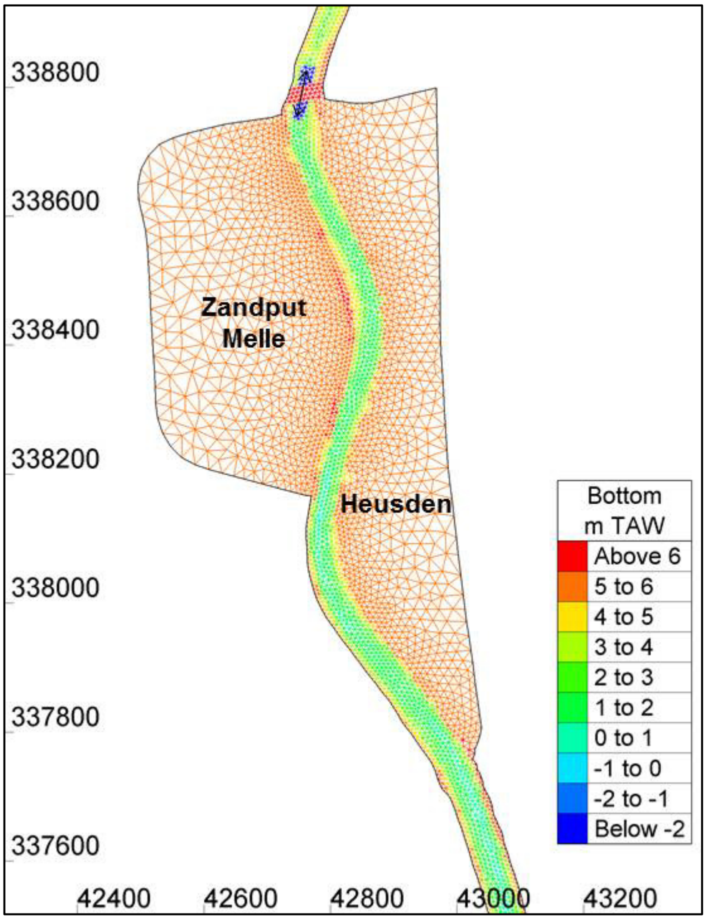
trash screen present

In 2050 two area, i.e. Heusden on the left bank and Zandput Melle on the right bank will be de-embanked. Their bed level will change from 4,91 m TAW and 3,50 m TAW in 2013 to 5,44 m TAW and 4,43 m TAW in 2050 for Heusden and Zandput Melle respectively, according to the elevation model.

Figure 63 – Variables for culvert at sluice Heusden in 2050 for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Heusden sluice	42752,81	338767,5	4,4	42763,27	338822,2	4,4	0,9	0,5	1	1	0	10	0	6	1	0,5	1,8	2,2	0,015	10	0
Heusden sluice	42750,65	338761,2	4,7	42762,11	338813,8	4,7	0,9	0,5	1	1	0	10	0	6	1	5,5	1,8	2,2	0,015	10	0

Figure 64 – Implementation of sluice Heusden in the Scaldis 2050.



4.3.32 FCA Bovenzanden

situation 2013: active as FCA (1983)

situation 2050: This area get the CRT function, but the dimensions are not yet known. Since this area is located on a tributaries of the Scheldt, the CRT function is not yet implemented as it is not yet known.

Overflow dike: - 1600 m long with crest level 6,7 m TAW

Water outflow: - 2 culverts: bottom level =2,95 m TAW

dimensions = 1,4 m wide x 1,4 m high

length = 30 m

non return valves present

trash screen present

Figure 65 – Variables for FCA Bovenzanden in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Bovenzanden out	87027,65	343453,6	3	86920,52	343414,6	3	0,5	0,5	1	1	1	10	1,5	6	1	1,4	1,4	1,4	0,015	30	2
Bovenzanden out	87051,2	343405,9	3	86933,34	343395,5	3	0,5	0,5	1	1	1	10	1,5	6	1	1,4	1,4	1,4	0,015	30	2

4.3.33 FCA Heindonk Tien Vierendelen

situation 2013: present in the mesh but not active

situation 2050: area becomes FCA and active.

Overflow dike: - 350 m long with crest level 7,0 m TAW

Water outflow: - 2 culverts: bottom level =1 m TAW

dimensions = 3 m wide x 2,2 m high

length = 18 m

non return valves present

trash screen present

Figure 66 – Variables for FCA Heindonk in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
FCA Heindonk tien Vierendelen out	87498,31	342660,8	1	87432,74	342632,1	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Heindonk tien Vierendelen out	87492,81	342670,8	1	87426,3	342646,1	1	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2

4.3.34 FCA/CRT Grote Vijver Noord

situation 2013: present in the mesh but not active.

situation 2050: Area becomes CRT area. The bed level changes from 2,80 m TAW in 2013 to 3,75 in 2050 according to the elevation model. This area is separated from Grote Vijver Zuid by a dike with crest level at 8,35 m TAW. There are connection culverts present. To allow water flowing between both areas two nodes in the dike between the two areas were lowered to 3,75 m TAW.

Overflow dike: - 200 m long with crest level 6,5 m TAW

- 200 m long with crest level 6,9 m TAW

- 600 m long with crest level 6,5 m TAW

Water outflow: - 6 culverts: bottom level =1,5 m TAW
dimensions = 3 m wide x 2,2 m high
length = 18 m
non return valves present
trash screen present

Water inflow: - 6 culverts: bottom level = 4,2 m TAW
dimensions = 3 m wide x 2,2 m high
length = 18 m
height of weir = 0,6 (2); 0,7 (2) and 1,0 (2) m
trash screen present

Figure 67 – Variables for CRT Grote Vijver Noord in 2050 in- and outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
CRT Grote Vijver Noord out	87708,13	343162,9	1,5	87713,6	343035,1	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Grote Vijver Noord out	87694,52	343159,6	1,5	87690,98	343034,3	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Grote Vijver Noord out	87681,99	343150	1,5	87670,86	343035,6	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Grote Vijver Noord out	87672,69	343141,7	1,5	87649,58	343026,5	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Grote Vijver Noord out	87660,76	343140	1,5	87625,98	343033,8	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Grote Vijver Noord out	87647,33	343136,4	1,5	87607,29	343025,2	1,5	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
CRT Grote Vijver Noord in	87634,22	343132,4	4,8	87585,36	343019,3	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,2	2,2	0,015	18	0
CRT Grote Vijver Noord in	87621,52	343128	4,8	87723,16	343014,5	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,2	2,2	0,015	18	0
CRT Grote Vijver Noord in	87598,2	343131,5	4,9	87703,52	343016	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,1	2,2	0,015	18	0
CRT Grote Vijver Noord in	87584,41	343126,3	4,9	87678,77	343010,6	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	1,1	2,2	0,015	18	0
CRT Grote Vijver Noord in	87570,27	343122,1	5,2	87650,44	342996,2	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	0,9	2,2	0,015	18	0
CRT Grote Vijver Noord in	87556,5	343118,2	5,2	87623,71	342983,6	4,2	0,9	0,5	1	1	0	10	0	6	1	2,6	0,9	2,2	0,015	18	0

4.3.35 FCA Grote Vijver Zuid

situation 2013: present in mesh but not active.

situation 2050: area becomes FCA

Overflow dike: - 1500 m long with crest level 7 m TAW

Water outflow: - 4 culverts: bottom level =1,2 m TAW
dimensions = 3 m wide x 2,2 m high
length = 18 m
non return valves present
trash screen present

Figure 68 – Variables for FCA Grote Vijver Zuid in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
FCA Grote Vijver Zuid out	88005,5	342091,3	1,2	88091,79	342134	1,2	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Grote Vijver Zuid out	87991,02	342105	1,2	88079,41	342150,2	1,2	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Grote Vijver Zuid out	87976,64	342118,9	1,2	88063,97	342165	1,2	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
FCA Grote Vijver Zuid out	87965,49	342133,2	1,2	88044,2	342178,4	1,2	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2

4.3.36 FCA/CRT Zennegat

situation 2013: present in mesh but not active.

situation 2050: Area becomes CRT. The bed level changes from 3,64 m TAW in 2013 to 3,91 m TAW in 2050 according to Table 5.

Overflow dike: - 1400 m long with crest level 6,5 m TAW

Water outflow: - 5 culverts: bottom level =1,6 m TAW
dimensions = 3 m wide x 2,2 m high
length = 43 m
non return valves present
trash screen present

Water inflow: - 3 culverts: bottom level = 4,8 m TAW
dimensions = 3 m wide x 2,2 m high
length = 43 m
trash screen present

Figure 69 – Variables for CRT Zennegat in 2050 in- and outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
CRT Zennegat out	88447,35	341768,9	1,6	88378,37	341715,9	1,6	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	43	2
CRT Zennegat out	88431,13	341780,5	1,6	88364,09	341720,6	1,6	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	43	2
CRT Zennegat out	88415,81	341793	1,6	88350,55	341728	1,6	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	43	2
CRT Zennegat out	88400,07	341805,3	1,6	88345,6	341742,9	1,6	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	43	2
CRT Zennegat out	88384,77	341818,2	1,6	88328,59	341749	1,6	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	43	2
CRT Zennegat in	88353,88	341825,9	4,8	88297,52	341772,2	4,8	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	43	0
CRT Zennegat in	88339,73	341840	4,8	88284,2	341786,7	4,8	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	43	0
CRT Zennegat in	88325,23	341853,7	4,8	88271,76	341803,3	4,8	0,9	0,5	1	1	0	10	0	6	1	2,6	1,8	2,2	0,015	43	0

Figure 70 – Cross section of the culverts designed for CRT Zennegat (source: W&Z)

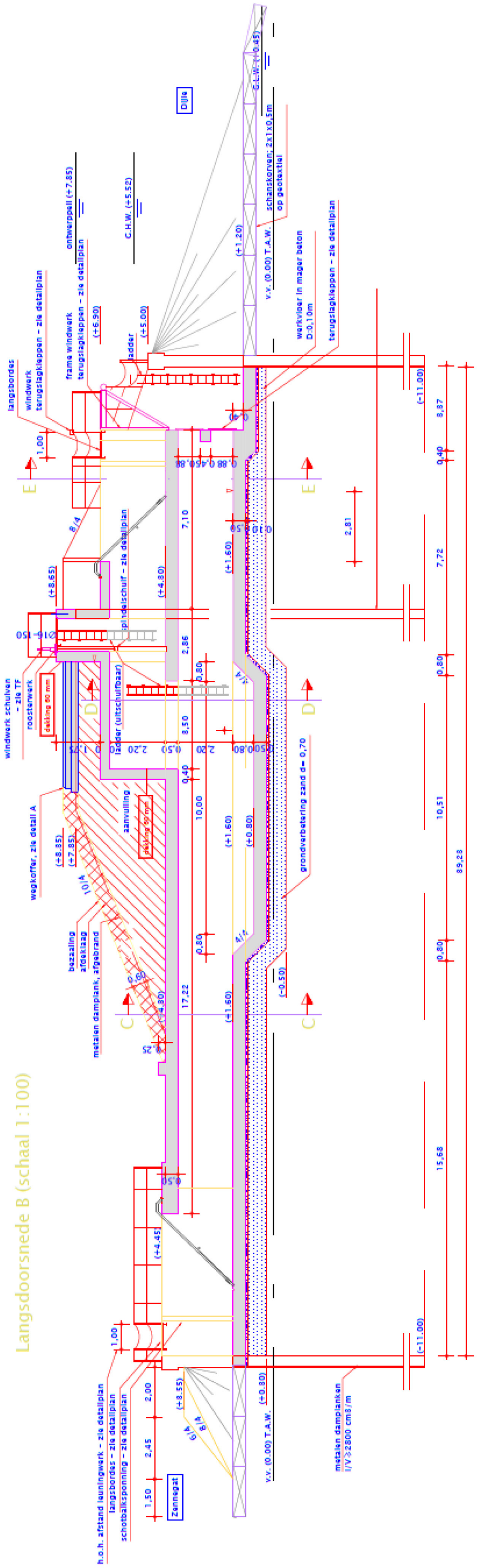


Figure 71 – Frontal view on the in- and outlet structure of CRT Zennegat (source: W&Z)

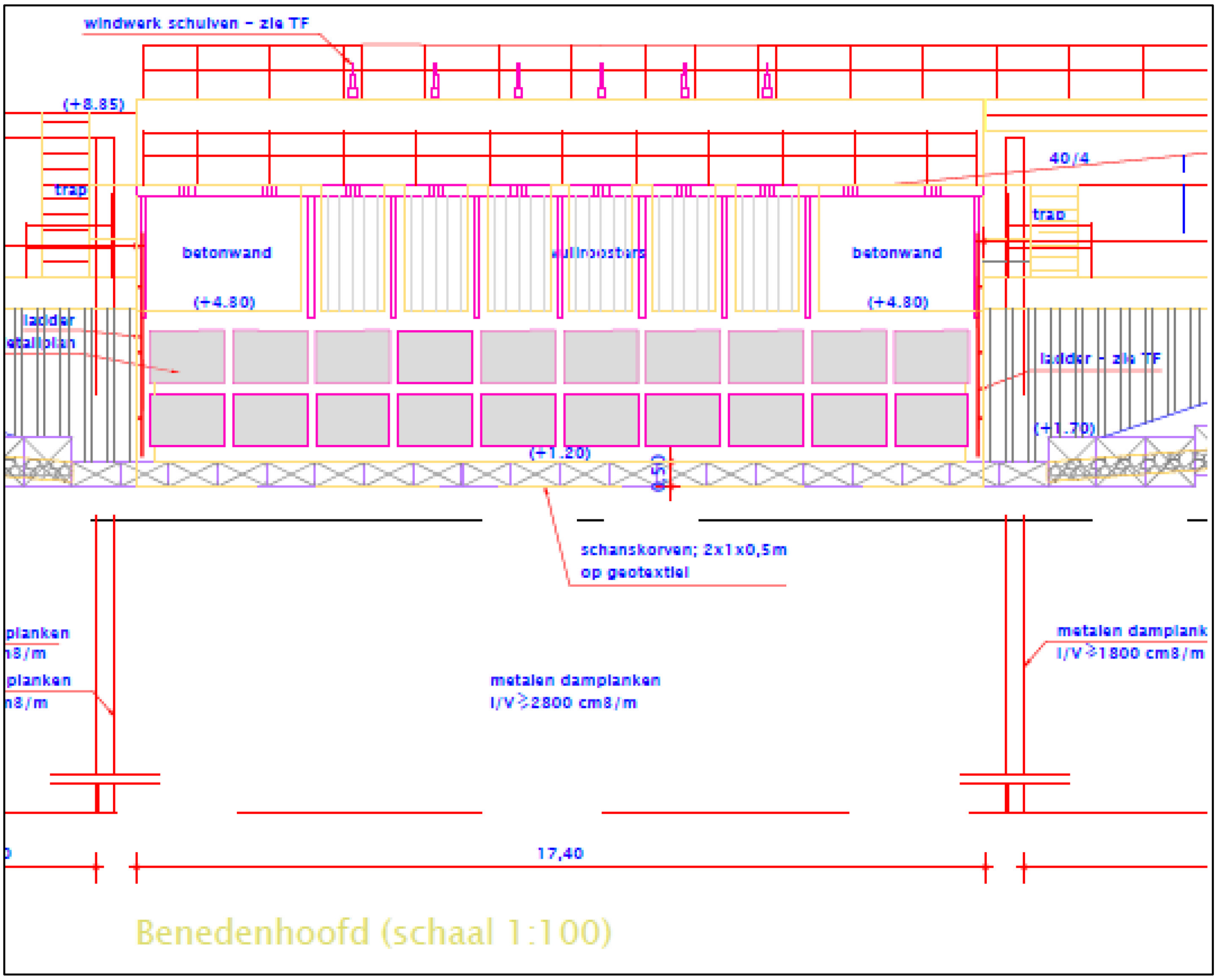
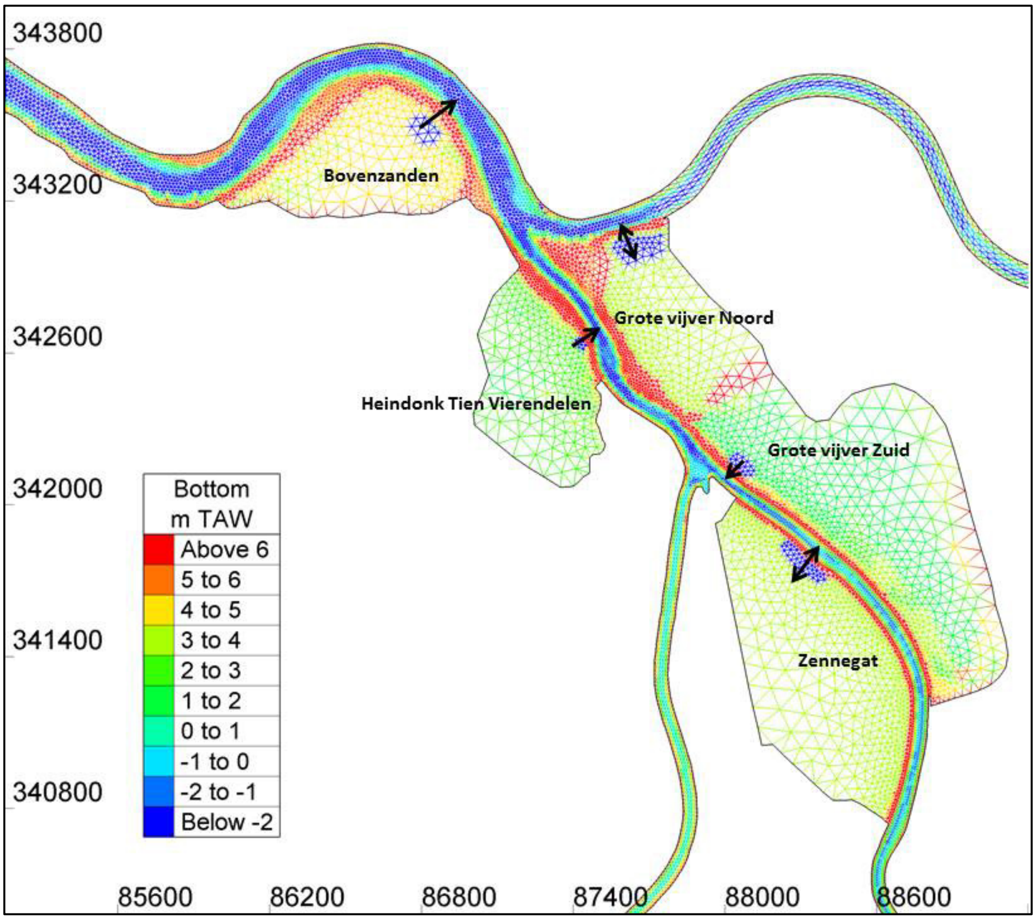


Figure 72 – Implementation of Bovenzanden, Heindonk Tien Vierendelen, Grote Vijver Noord and Zuid and Zennegat in the Scaldis 2050.



4.3.37 FCA Rijmenam

Situation 2013: present in the mesh but not active.

Situation 2050: FCA function but dimensions of outlet structure are unknown. We have put 2 outlet culverts in the model to drain the area in case of flooding. This FCA can be updated later in the Scaldis model when it is more clear how the final design would look like.

overflow dike crest level at 7,8 m TAW over full length.

Water outflow: - 2 culverts: bottom level =2,4 m TAW

dimensions = 3 m wide x 2,2 m high

length = 18 m

non return valves present

trash screen present

Figure 73 – Variables for FCA Rijmenam in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Rijmenam out	96778,38	335004,8	2,4	96814,68	335071,6	2,4	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Rijmenam out	97584,69	334662,3	2,4	97605,2	334755,3	2,4	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2

4.3.38 FCA Hollaken Hoogdonk

Situation 2013: present in the mesh but not active.

Situation 2050: FCA function but dimensions of outlet structure are unknown. We put 2 outlet culverts in the model to drain the area in case of flooding. 2 culverts because it is a big area. In reality 2 culverts is not enough, but as the dimensions are not yet known, we don't want to put in too many culverts in the model as this is computationally time consuming. Like FCA Rijmenam, this FCA can be updated later in the Scaldis model when it is more clear how the final design would look like.

overflow dike crest level at 8,2 and 8,4 m TAW over half-length each.

Water outflow: - 2 culverts: bottom level =2,4 m TAW

dimensions = 3 m wide x 2,2 m high

length = 18 m

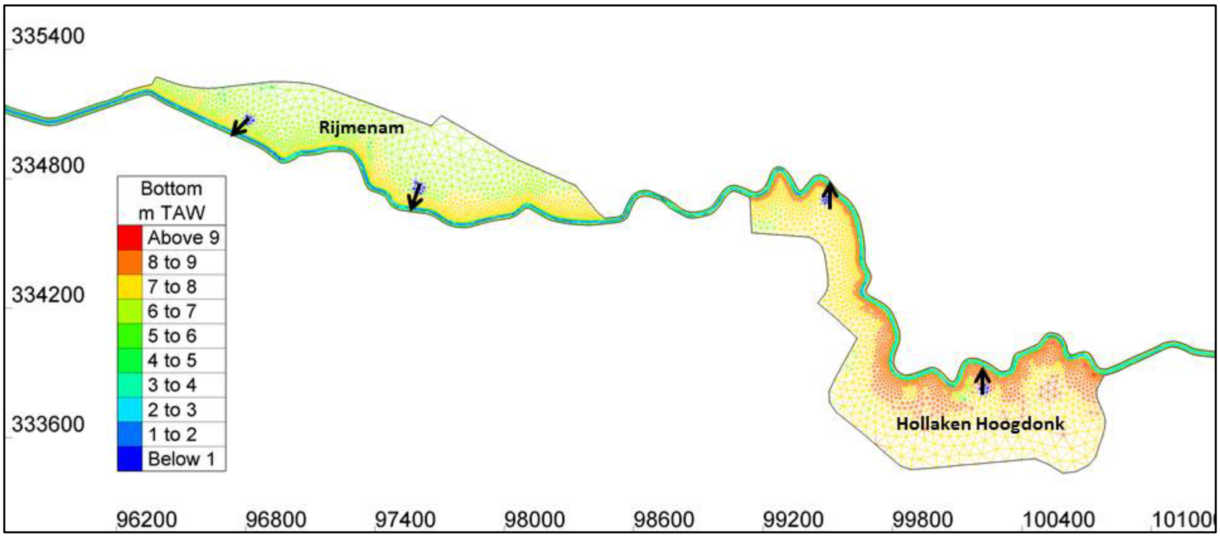
non return valves present

trash screen present

Figure 74 – Variables for FCA Hollaken Hoogdonk in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Hollaken Hoogdonk out	100262,7	333913	2,4	100224,1	333827,3	2,4	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2
Hollaken Hoogdonk out	99528,11	334737,7	2,4	99489,64	334703,1	2,4	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	18	2

Figure 75 – Implementation of FCA Rijmenam and FCA Hollaken Hoogdonk in the Scaldis model.



4.3.39 FCA Polder van Lier

situation 2013: active.

Overflow dike: - 1300 m long with crest level 6,7 m TAW

Water outflow: - 1 culvert: bottom level =2,4 m TAW

dimensions = 1,5 m wide x 1,5 m high

length = 30 m

non return valves present

trash screen present

Situation 2050: one extra outflow culvert will be added to the area. The area remains FCA. The dimensions of this new culvert are not yet known, but we combine the dimensions of the existing culvert with the standard sigma culvert dimensions.

Water outflow: - 1 culvert: bottom level =2,4 m TAW

dimensions = 3 m wide x 2,2 m high

length = 30 m

non return valves present

trash screen present

Figure 76 – Variables for FCA Polder van Lier in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Polder van Lier out	97119,72	348119,5	2,4	96846,42	347901,3	2,4	0,5	0,5	1	1	1	10	1,5	6	1	1,5	1,5	1,5	0,015	30	2
Polder van Lier out 2050	96890,9	347829,7	2,4	97032,75	348116,4	2,4	0,5	0,5	1	1	1	10	1,5	6	1	2,6	1,8	2,2	0,015	30	2

4.3.40 De-embankment Anderstadt 1 (downstream)

situation 2013: FCA and active.

Overflow dike: - 730 m long with crest level 6,1 m TAW

Water outflow: - 3 culverts: bottom level =3-3,5 m TAW (exact value unknown)

dimensions = 0,8 m diameter

length = 18 m

non return valves present

trash screen present

Figure 77 – Variables for FCA Anderstadt I in 2013 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Anderstadt afwaarts	96116,09	347702,3	3	96158,13	347636,7	3	0,5	0,5	1	1	1	10	1,5	6	1	0,8	0,8	0,8	0,015	30	2
Anderstadt afwaarts	96108,32	347682	3	96141,68	347637,6	3	0,5	0,5	1	1	1	10	1,5	6	1	0,8	0,8	0,8	0,015	30	2
Anderstadt afwaarts	96092,8	347669,4	3	96124,43	347636,8	3	0,5	0,5	1	1	1	10	1,5	6	1	0,8	0,8	0,8	0,015	30	2

situation 2050: de-embanked: mean bed level increases from 5,34 m TAW in 2013 to 5,98 m TAW in 2050 according to Table 4. A small channel is created that runs through this area.

4.3.41 FCA Anderstadt 2 (upstream)

situation 2013: FCA active.

situation 2050: the same as in 2013

Overflow dike: - 600 m long with crest level 6,8 m TAW

Water outflow: - 2 culverts: bottom level =3,08 and 3,10 m TAW

dimensions = 1,5 m wide x 1,8 m high

length = 18 m

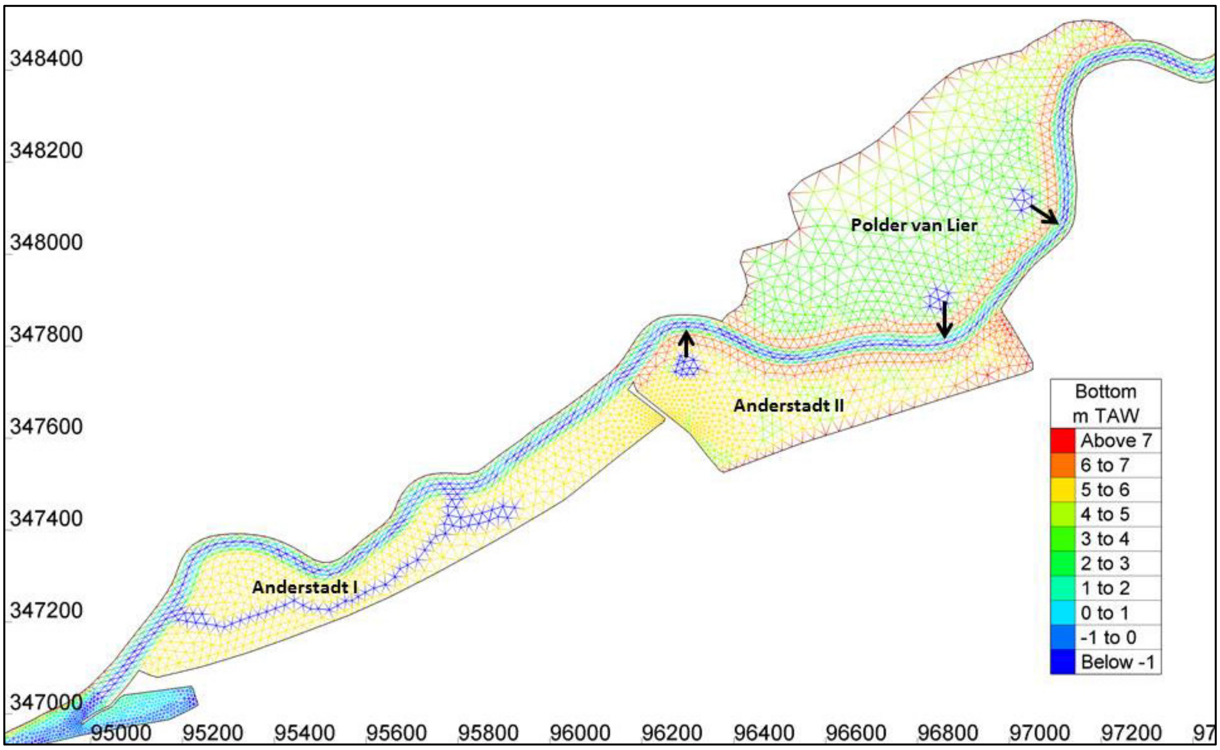
non return valves present

trash screen present

Figure 78 – Variables for FCA Anderstadt II in 2050 outlet structure for the culvert subroutine of TELEMAC 3D

area	X	Y	Z	X2	Y2	Z2	CE1	CE2	CS1	CS2	CV	C56	CV5	C5	CTRASH	LARG	HAUT	HAUT2	N	LENGTH	CLP
Anderstadt opwaarts	96299,56	347842,2	3,1	96304,28	347752,6	3,1	0,5	0,5	1	1	1	10	1,5	6	1	1,5	2,2	2,2	0,015	30	2
Anderstadt opwaarts	96260,09	347837,7	3,1	96288,53	347749,8	3,1	0,5	0,5	1	1	1	10	1,5	6	1	1,5	2,2	2,2	0,015	30	2

Figure 79 – Implementation of de-embankment Anderstadt I, FCA Anderstadt II and FCA Polder van Lier in the Scaldis 2050.



4.4 Computation time in TELEMAC

4.4.1 Problem

In the TELEMAC version V6P3 the sinks and sources are put on a specific node. When water is extracted or added to this node it is immediately done in communication with the neighboring nodes according to the finite element method. This procedure consumes a lot of computational power and poses problems for parallel computation if the sink or source node is on the boundary of one of the partial meshes.

The Scaldis model 2013 uses 40 culverts which translates into 40 sinks and 40 sources. The full deployment of the Sigmaplan in the Scaldis model 2050 includes an extra of 216 culverts, which given in total 256 culvert or 512 sinks and sources. This will demand a lot of extra computational power.

Example: on the KUL cluster we started a computation of the Scaldis 2050 model with 256 culverts. The time step was 4 seconds and 1 day was simulated on 180 (9x20) processors. This simulation took 9h05min31s which gives us a speed up time of 2,64.

In the same way we started a computation of the Scaldis 2013 model with only 40 culverts. The time step was 4 seconds and 1 day was simulated on 180 (9x20) processors. This simulation only took 2h49min25s, which gives us a speed up of 8,52!

4.4.2 Possible solutions?

“Dirac” sources

Flanders Hydraulics Research is cooperating with EDF in Paris on the implementation of the culvert subroutine in the latest version of TELEMAC (i.e. V7P2). This new version will only be released probably around December 2016, but the implementation of the code will be available before on the SVN. From version V7P1 in TELEMAC the user can choose an option for sinks and sources. This option lets the user select to use the so called “Dirac” sources. In contrast to the approach of sinks and sources in communication with their neighboring nodes, the “Dirac” nodes have no such communication and the exchange of water between sink and source is merely done by the two nodes (i.e. the sink node and the source node) itself. This has a significant effect on the speed of computation on handling a large number of sink and sources. A test was performed with the Scaldis model on 72 processors and 1 day was simulated (time step = 4s). 35 culverts were active (= 70 sinks and sources). The simulation with the Dirac option for sinks and sources was finished after 2 hours and 12 minutes, which gives us a speed up of 10,9. Without the Dirac option the simulation took 5 hours and a half, which gives a speed up of only 4,4. So we notice a big difference in computation time and we only activated 35 culverts.

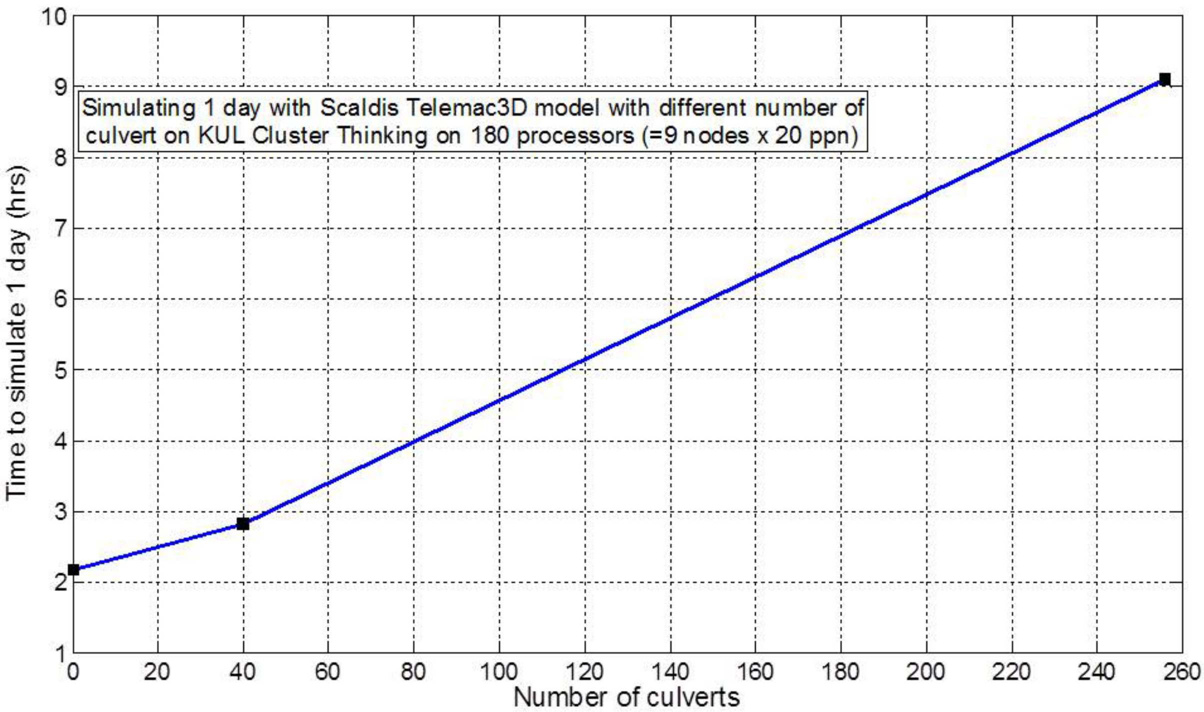
4.4.3 TELEMAC 3D Scaldis performance on increasing number of processors

Comparing the same simulation executed with different amounts of processors is difficult, because we noticed that the speed of the computation is highly dependent on the number of jobs already running on the cluster. On a cluster fully occupied with jobs the communication between the different nodes in parallel computation slows the computation down. This time delay is significant!

First we tested how the number of culverts influences the total computation time. Therefore we simulated 1 day with the Scaldis3D model on the KUL Cluster, Thinking, on 180 processors (= 9 nodes x 20 ppn).

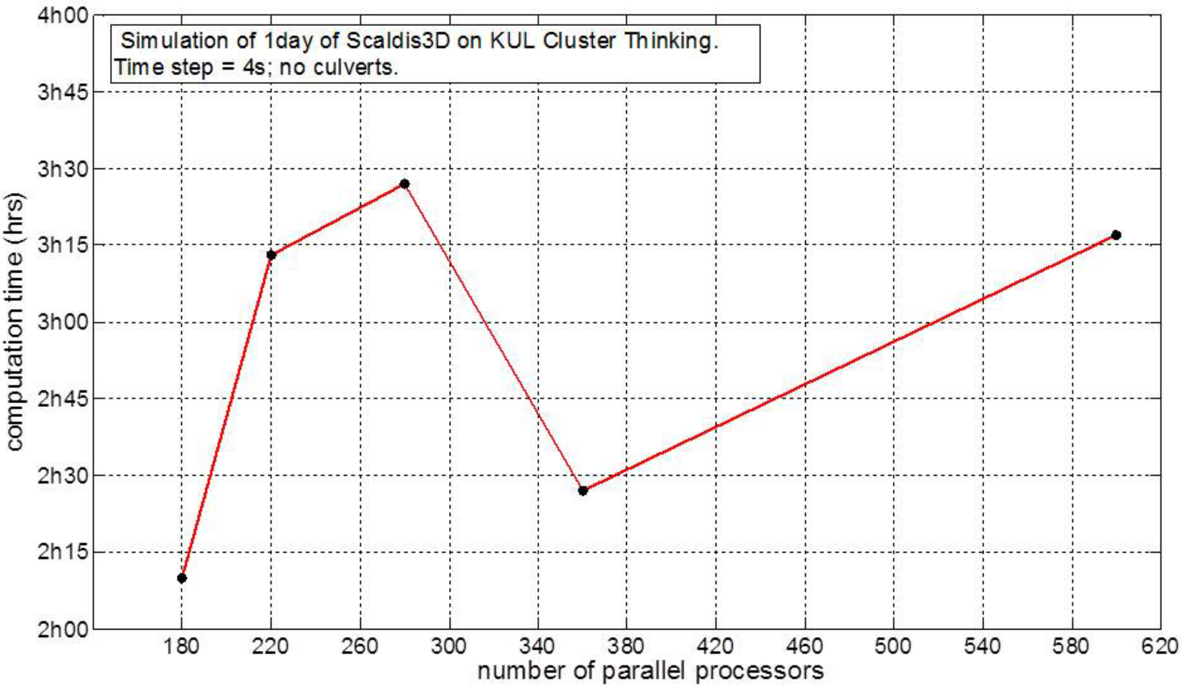
The time step of the computation was 4 seconds. The simulation was done without culverts, with 40 culverts (situation 2013) and with 256 culverts (situation 2050). Figure 80 shows the results graphically. Without a culvert the simulation took 130 minutes (speed-up time = 11,08). The simulation with 40 culverts (= 40 sinks and 40 sources) took 169 minutes (speed-up time = 8,52). The simulation with 256 culverts took 546 minutes (speed-up time = 2,64). These values are calculated based on three simulations. As we noted before, the simulation time is also highly dependent on the number of jobs running on the cluster, so simulations may take more or less time than the values given here! But they are a good indication of the computational cost of culverts in Scaldis 3D. These simulations were done before the Dirac function was available in TELEMAC.

Figure 80 – Computation cost of adding culverts (sinks and sources) to a TELEMAC 3D Scaldis simulation of 1 day.



In a second test the computational performance is tested while increasing the number of parallel processors. The same test case as above was used. No culverts were active. One day was simulated using 180, 220, 280,360 and 600 parallel processors. The simulation with 180 processors was the fastest. Figure 81 shows the results of this test. The results show no clear increase or decrease in computational cost when increasing the number of parallel processors. This shows that the speed of computation is highly dependent on other factors than the number of parallel processors. One of the reasons might be that communication between computation nodes is taking more time when more jobs are submitted on the cluster.

Figure 81 –TELEMAC 3D Scaldis model performance on KUL Cluster Thinking on different number of parallel processors.



4.5 Updated use of culvert formulations in TELEMAC v7p2

As mentioned before in section 4.4.2 Flanders Hydraulics Research wants to get the culverts formulations in the next official release of TELEMAC. To make the culvert formulations more generally applicable and accessible for other users, the Fortran code and implementation in TELEMAC was changed. The culvert formulations used in this project will be available in the next official release of TELEMAC v7p2. For this project the culvert formulations and the way head losses were implemented stay the same like described in Smolders et al. (2016), only the way they are implemented in the code has changed. For the simulations of scenarios in the project 13_131 Bevaarbaarheid Boven Zeeschelde, we will use a stable and tested subversion of the code of our own development branch, called Balloonfish. We will use revision 7378. We will discuss the changes here below and give information on how to use culverts in new simulations.

4.5.1 Reading culvert data file

The culvert formulations were implemented in an existing 2D subroutine called BUSE.f. All necessary information about the culverts is read from a text file like before, but the structure of this file changed. The text file is given by the keyword CULVERTS DATA FILE. This file will be read by an existing subroutine called LECBUS.f. This is a 2D subroutine that from now on will also be called by TELEMAC 3D if culverts are activated by the keyword NUMBER OF CULVERTS. The subroutine was changed in order to be able to read new variables from the file necessary for the different culvert formulations that will be implemented in BUSE.f.

The first line in this text file is a line for text and is skipped by the subroutine. Typically it says “Relaxation” and “Number of Culverts”; because those are the parameters put on the next line. On line two the first number gives a value for relaxation (= a number between 0 and <1; explained in the next section) followed by a space and a number indicating the number of culverts. This last number will be used to check the keyword NUMBER OF CULVERTS; so make sure they have the same numerical value. The next line is again a text line that will be skipped by the subroutine. It gives information about the parameters on the next lines. For our model this text line looks like:

I1 I2 CE1 CE2 CS1 CS2 LRGbus HAUT1 CLP LBUS Z1 Z2 CV C56 CV5 C5 Ctrash HAUT2 FRIC L CIRC

with:

I1	Node number of culvert end in the river
I2	Node number of culvert in the polder area
CE1	head loss coefficient for the culvert end in the river (1) when flow is entering
CE2	head loss coefficient for the culvert end in the polder (2) when flow is entering
CS1	head loss coefficient for the culvert end in the river (1) when flow is exiting
CS2	head loss coefficient for the culvert end in the polder (1) when flow is exiting
LRGBUS	width of the culvert
HAUT1	Height of culvert at river side (1)
CLP	imposed flow direction
LBUS	combined head loss for flow under a bridge (when OPTION FOR CULVERTS=1)
Z1	Bed level of culvert at river side (1)
Z2	Bed level of culvert at polder side (2)
CV	head loss coefficient due to the presence of a valve

C56	constant used to differentiate flow types 5 and 6
CV5	correction coefficients to C1 and to CV coefficients due to the occurrence of the type 5 flow
C5	correction coefficients to C1 and to CV coefficients due to the occurrence of the type 5 flow
Ctrash	head loss coefficient due to the presence of trash screens
HAUT2	Height of culvert at polder side (2)
FRIC	Manning friction coefficient for culvert wall friction
L	Length of the culvert
CIRC	Give value 1 for circular culverts and zero for rectangular.

Compared to the parameters discussed in Smolders et al. (2016) section 6 there are three major differences:

1. The sinks and sources are given by the node number and no longer by the coordinates. The coordinates had to be correct to 8 decimals. Every time a small change was made to the geometry file and this file was saved again the decimals changed slightly resulting in errors when the same culvert file was used as before. This problem is now solved by giving the node numbers. Be aware that if the grid itself is changed by adding nodes or removing nodes, that the numbering will change and a new culvert file, with the appropriate node numbers has to be made.
2. LBUS is a parameter used for flow under a bridge in the subroutine BUSE.f. It is not used for our culvert formulations. In the culvert file you can give it any value you like; it will not be used.
3. CIRC is a parameter that differentiates between circular or rectangular culverts. If the cross section is circular one should give a value of 1 to this parameter. If the cross section is square or rectangular one should give the value 0 to this parameter.

Note that the order of these parameters is important and is different from the order mentioned in Smolders et al. (2016).

After this third line, every next line represents one culvert and all parameter values for this culvert should be given in the correct order.

4.5.2 The subroutine BUSE.f

This subroutine existed already in TELEMAC 2D and was used to simulate flow under bridges. The formulations used are similar to the culvert formulations of Bodhaine (1968). We make use of the existing structure of this subroutine to add our own formulations. To differentiate between the existing formulations and the new Bodhaine (1968) formulations a new keyword was added, OPTION FOR CULVERTS. When this keyword is given the value 1, the original formulations of the subroutine will be used (to simulate flow under a bridge) and when the value 2 is given to the keyword the culvert formulations according to Bodhaine (1968) will be used. The Bodhaine culvert formulations were discussed and shown in Smolders et al. (2016) and were not changed when implemented in this subroutine. Some stability and precautionary measures were also implemented. In the next list we report the most important changes or implementations:

- A maximum discharge per time step is set as 90% of the available water in the node of interest.
- Circular culverts are taken into account if present
- The keyword OPTION FOR CULVERTS can have only the values 1 or 2. If another value is assigned to this keyword an error message will report this to the user.

- An extra loop checks if water levels are above the lowest z level of both culvert ends. It will equal the discharge to zero if the water level doesn't reach the nozzles.
- If the height of one of the ends of the culvert is zero, the discharge will be zero
- Relaxation: the following formula is used for relaxation of the results: $Q_t = r * Q_{t-1} + (1-r) * Q_t$ where r is the relaxation parameter given in the culverts data file. This relaxation parameter needs to be smaller than 1.
- If the flow direction is not according to the assigned flow direction possibilities, the discharge will be set to zero.
- It is possible to use other sinks and sources apart from the culverts.

Apart from these extras, also flow velocities at the source points are calculated and tracers can pass the culverts.

Although this was a subroutine for TELEMAC 2D it is now (Balloonfish revision 7378) called by TELEMAC 3D if the culverts are activated. So the same culvert formulation according to Bodhaine (1968) is now available in TELEMAC 2D and 3D.

5 Grid adaptation

Different bathymetries will be implemented in the Scaldis model for the calculation of different alternatives. This chapter describes the changes to the model grid that were done for the calculation of the B variants: 'Schaaf', 'VAH schaaf' and 'VAG plus RV'. Bathymetry for these variants was provided by IMDC and was converted from Lambert 1972 to RD Paris projected coordinate system. The complete list of scenarios is given in chapter 8.

5.1 Changes in the model grid

The model grid is adapted so that it can be used for the calculation of all B variants. The outline of the previous grid (Scaldis 2013) was compared to the dike or levee lines in the bathymetry of the variants B to find zones where the model grid had to be extended or refined. All the necessary adaptations for all the B variants are combined in one grid so the scenario results can easily be compared one on one.

The new grid has 472400 nodes in 2D and 898372 elements. This is 12708 nodes more than the grid of Scaldis 2013 (in 2D). In 3D (5 levels) the new model grid has 2,362,000 nodes in total. Figure 82 and Figure 83 show an overview of the zones where the model grid was changed. Figure 84 to Figure 124 show the changes made to the model grid. The old grid is presented in blue color; the new grid is red.

Figure 82 – Zones where the model grid is adapted downstream Schoonaarde

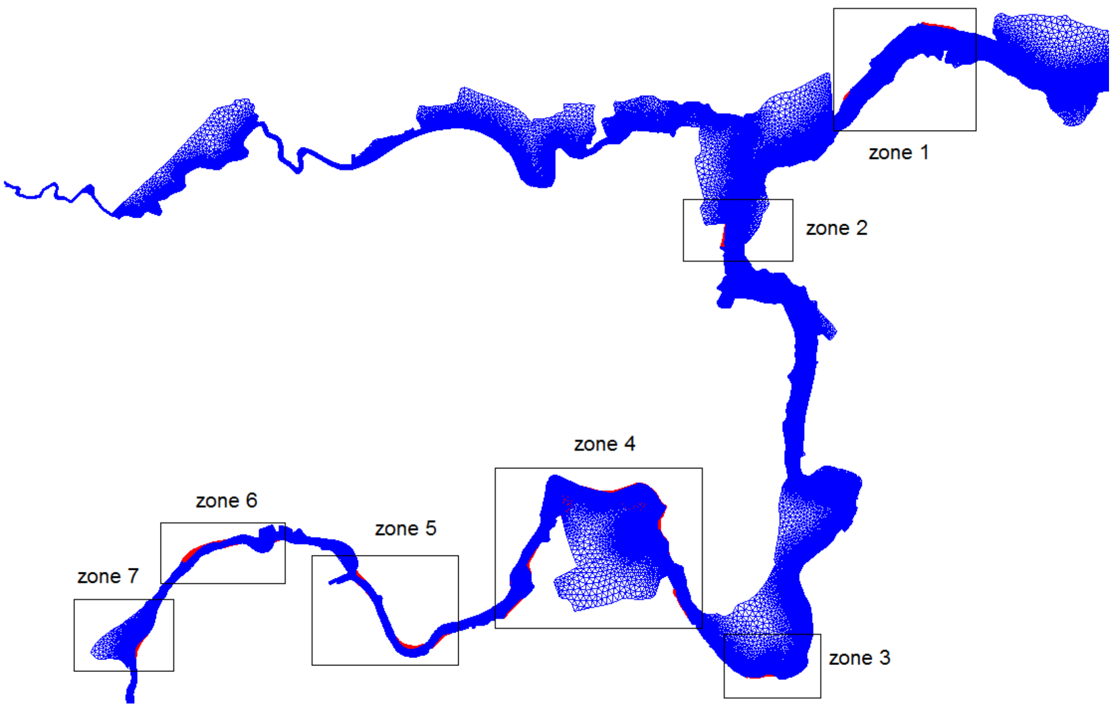


Figure 83 – Zones where the model grid is adapted upstream Schoonaarde

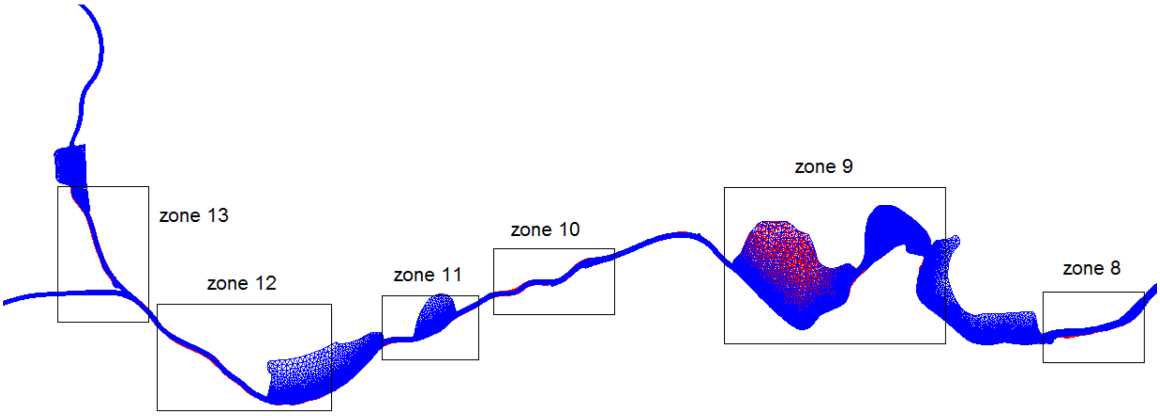


Figure 84 – Changes in the model grid in zone 1

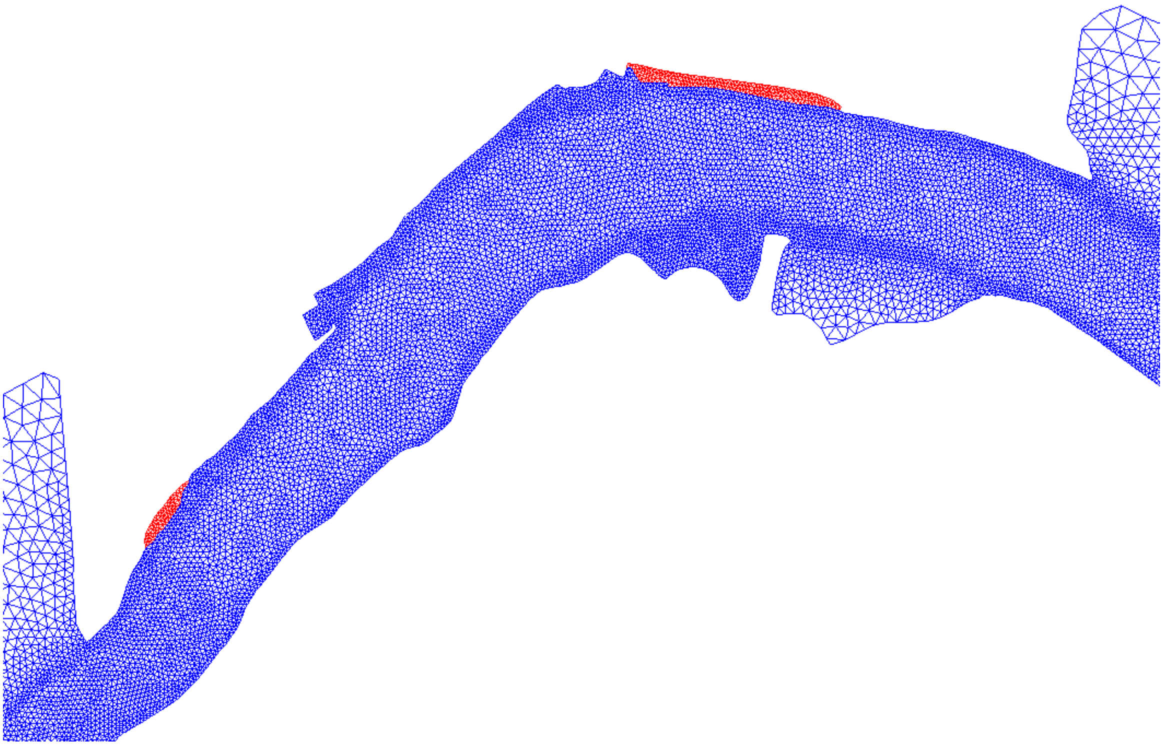


Figure 85 – Bathymetry in VAG plus in zone 1 (m TAW)

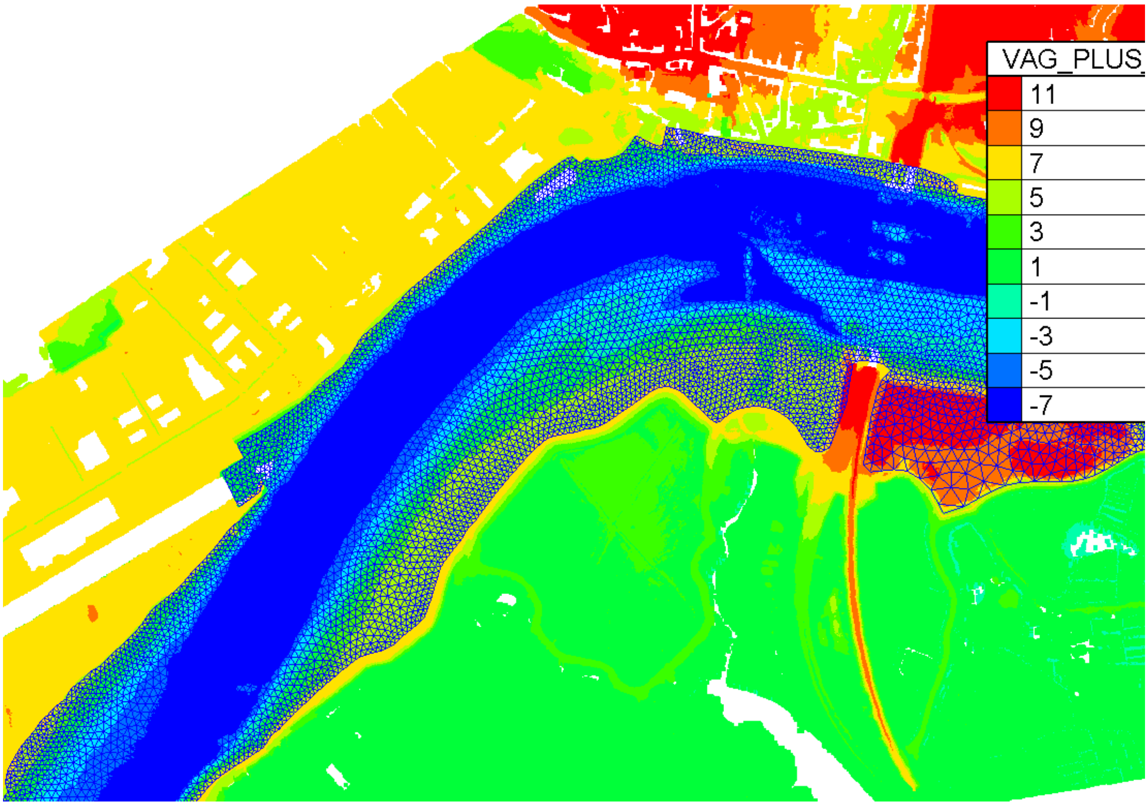


Figure 86 – Changes in the model grid in zone 2

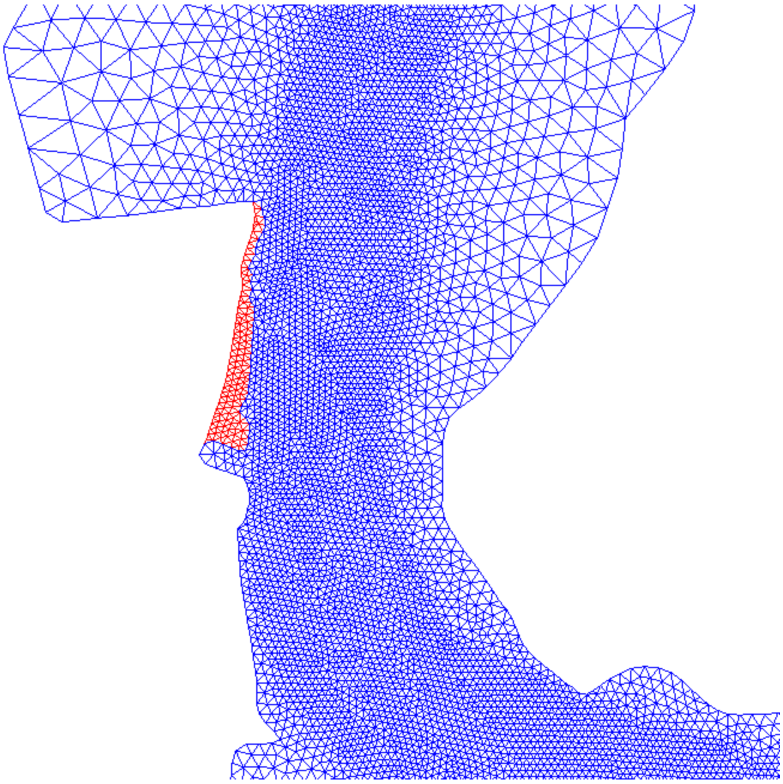


Figure 87 – Bathymetry in VAG plus in zone 2 (m TAW)

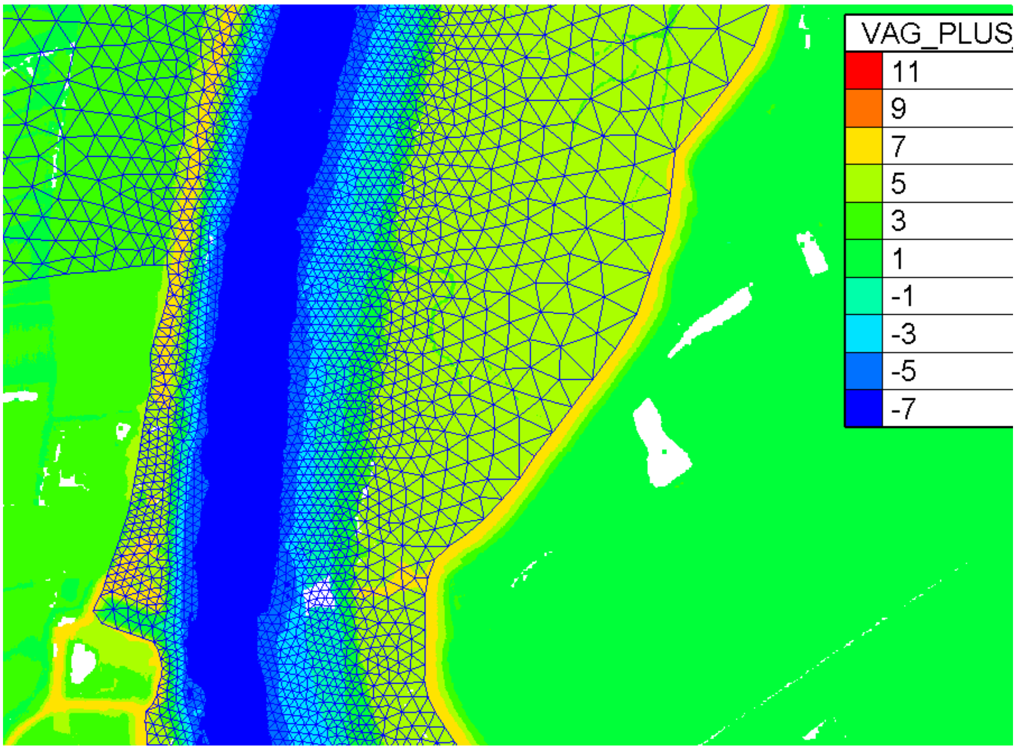


Figure 88 – Changes in the model grid in zone 3

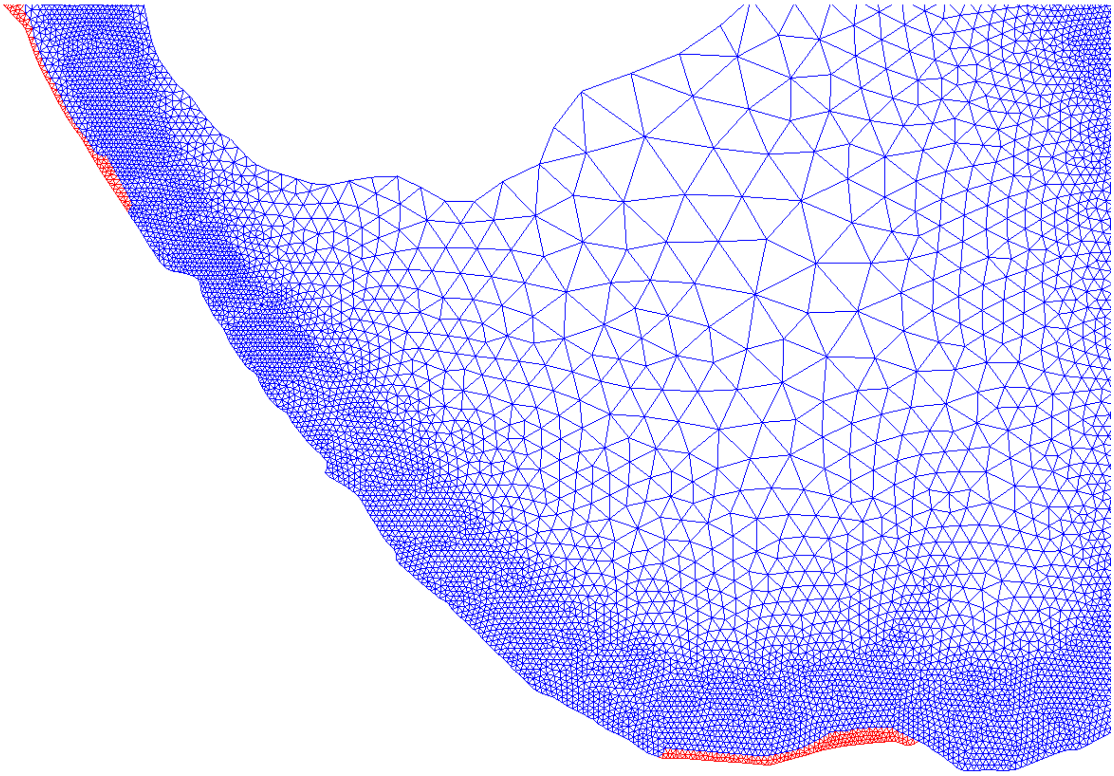


Figure 89 – Bathymetry in VAG plus in zone 3

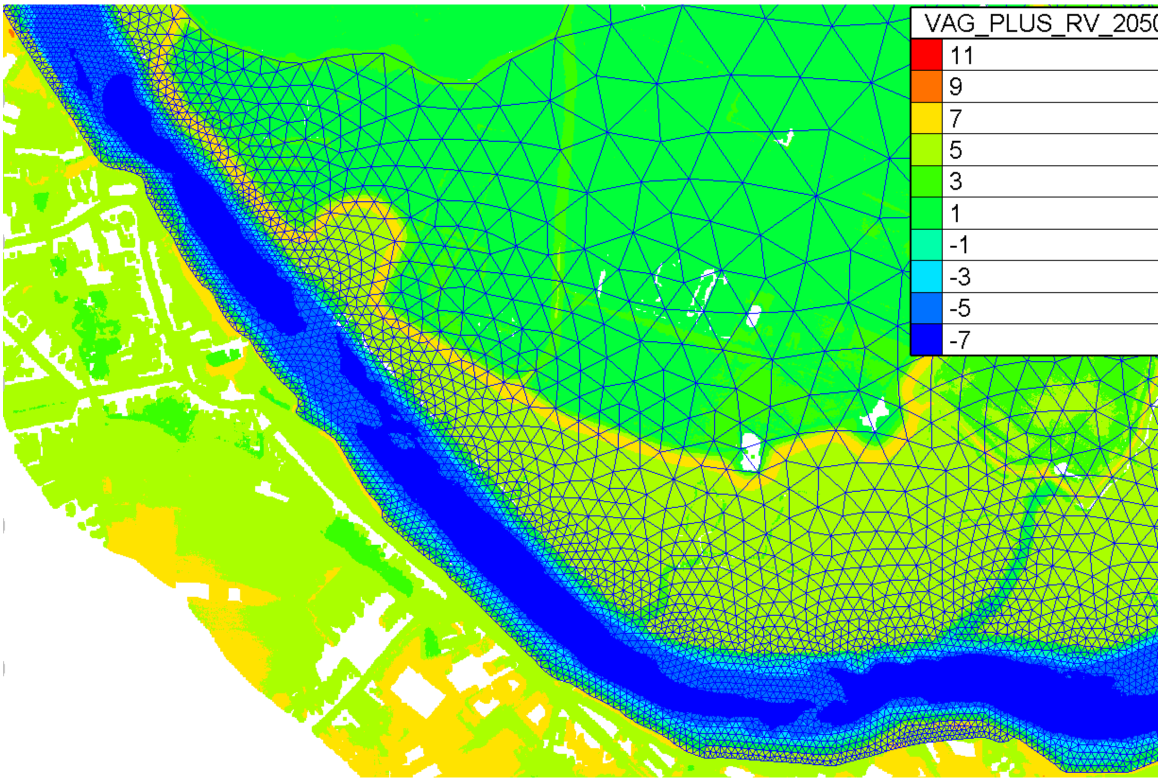


Figure 90 – Changes in the model grid in zone 4

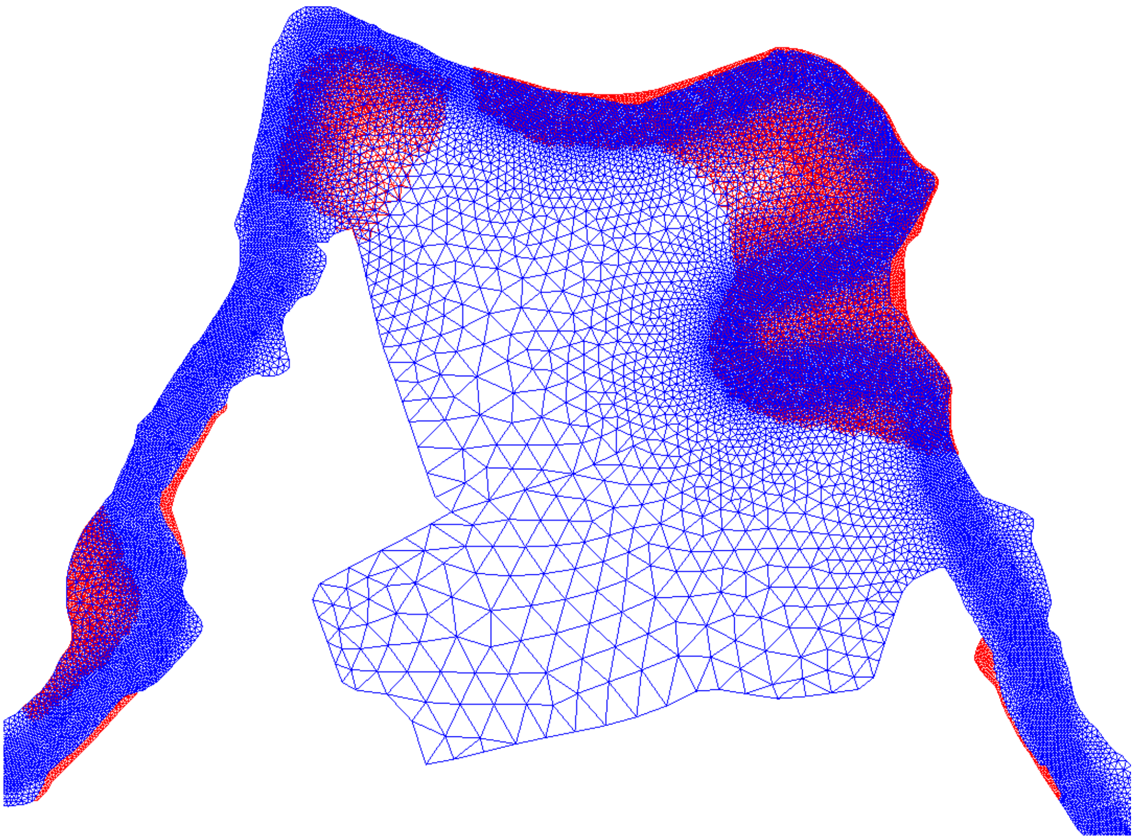


Figure 91 – Changes in the model grid in zone 4 near Kramp

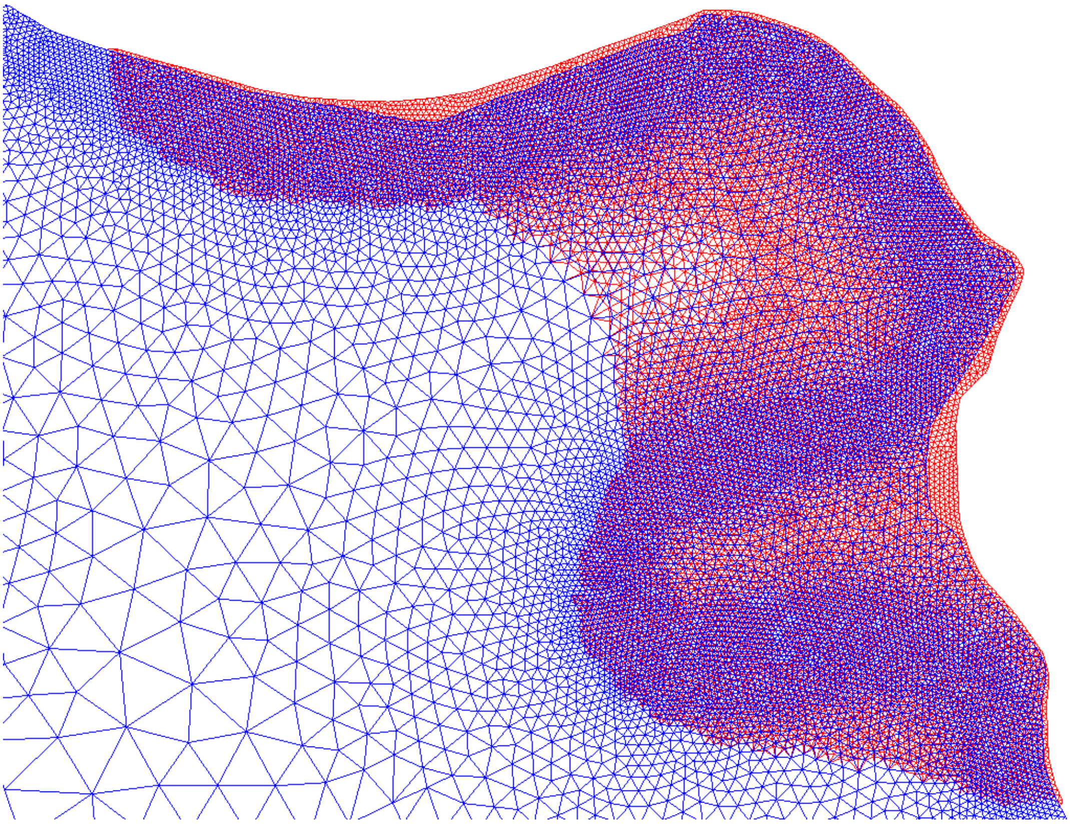


Figure 92 – Bathymetry in VAG plus in zone 4 near Kramp (m TAW)

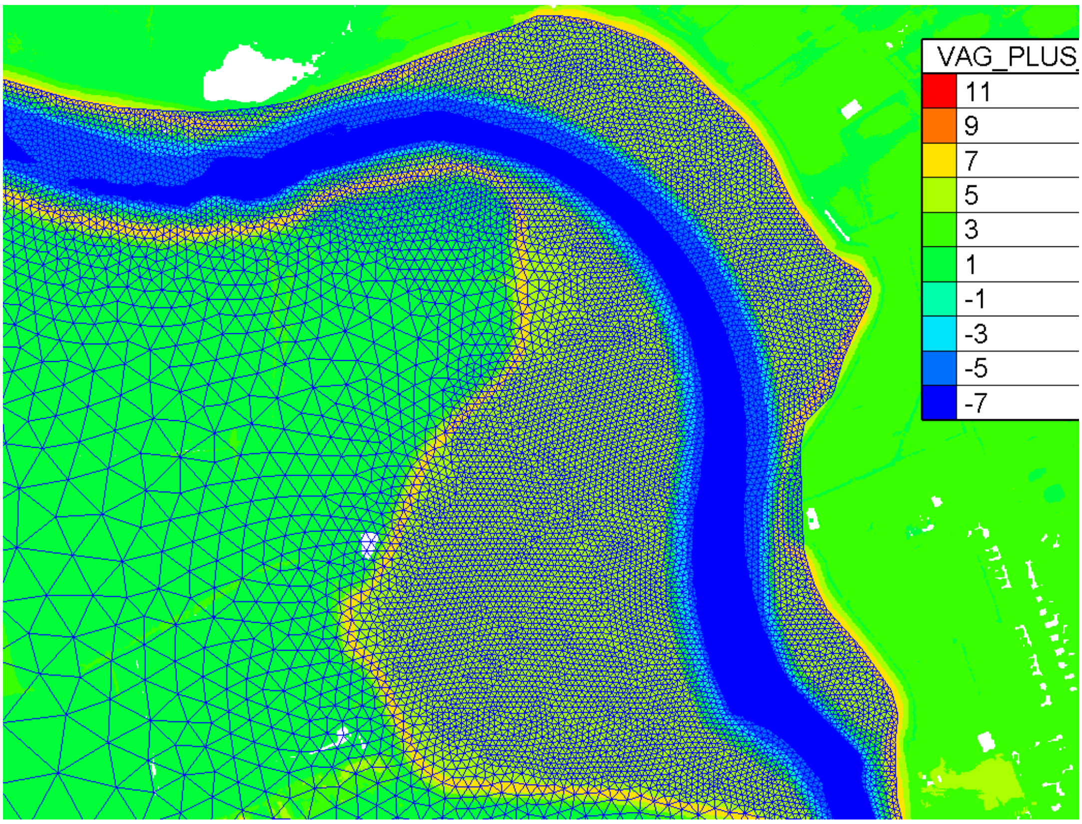


Figure 93 – Bathymetry in Schaaf in zone 4 near Kramp (m TAW)

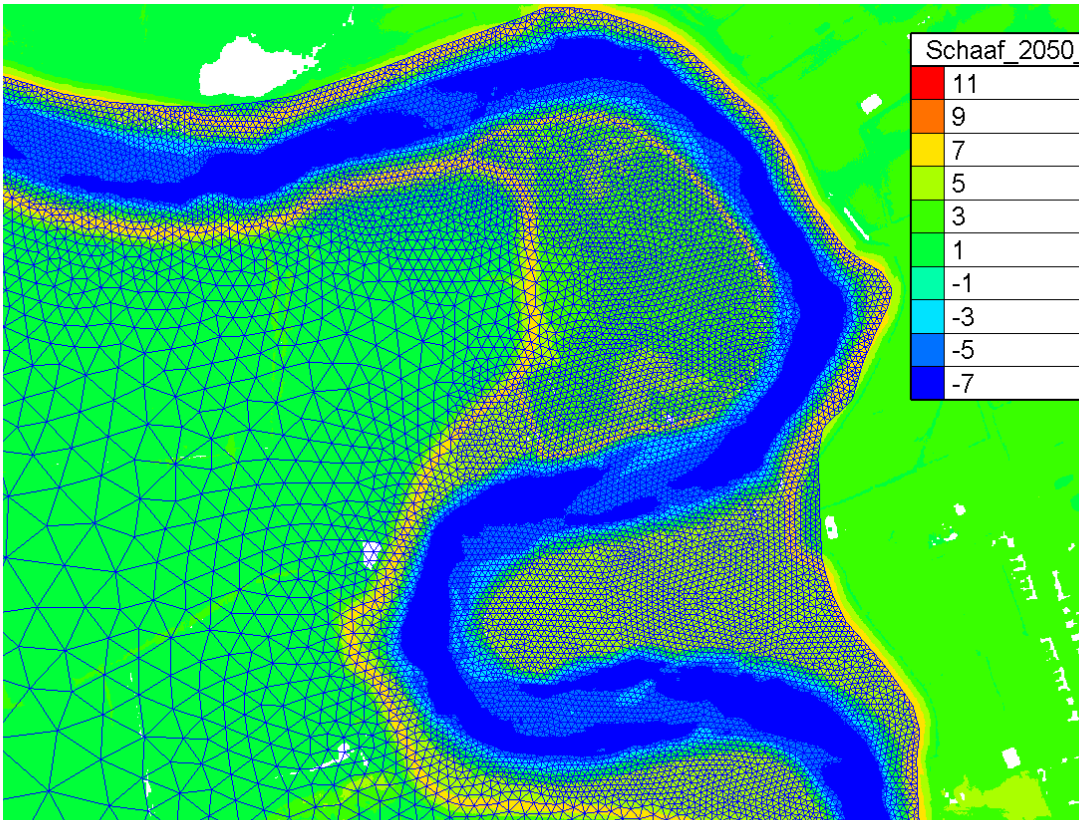


Figure 94 – Changes in the model grid in zone 4 upstream Kramp

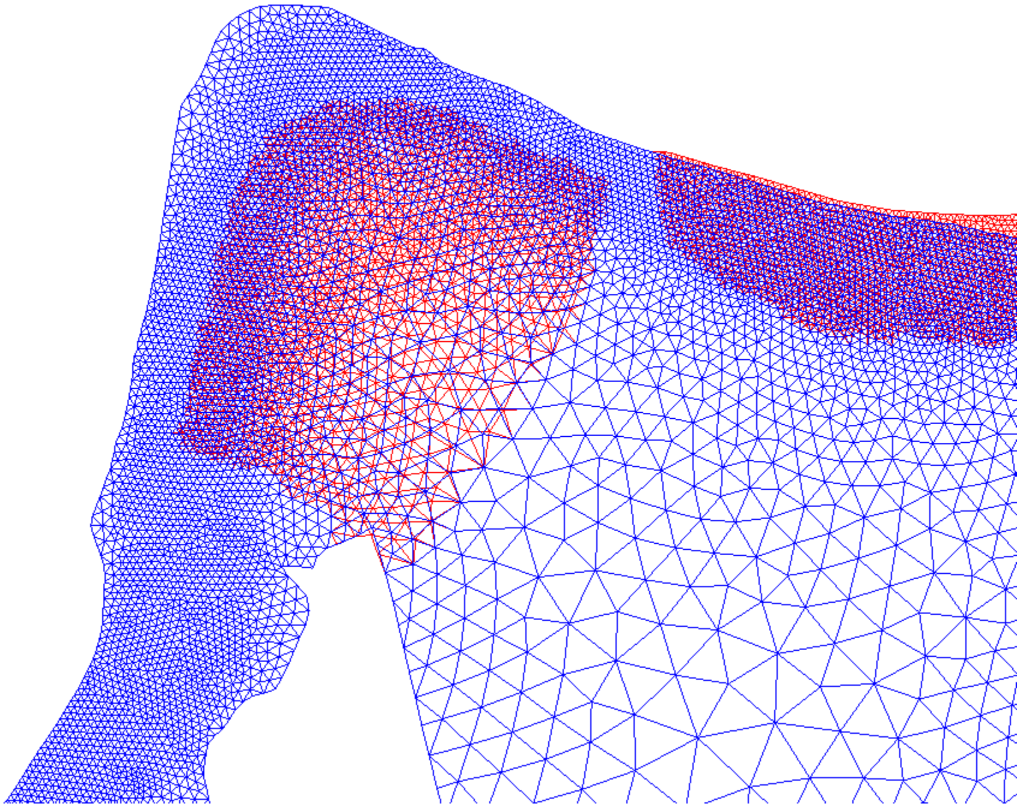


Figure 95 – Bathymetry in VAG plus in zone 4 upstream Kramp

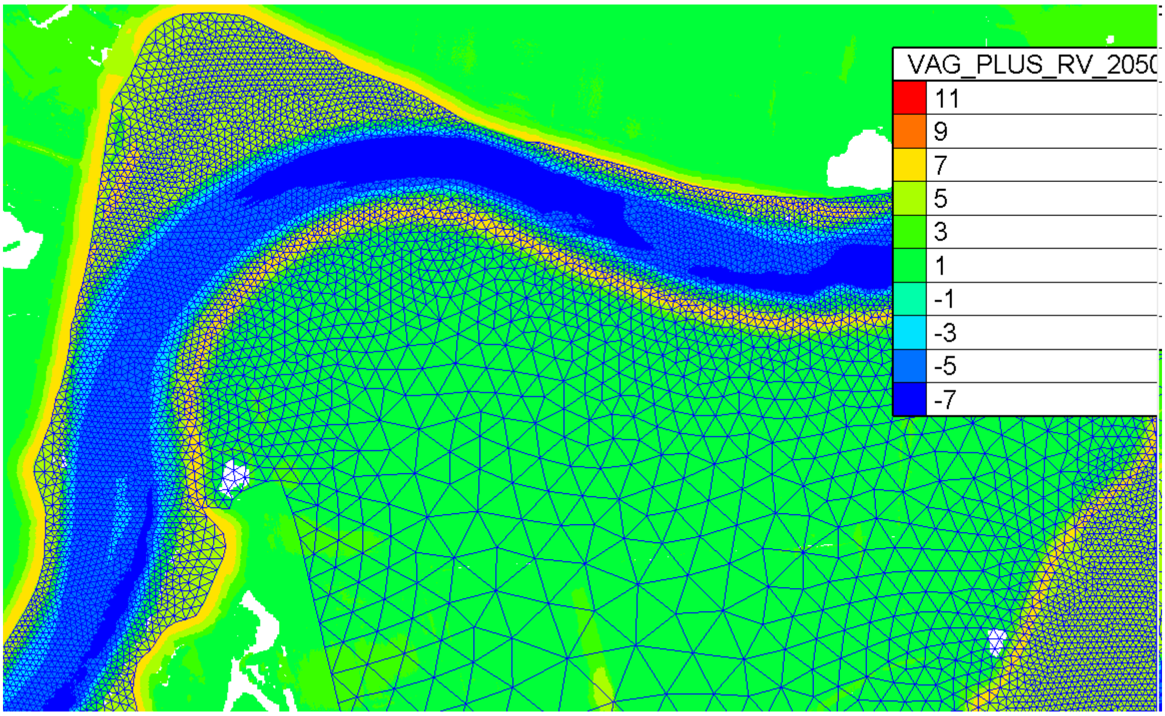


Figure 96 – Bathymetry in Schaaf in zone 4 upstream Kramp

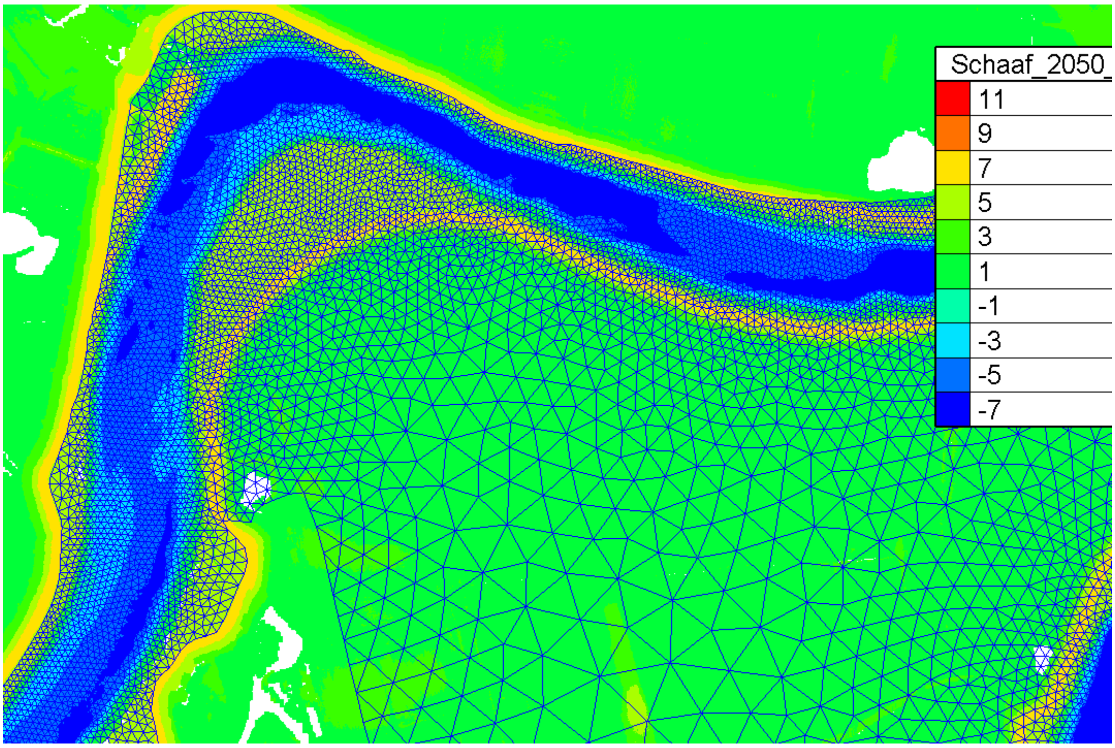


Figure 97 – Changes in the model grid in the upstream part of zone 4

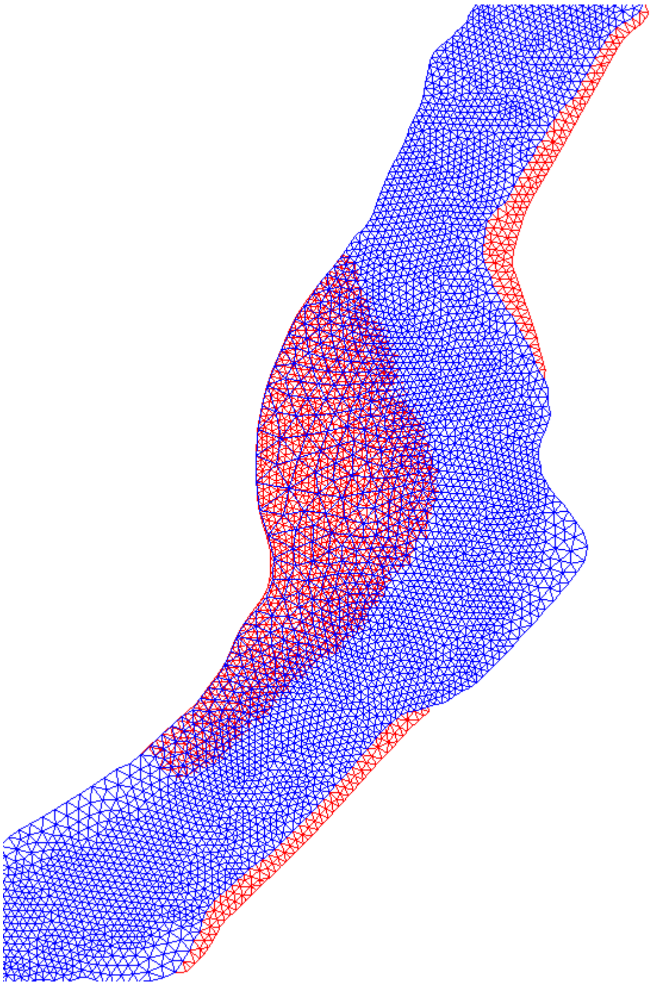


Figure 98 – Bathymetry in VAG plus in the upstream part of zone 4 (m TAW)

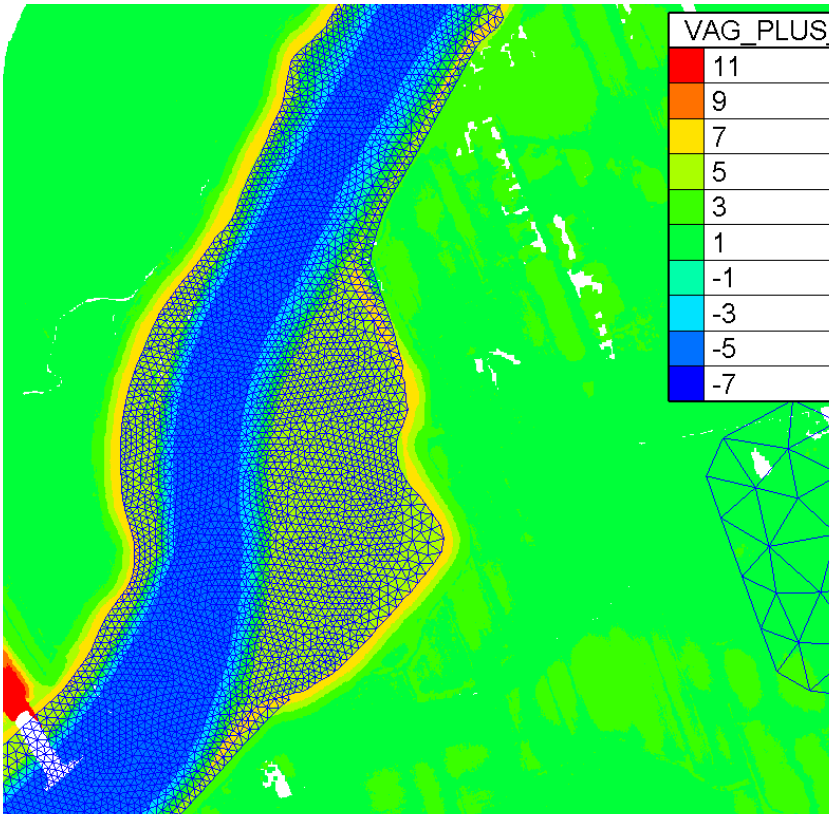


Figure 99 – Bathymetry in Schaaf in the upstream part of zone 4 (m TAW)

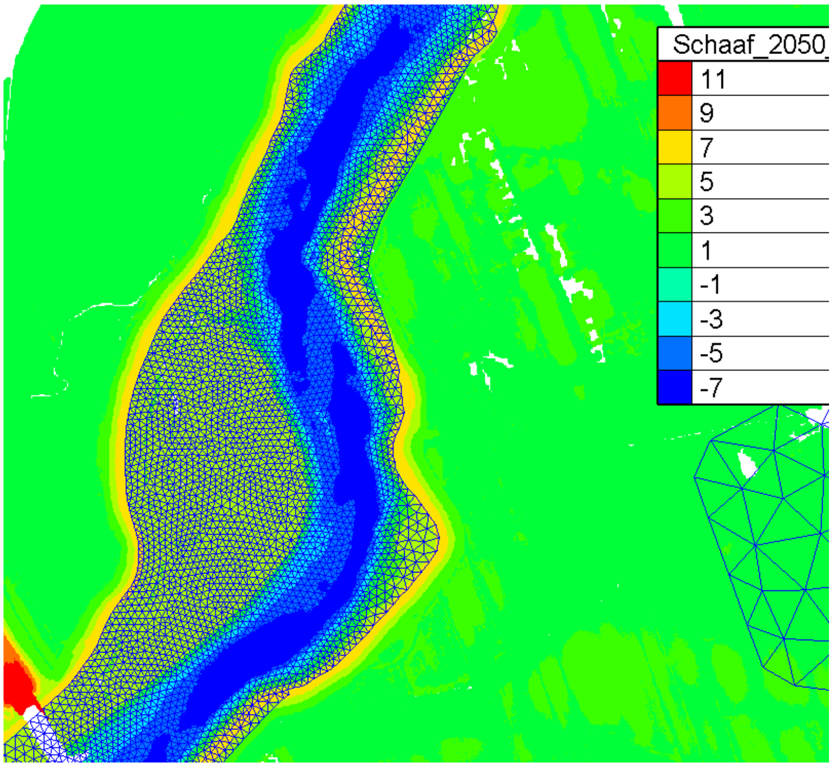


Figure 100 – Changes in the model grid in zone 5

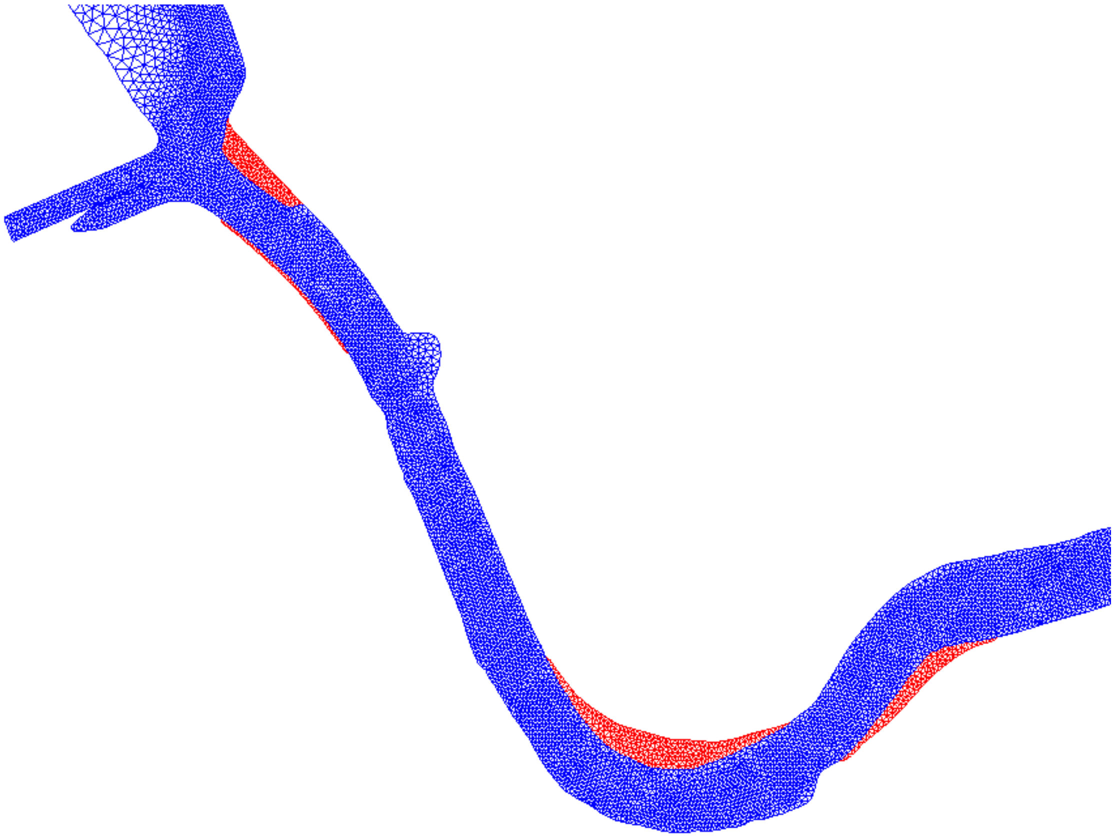


Figure 101 – Bathymetry in VAG plus in the downstream part of zone 5 (m TAW)

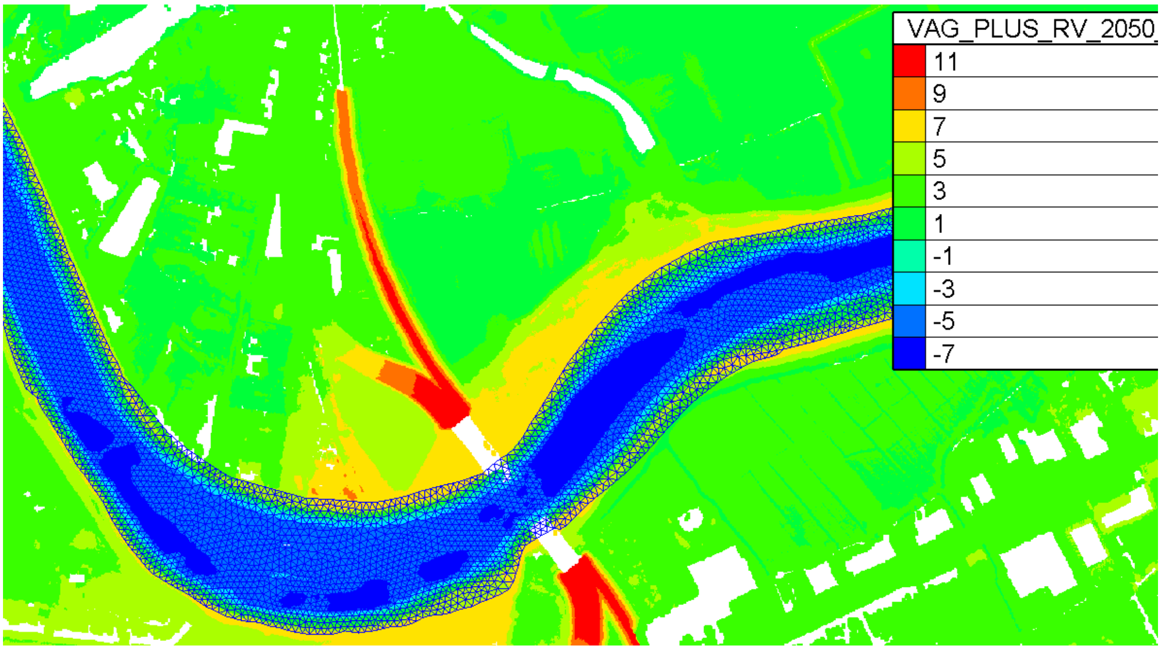


Figure 102 – Bathymetry in Schaaf in the downstream part of zone 5 (m TAW)

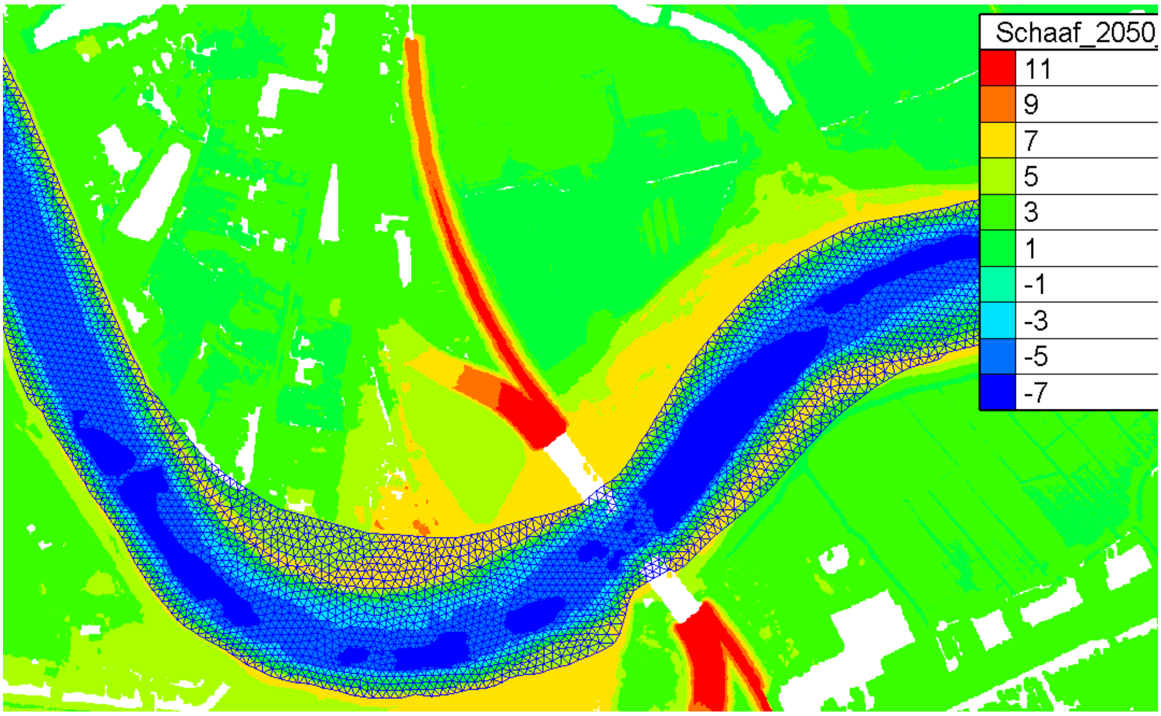


Figure 103 – Bathymetry in VAG plus in the upstream part of zone 5 (m TAW)

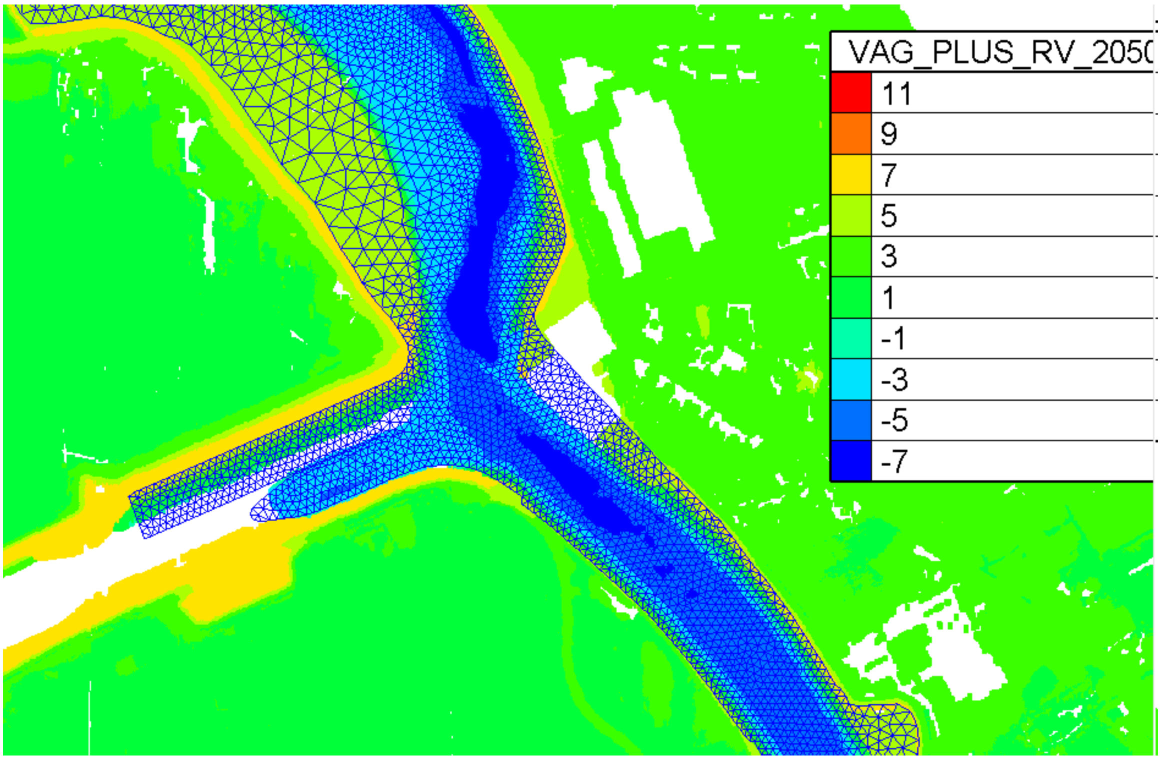


Figure 104 – Bathymetry in Schaaf in the upstream part of zone 5 (m TAW)

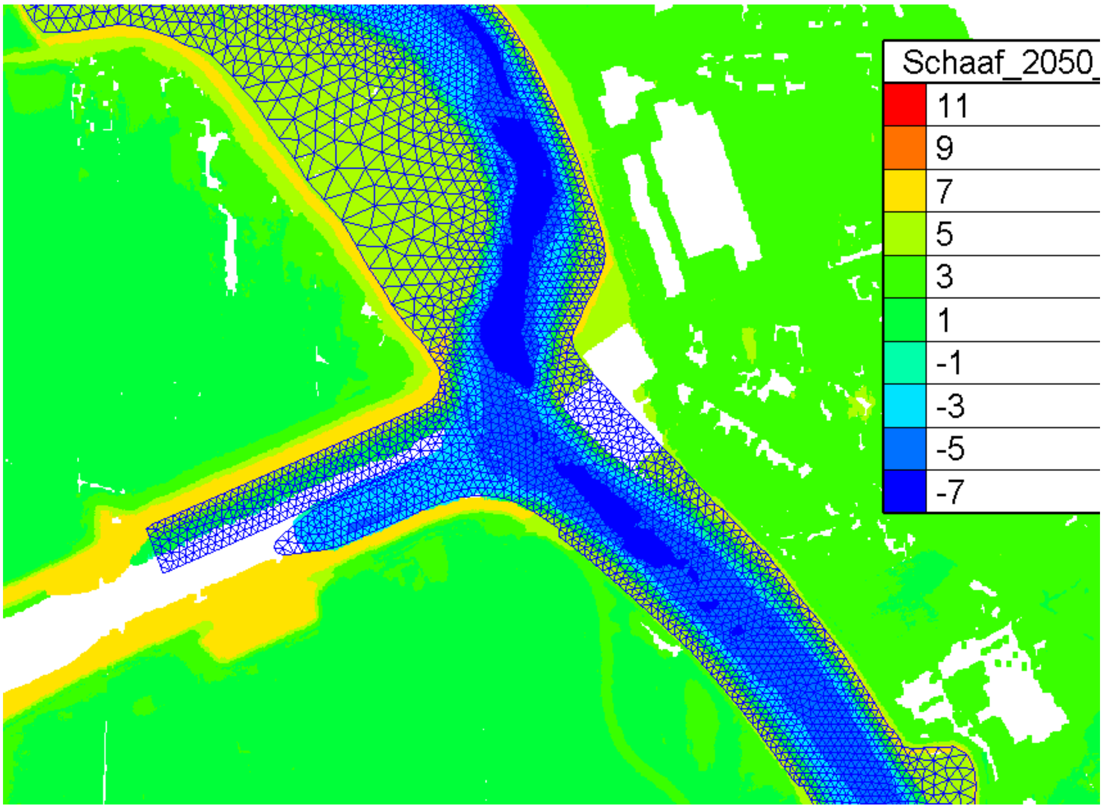


Figure 105 – Changes in the model grid in zone 6

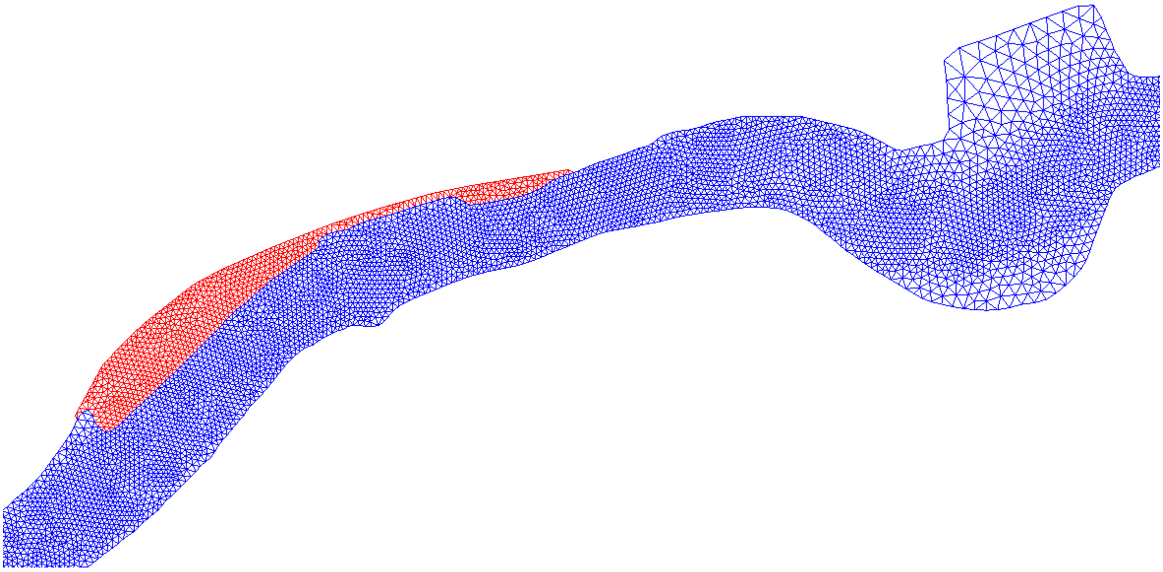


Figure 106 – Bathymetry in VAG plus in zone 6 (m TAW)

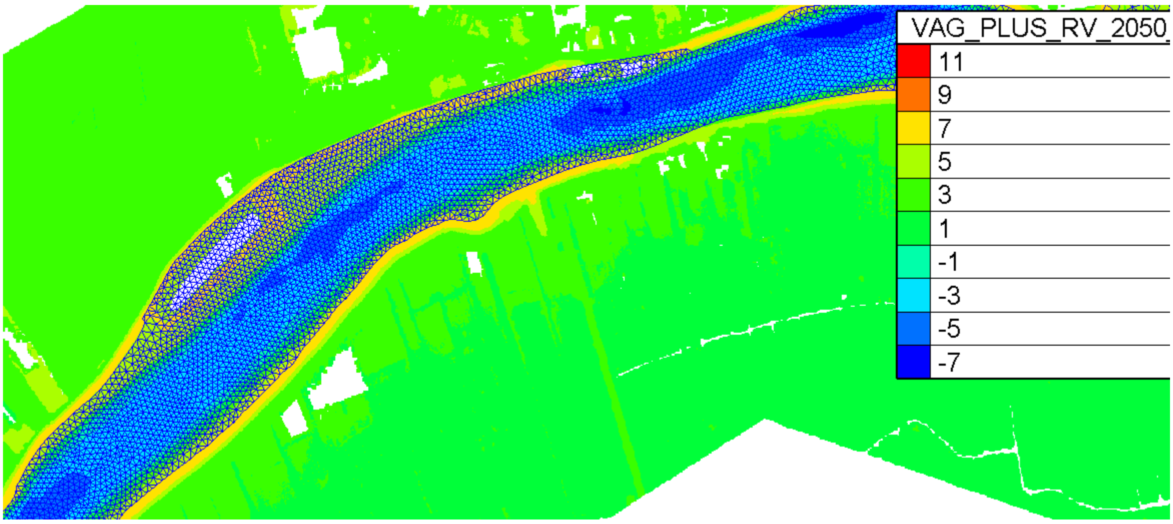


Figure 107 – Changes in the model grid in zone 7

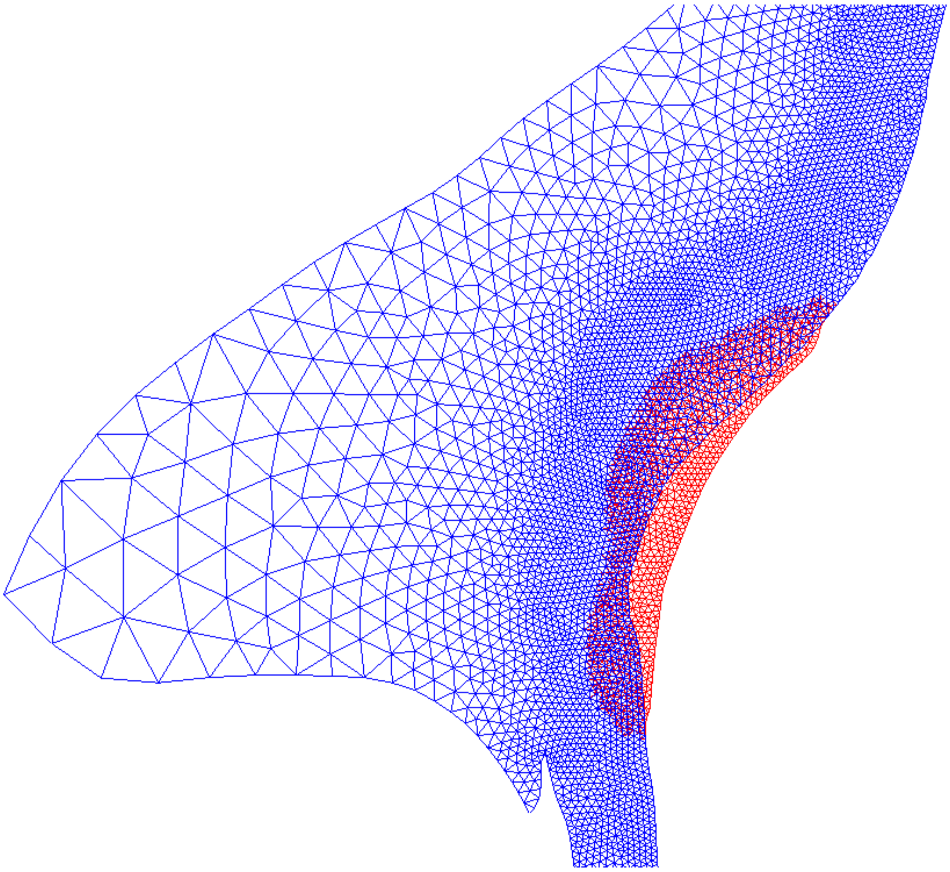


Figure 108 – Bathymetry in VAG plus in zone 7 (m TAW)

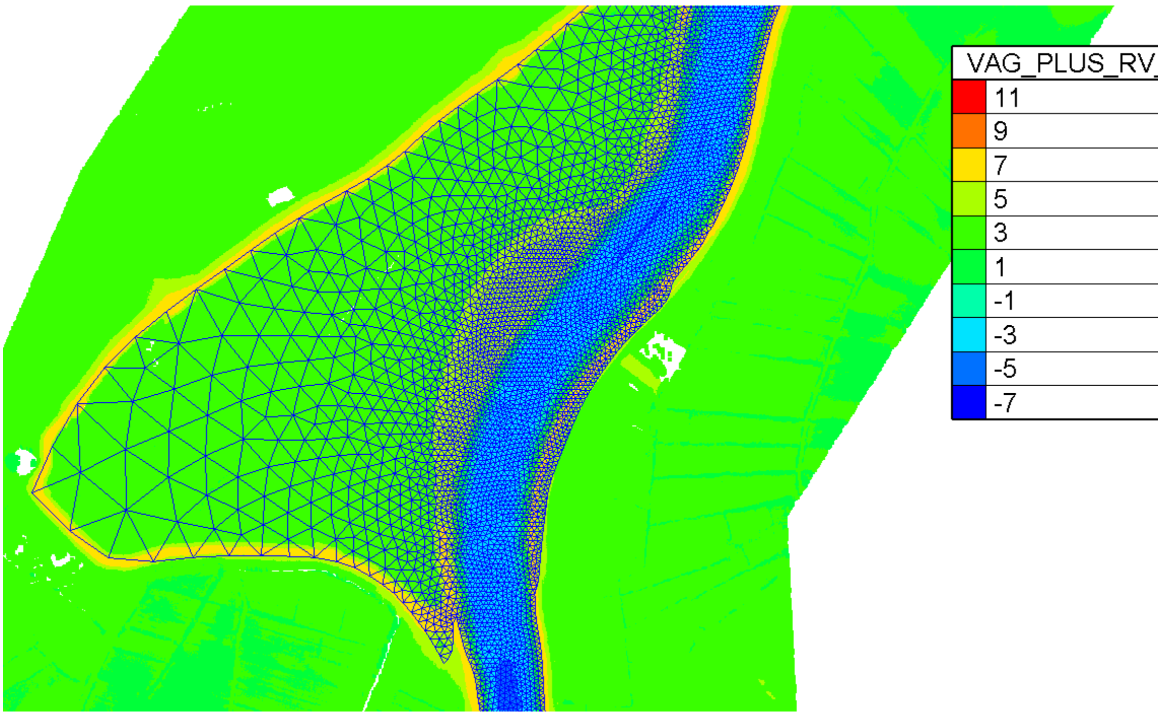


Figure 109 – Bathymetry in Schaaf in zone 7 (mTAW)

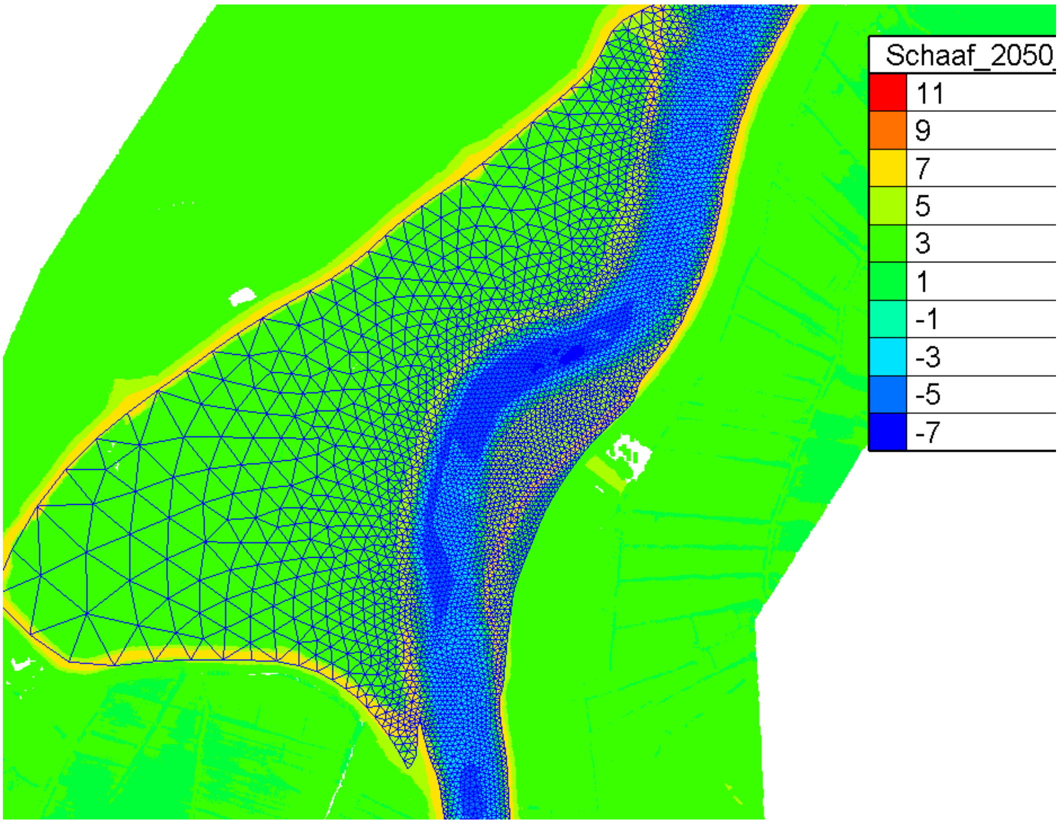


Figure 110 – Changes in the model grid in zone 8

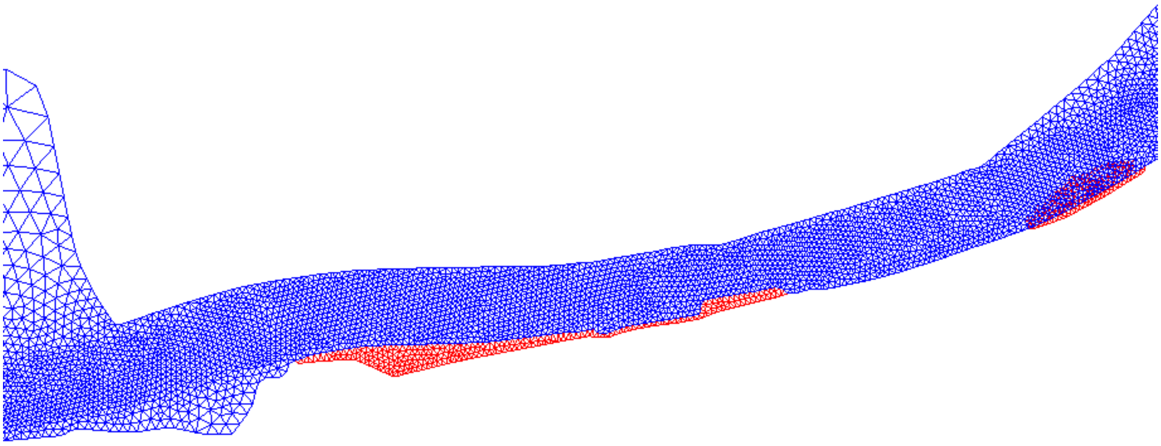


Figure 111 – Bathymetry in VAG plus in zone 8 (m TAW)

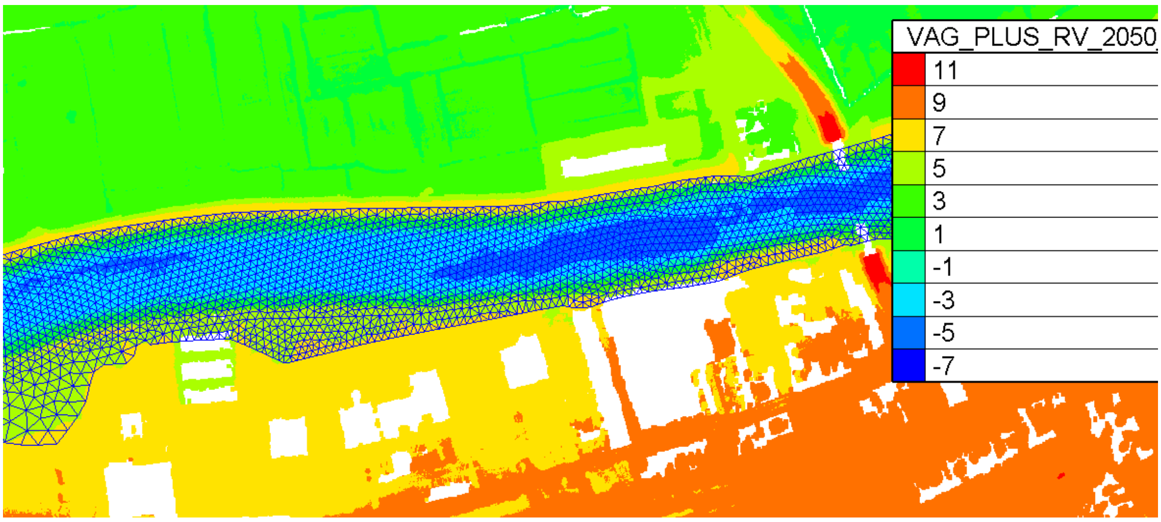


Figure 112 – Changes in the model grid in zone 9

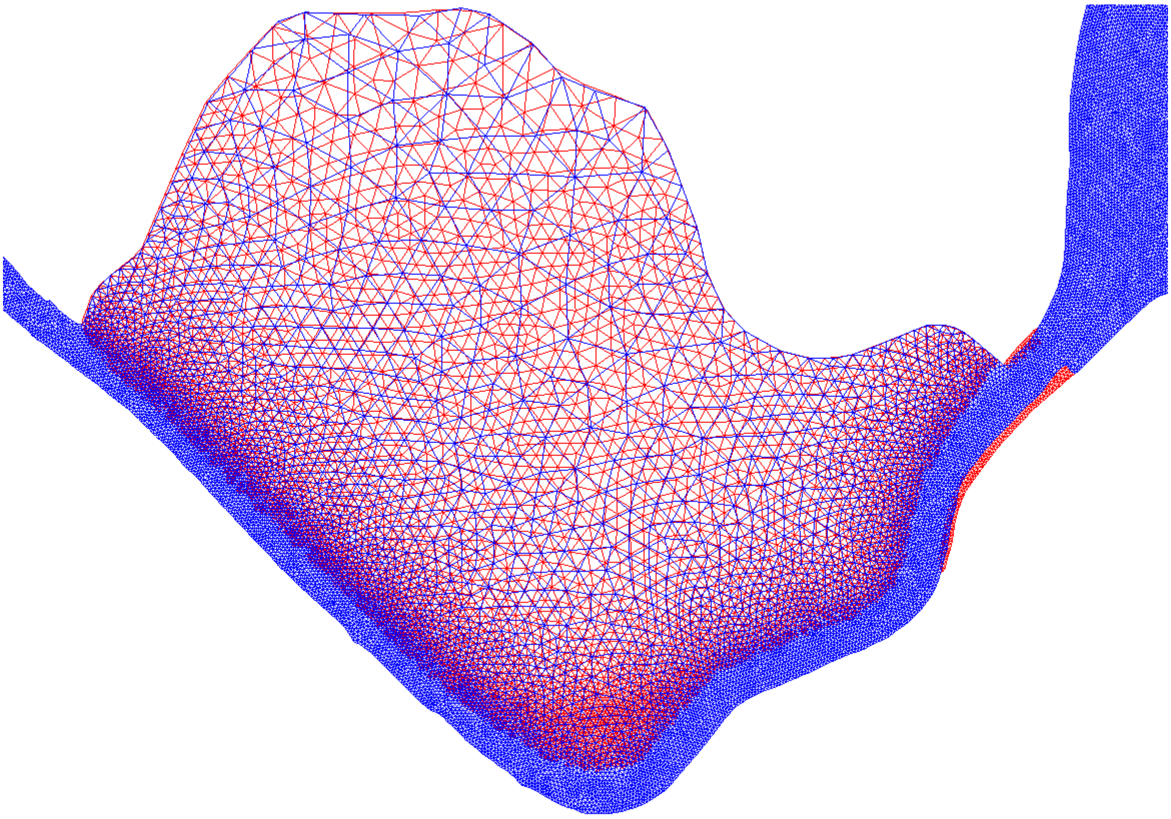


Figure 113 – Changes in the model grid in zone 9 (zoom)

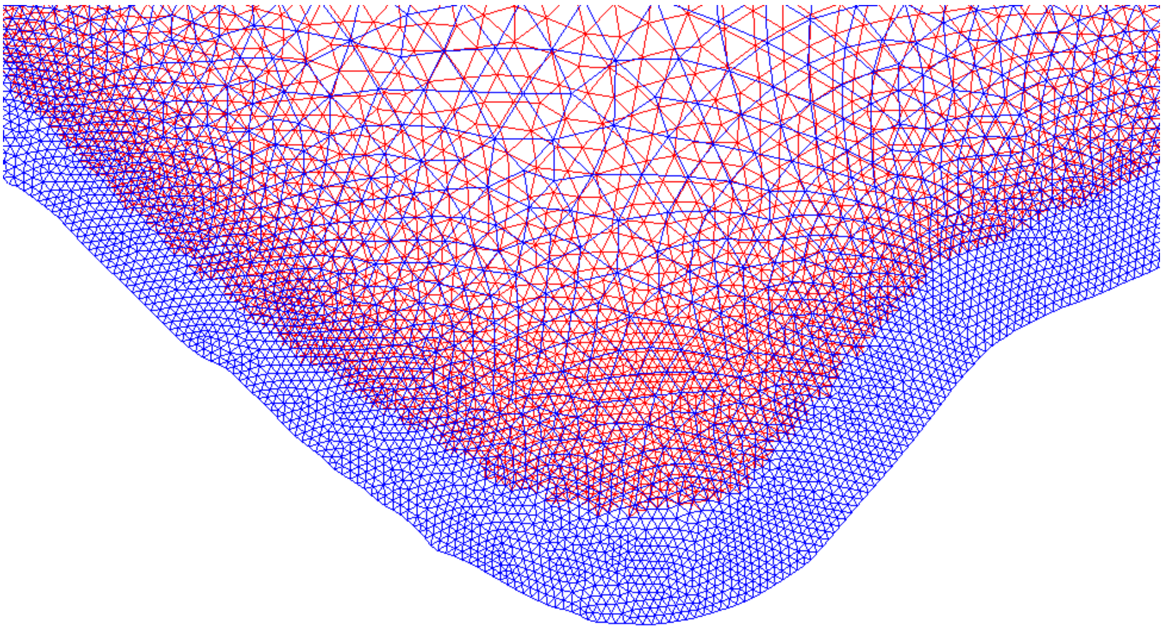


Figure 114 – Bathymetry in VAG plus in zone 9 (mTAW)

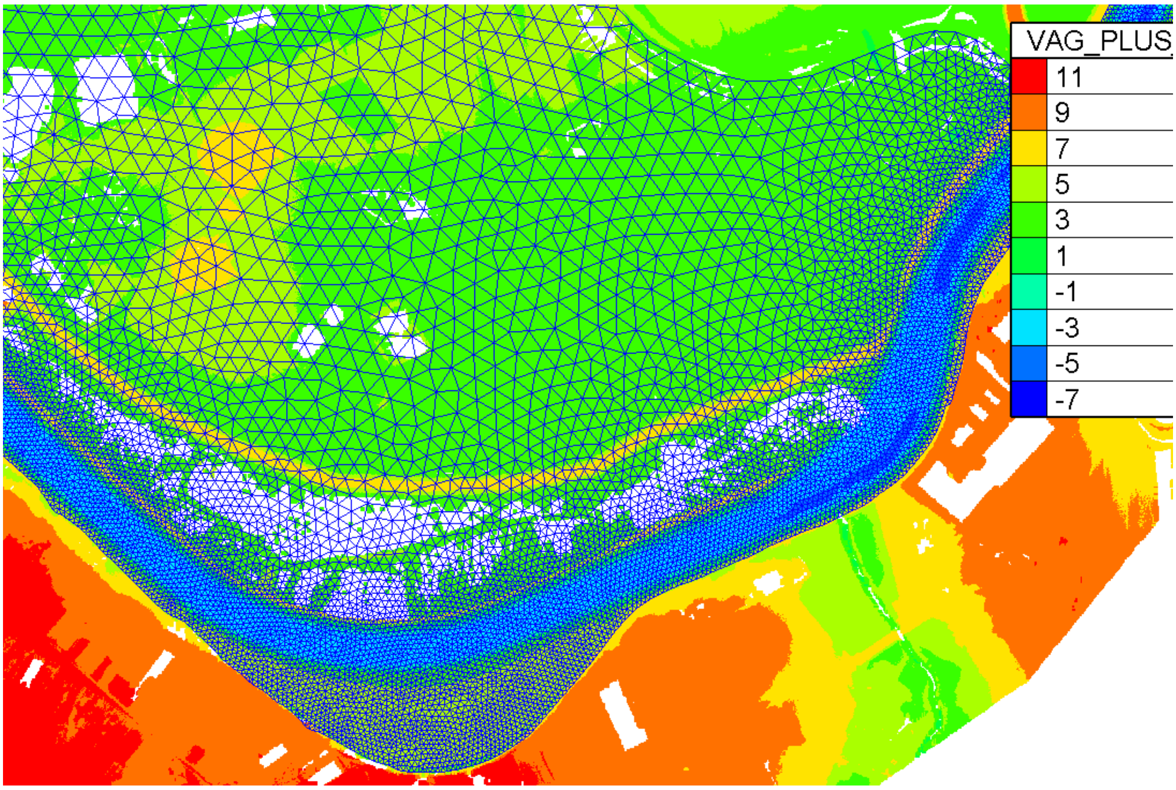


Figure 115 – Bathymetry in Schaaf in zone 9 (m TAW)

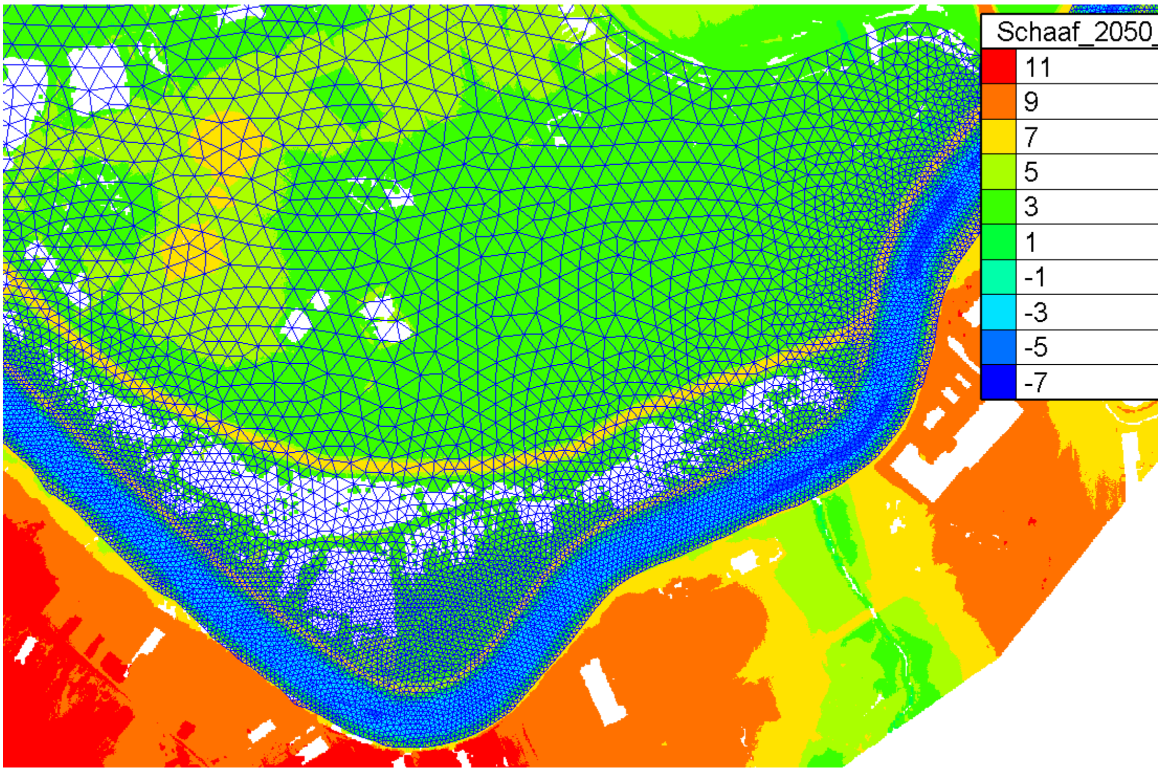


Figure 116 – Changes in the model grid in zone 10

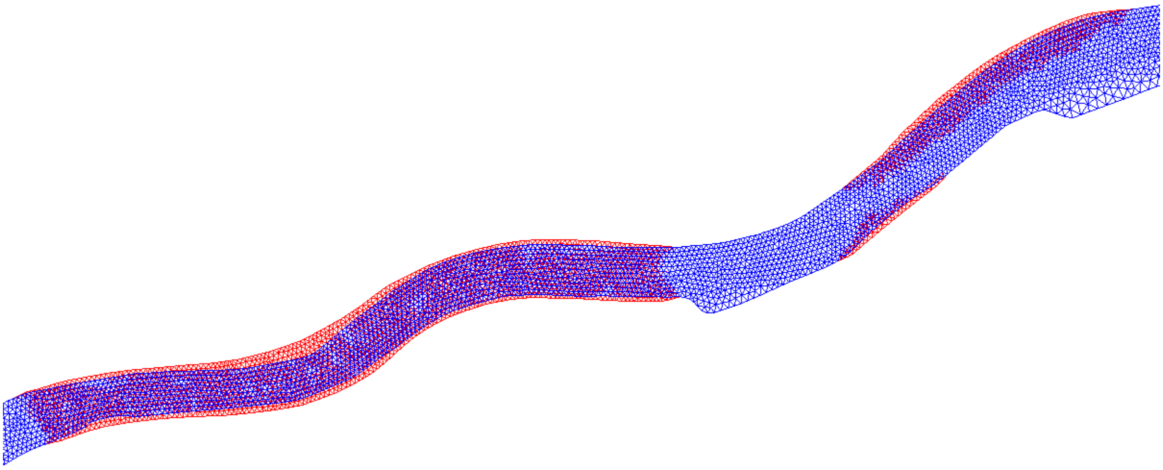


Figure 117 – Bathymetry in VAG plus in zone 10 (m TAW)

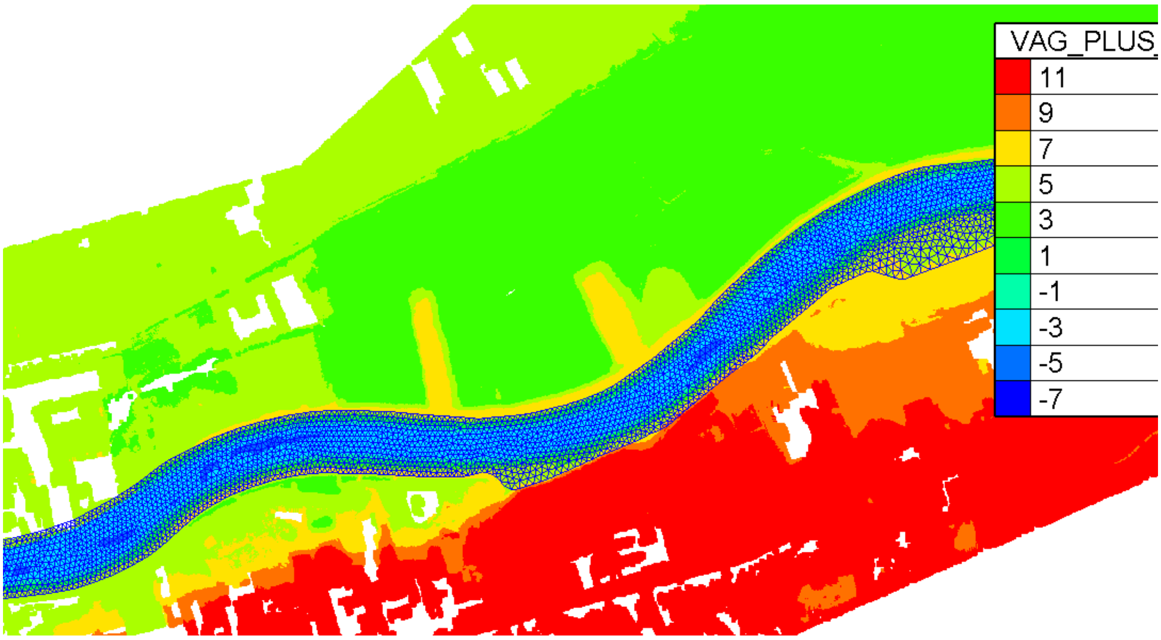


Figure 118 – Changes in the model grid in zone 11

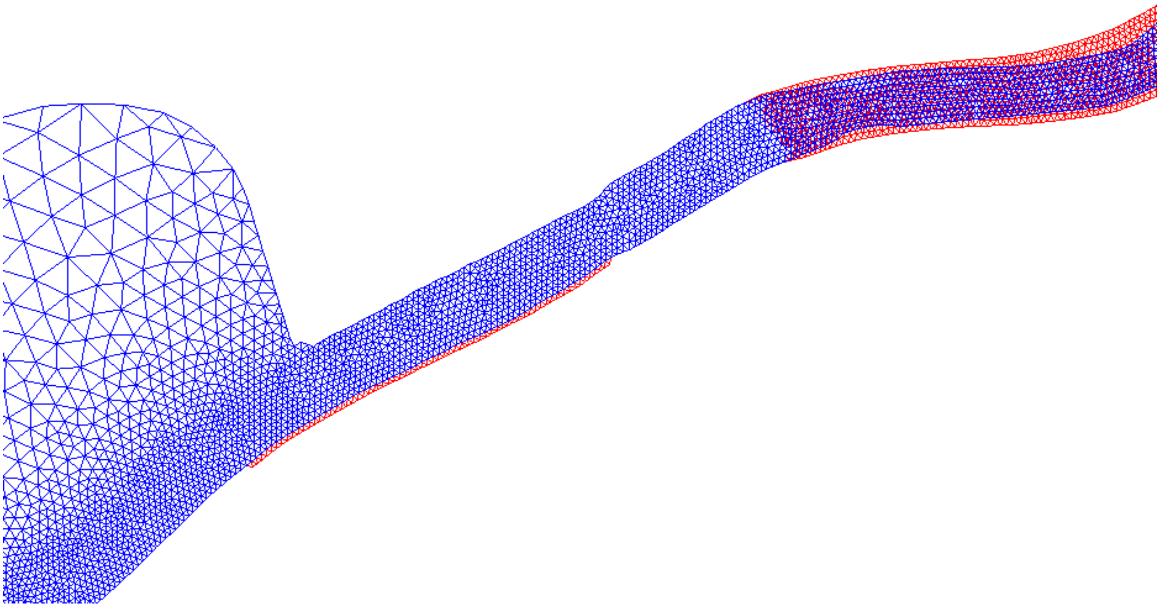


Figure 119 – Bathymetry in VAG plus in zone 11 (m TAW)

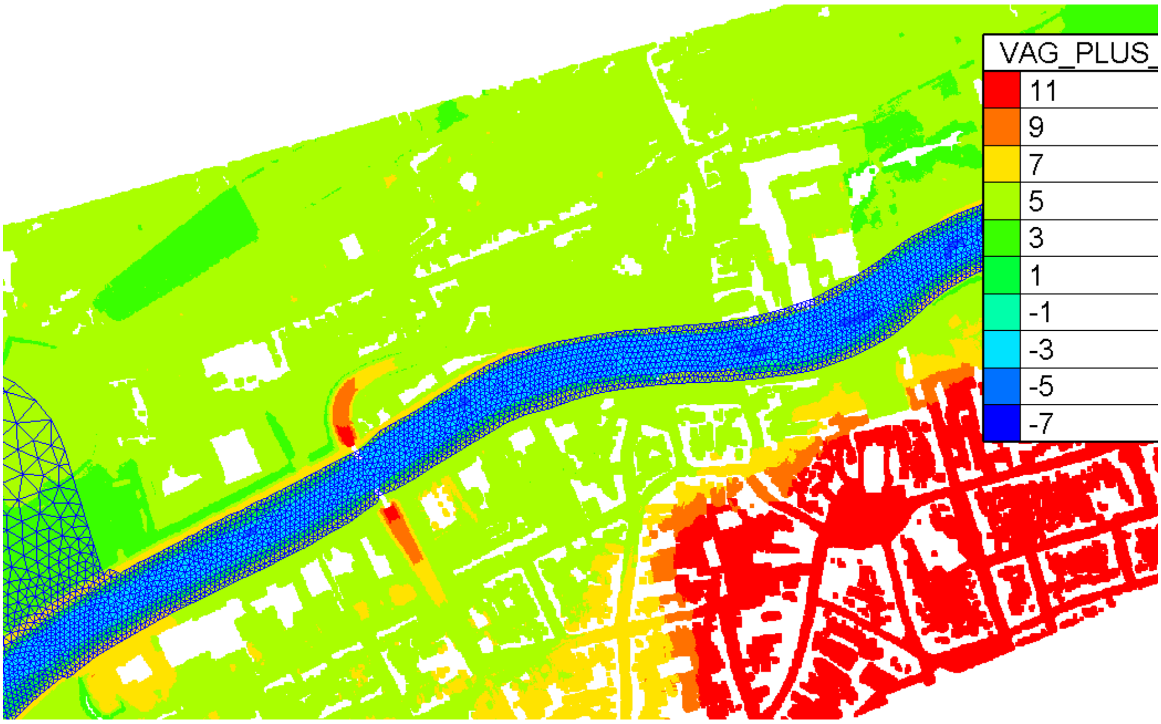


Figure 120 – Changes in the model grid in zone 12

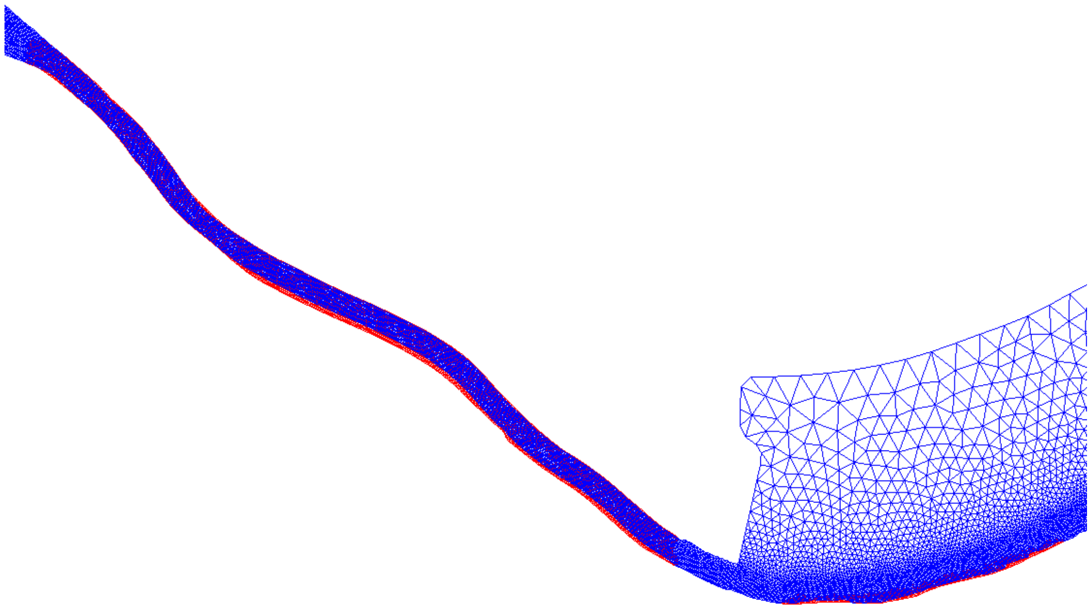


Figure 121 – Changes in the model grid in zone 12 (zoom)

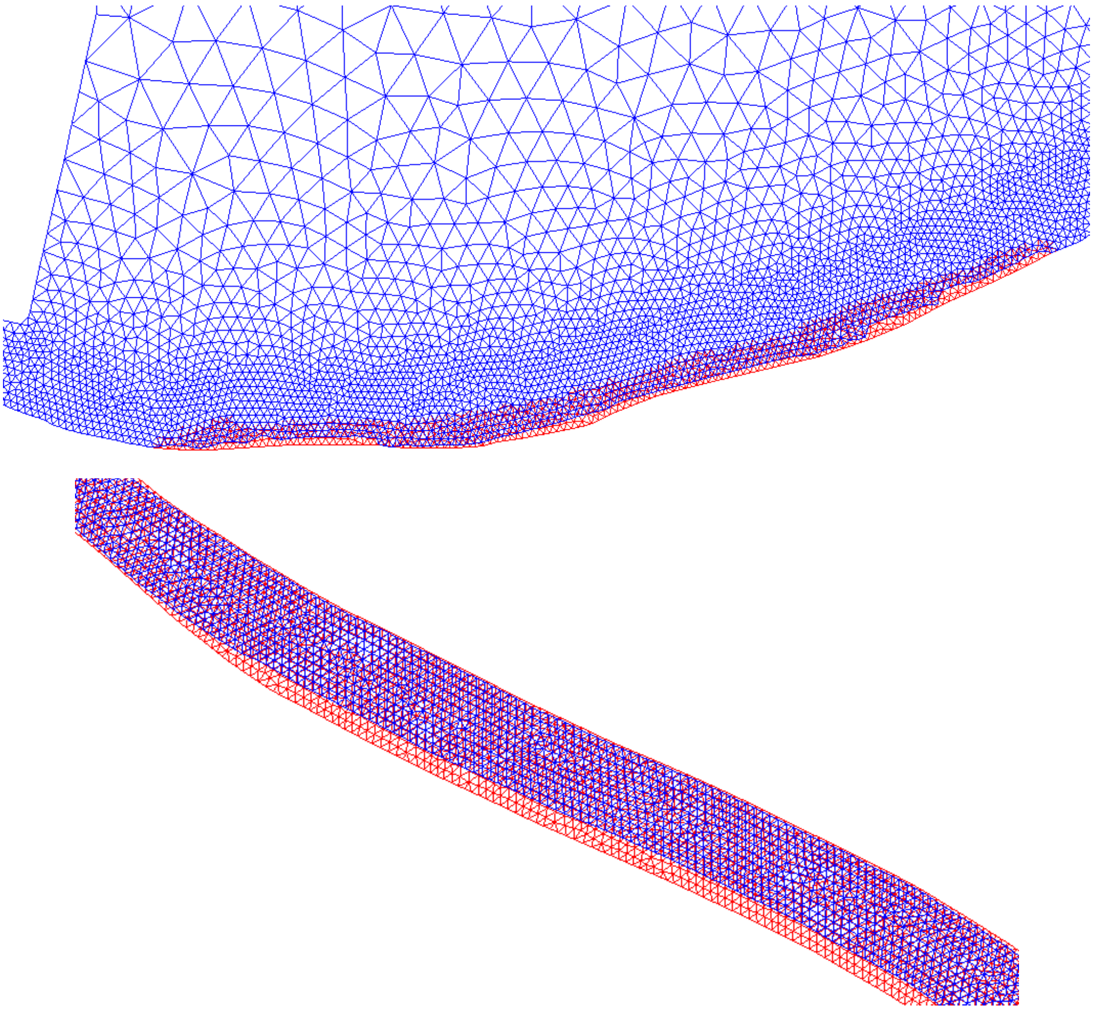
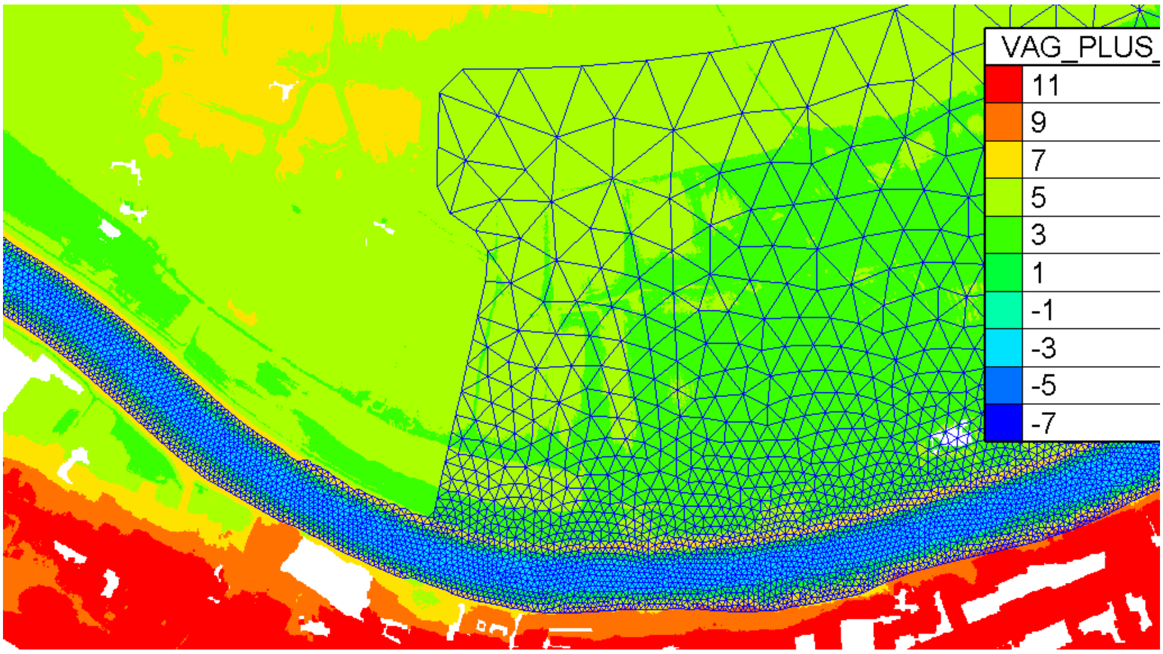


Figure 122 – Bathymetry in VAG plus in zone 12 (m TAW)



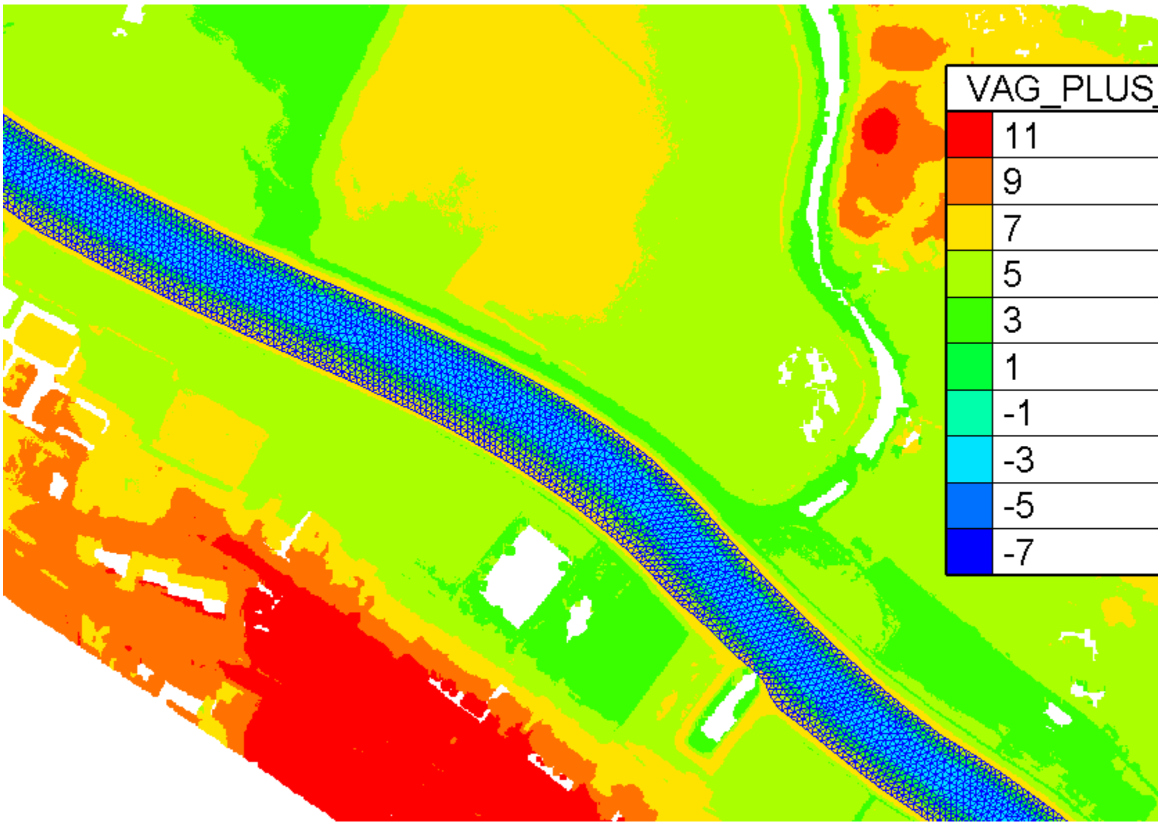


Figure 123 – Changes in the model grid in zone 13

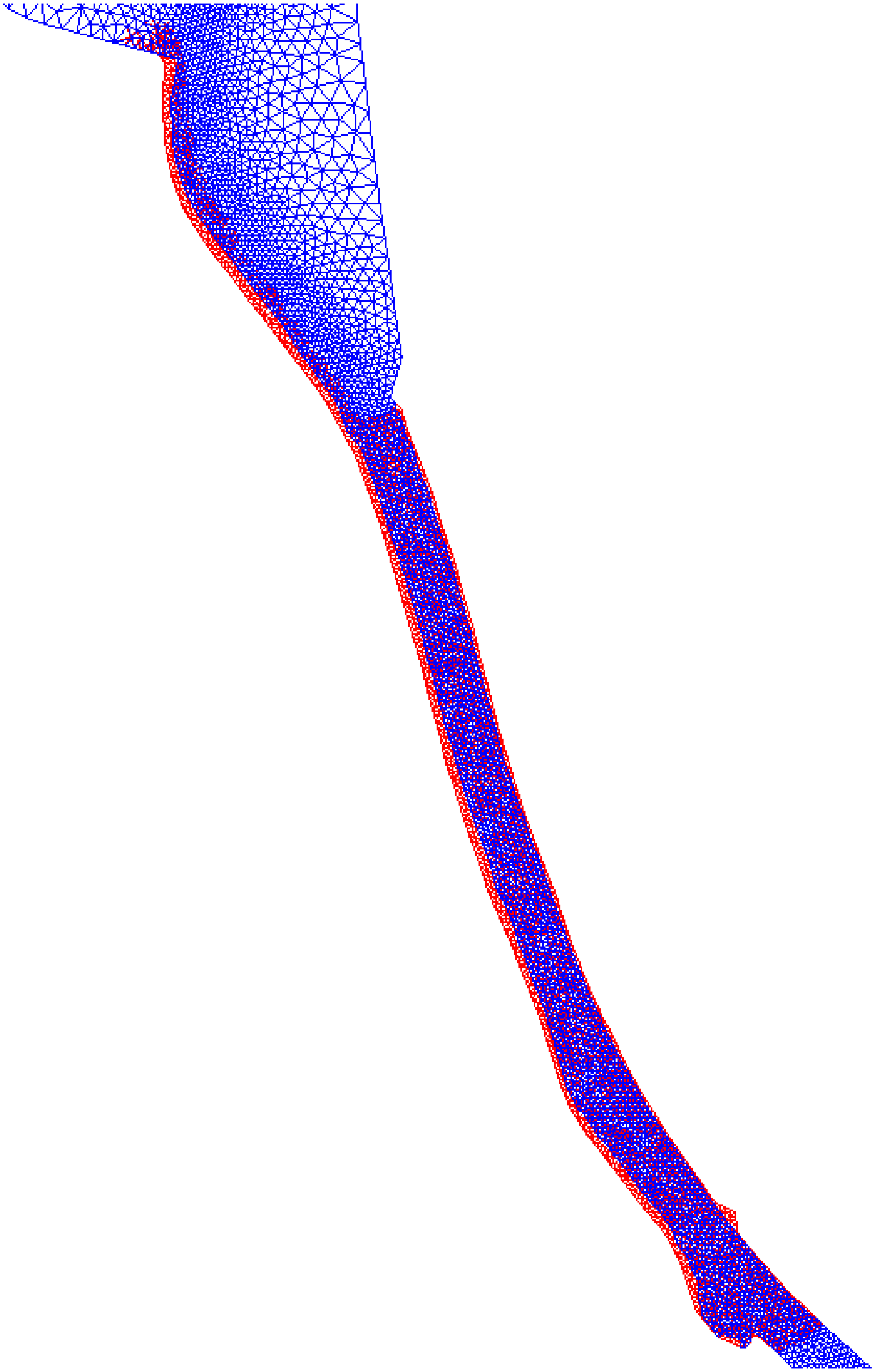
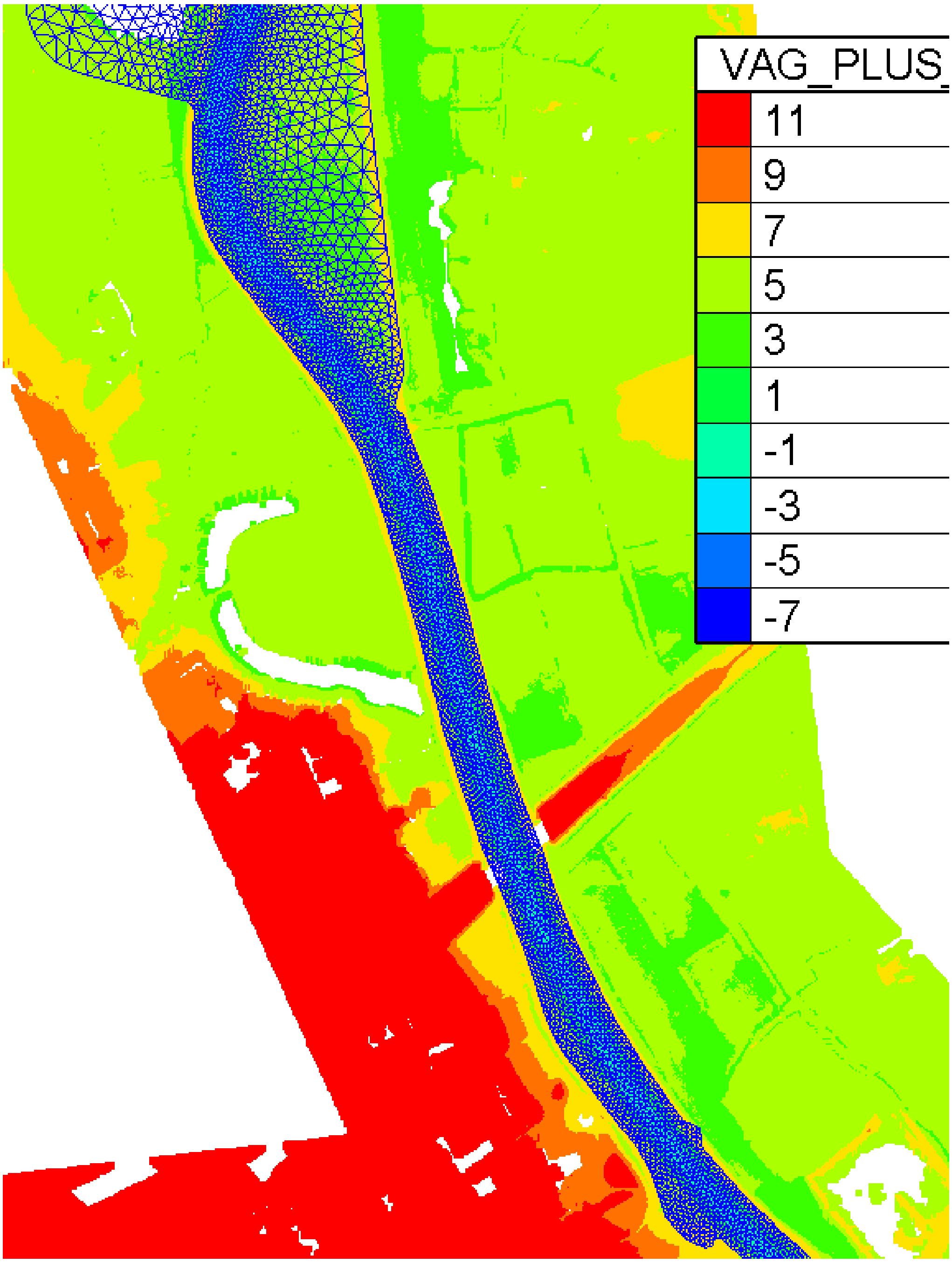


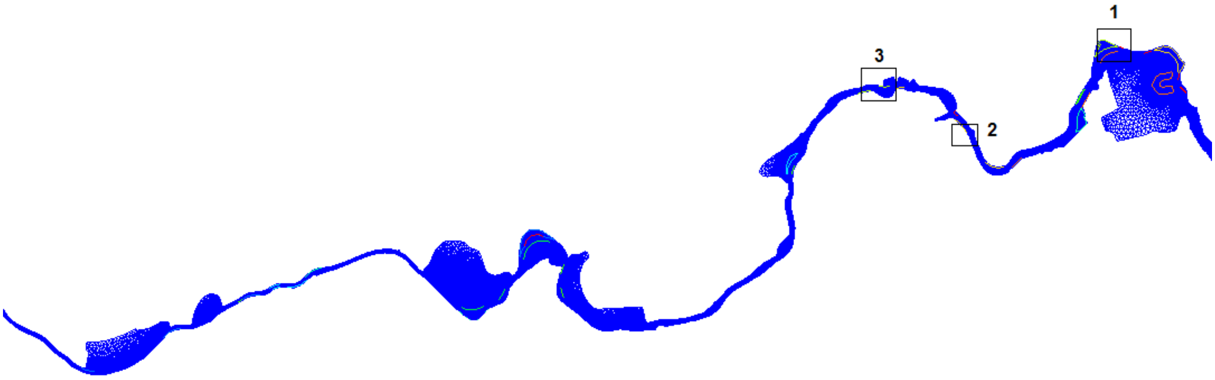
Figure 124 – Bathymetry in VAG plus in zone 13 (m TAW)



5.2 Comparison with the dike lines

Dike or levee lines were provided by IMDC after the grid adaptations that were made to be able to run all scenarios with the same model grid. The grid adaptations were based on the provided bathymetries of all these scenarios. So afterwards this check was done to see if the modified grid beholds all dike or levee lines. We noticed there were three locations were the lines fall outside the grid in three zones. (Figure 125).

Figure 125 – The dike lines and model grid with 3 areas presented in Figure 126 to Figure 128



The differences are small and are shown and explained further. The dike line provided by IMDC for the area upstream Kramp is plotted in the middle of the dike. The adapted model grid includes the area until the dike (Figure 126). This small difference will not have a significant effect on the simulation results.

Figure 126 – Model grid and the dike line upstream Kramp (area 1)

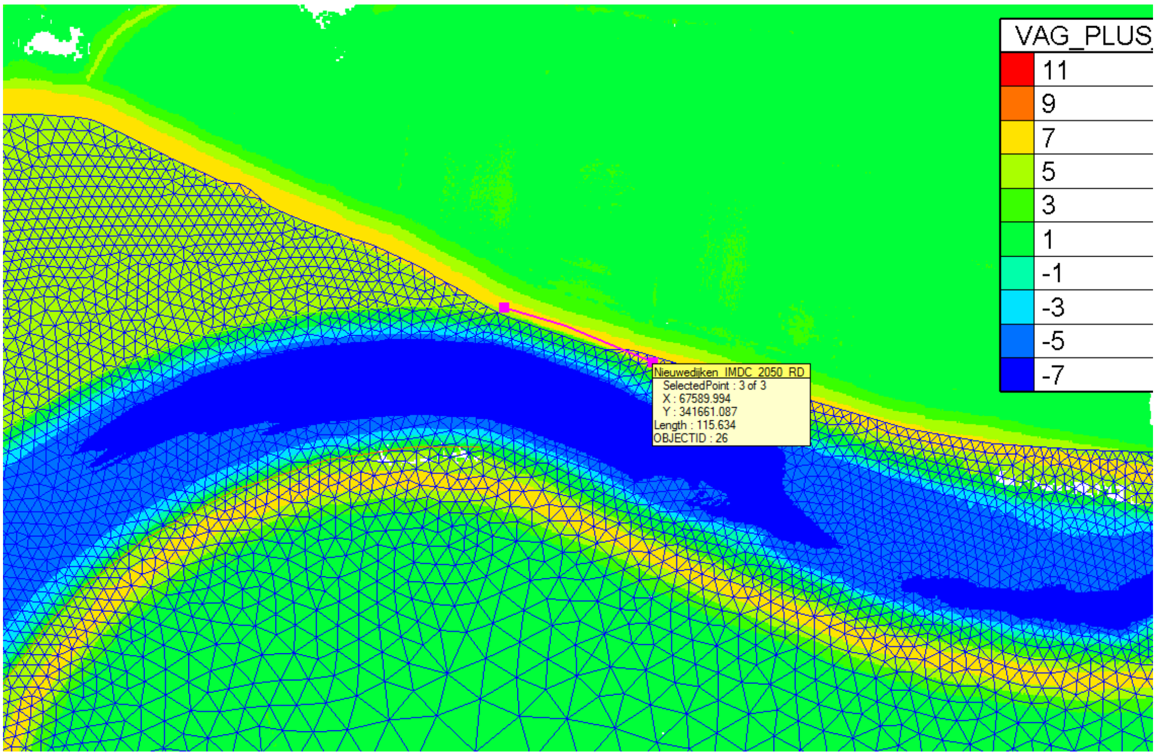


Figure 127 and Figure 128 show small differences between the dike lines (from IMDC) and the model grid. The grid follows the dike line in the bathymetry of the B variants. It does not include the dike itself. It was the same as in the model for 2013 (Figure 129). No grid adaptations are needed, because the difference are small and will not significantly affect the simulation results.

Figure 127 – Model grid and the dike line in area 2

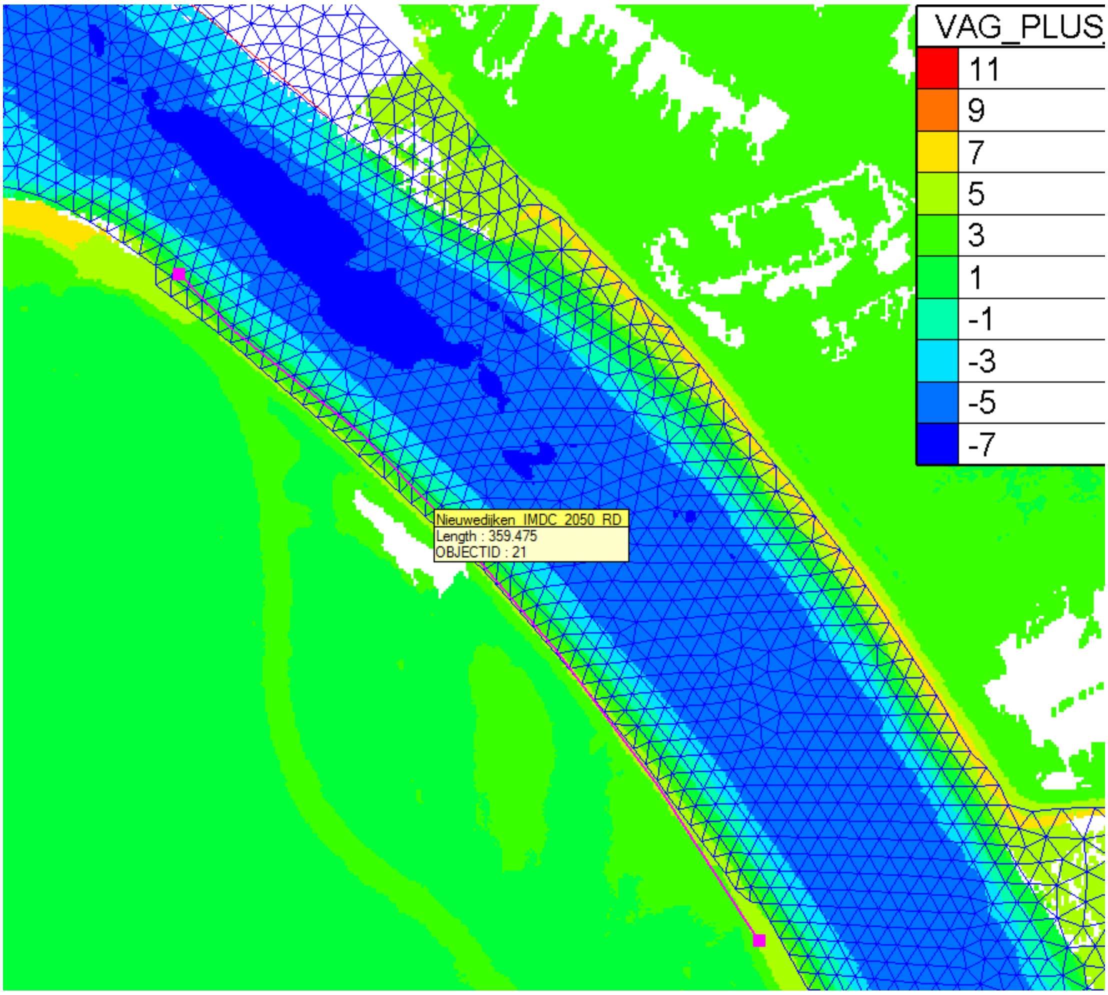


Figure 128 – Model grid and the dike line in area 3 (bathymetry of ‘VAG plus’ variant)

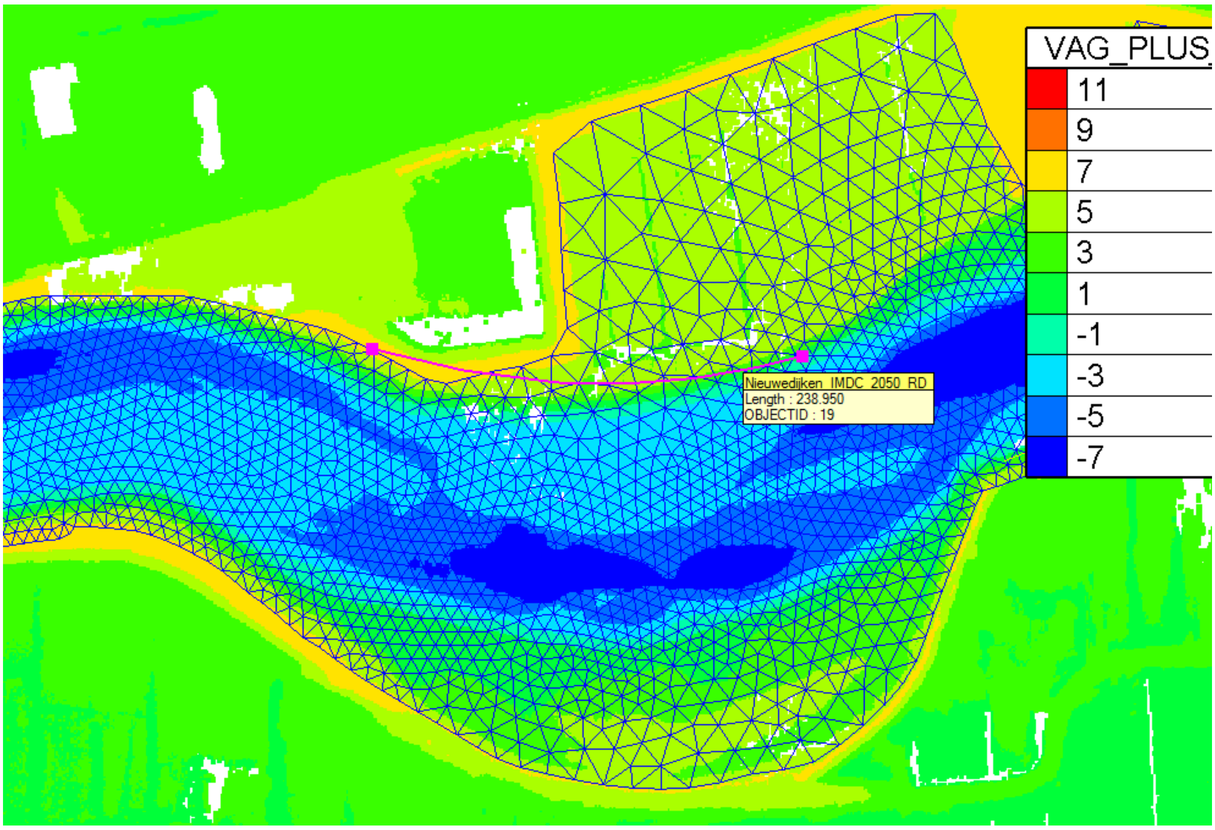
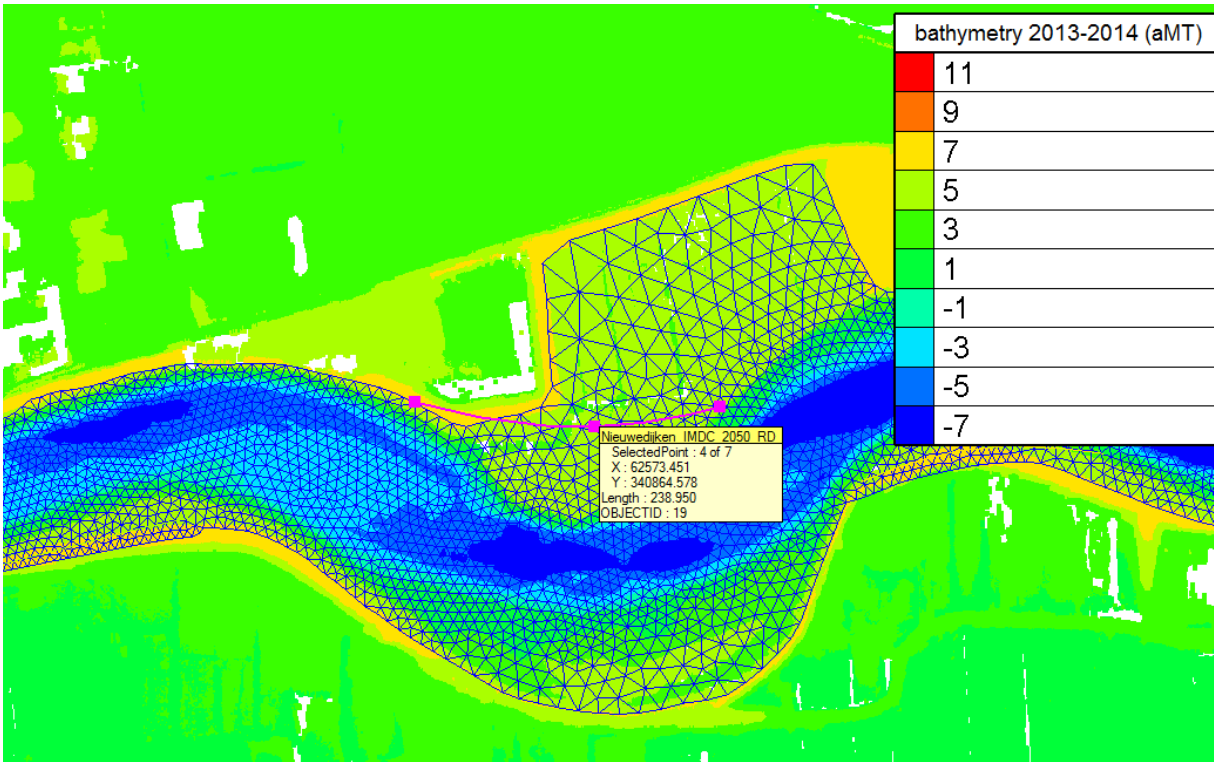


Figure 129 – Model grid and the dike line in area 3 (bathymetry 2013 - 2014)



6 Boundary conditions

This chapter describes the definition of the boundary conditions for the normal discharge (QN) and events discharge (QE) scenarios for the current state (year 2013) and for the reference state (year 2050). More information about these scenarios is given in section 6.2.

6.1 Available data

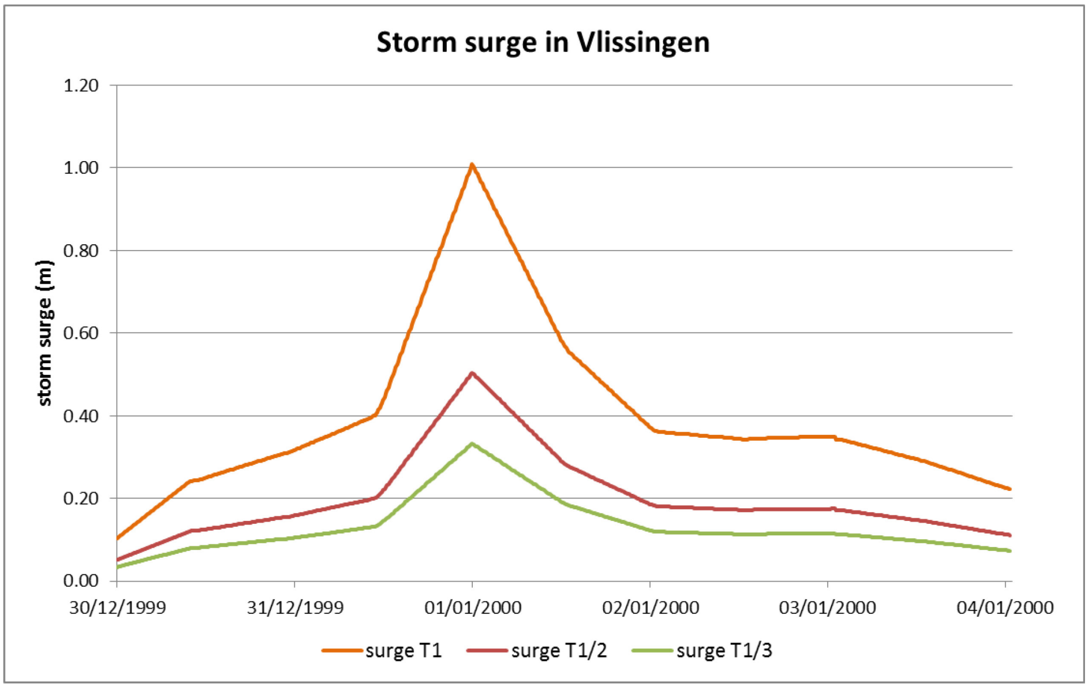
6.1.1 Water levels

Based on the statistical analysis in IMDC (2015) the following time series of water levels are available for Vlissingen:

- Storm surge (5 days) for the return periods T1, T1/2 and T1/3;
- Harmonic tide for 3 months for the current state;
- Harmonic tide for 3 months for 2050;
- Harmonic tide for an upstream storm for the current state;
- Harmonic tide for an upstream storm for 2050.

The downstream boundary of the TELEMAC model is located in the North Sea. Therefore, the tide in Vlissingen will not be used directly for the calculations. Instead, the storm surge at Vlissingen (Figure 130) will be combined with a harmonic model boundary condition obtained from a harmonic ZUNO run.

Figure 130 – Storm surge at Vlissingen



6.1.2 Discharges

The following time series of discharge are available for Rupel, Dender and Scheldt (Leie-Bovenschelde):

- 3 month with representative May – June month and summer month for the current state (Figure 131);
- 3 month with representative May – June month and summer month for 2050 (Figure 132);
- 7 days with storm events for T1 for the current state (Figure 133);
- 7 days with storm events for T1/2 for the current state (Figure 135);
- 7 days with storm events for T1 for 2050 (Figure 134);
- 7 days with storm events for T1/2 for 2050 (Figure 136).

Figure 131 – Synthetic discharge time series for 3 months for the current state

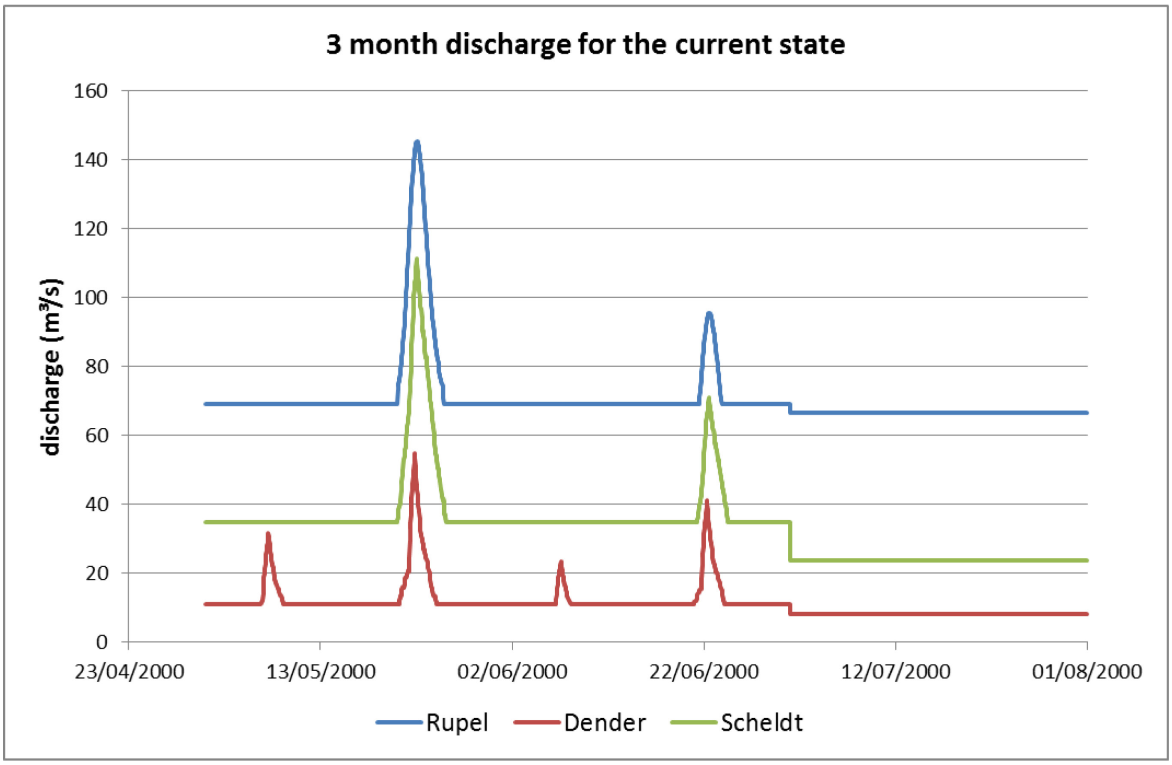


Figure 132 – Synthetic discharge time series for 3 months for 2050

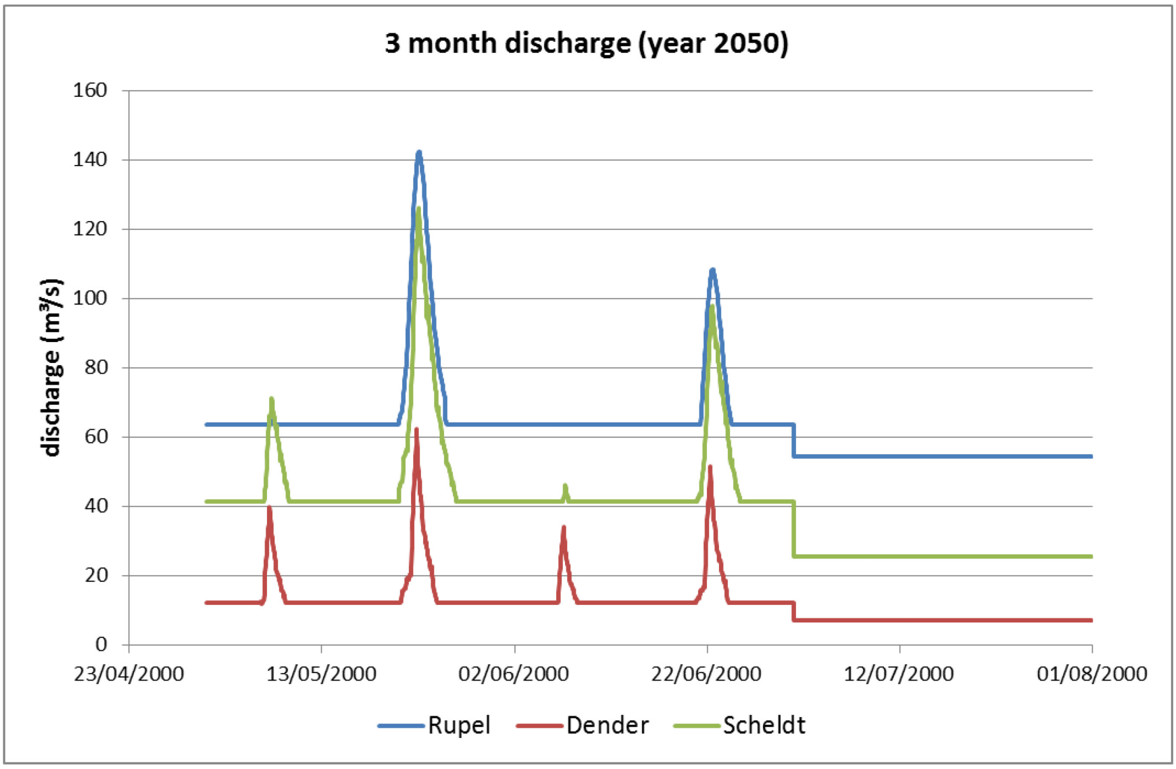


Figure 133 – Discharges with return period T1 for the current state

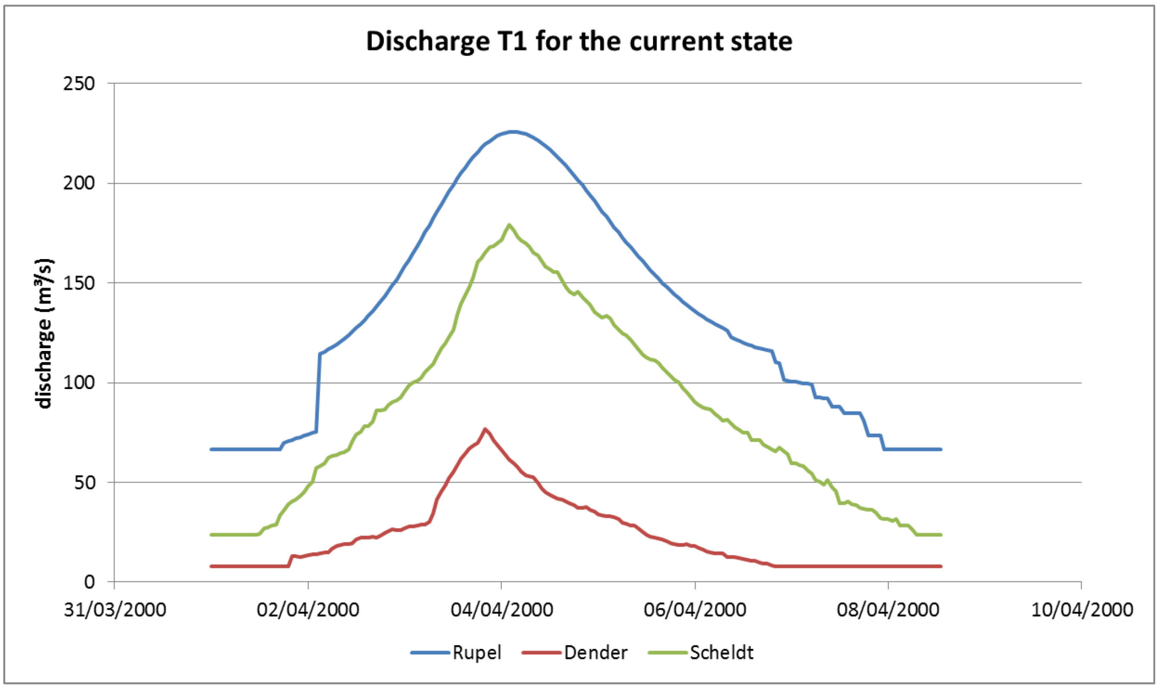


Figure 134 – Discharge with return period T1 for 2050

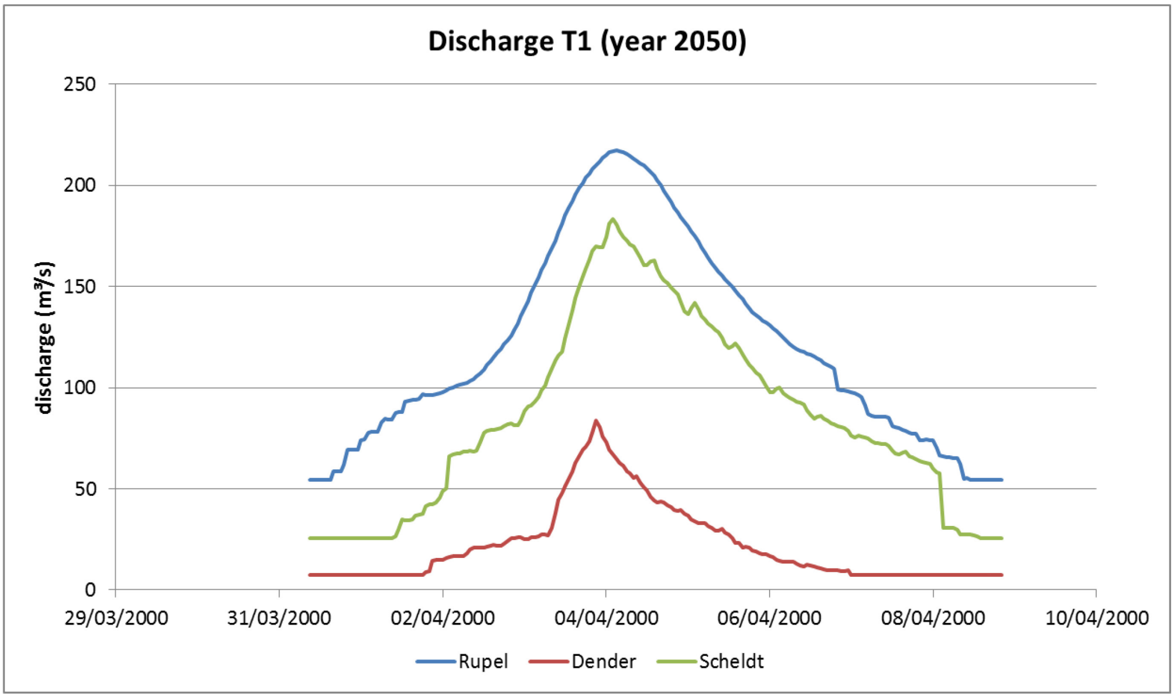


Figure 135 – Discharges with return period T1/2 for the current state

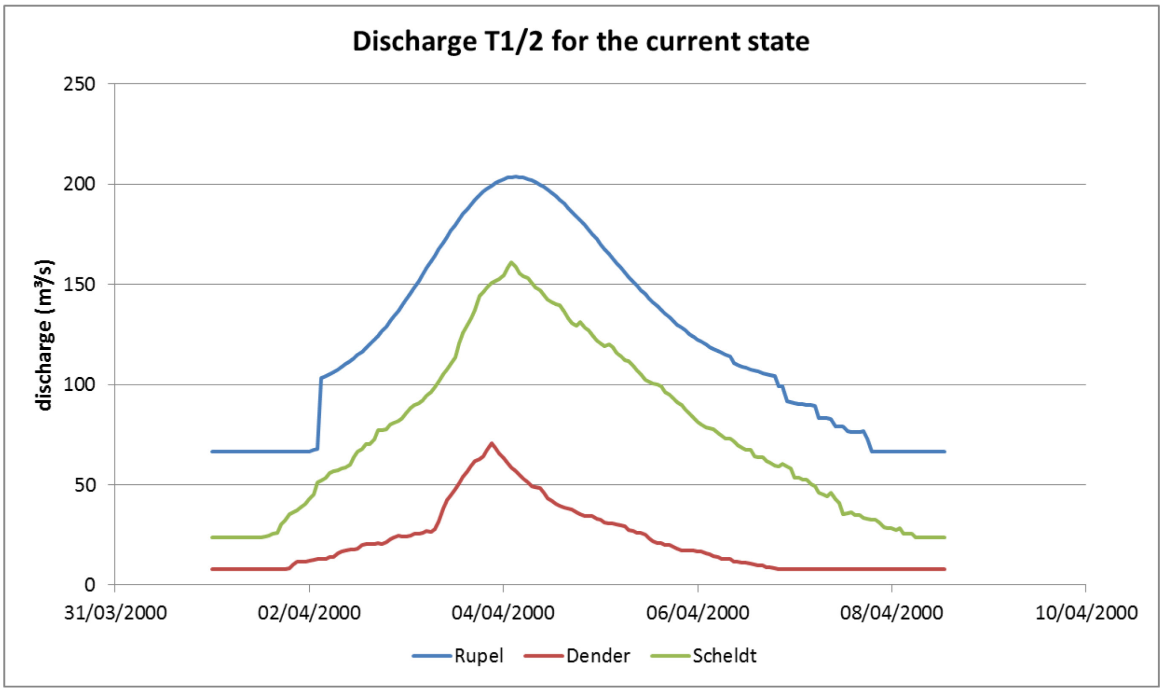
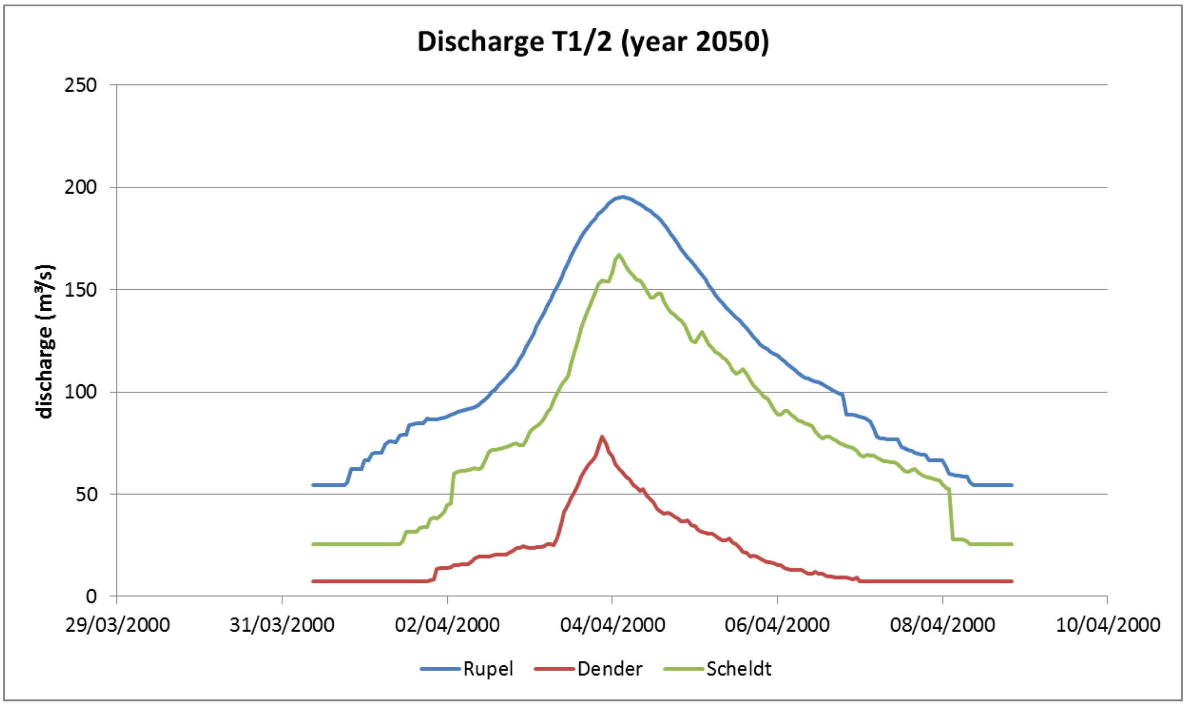


Figure 136 – Discharge with return period T1/2 for 2050



6.2 Scenarios

Normal discharge and events discharge scenarios are described in this chapter. Water level distribution in specific points are obtained by adding the 4 x “normal” and 1 x “events” scenarios.

6.2.1 Normal discharge scenario (QN)

Description of scenario

Downstream boundary is a harmonic boundary without storm surge.

Upstream boundary is a synthetic discharge boundary containing evens with a return period equal to or smaller than 1/6 year (Combined with QE (T1 & T1/2) this results in 6 exeedences of this discharge)

The simulation period is 3 months.

Implementation of boundary conditions

3 months time series of the harmonic tide without storm surge is used as the downstream boundary condition. 3 months discharge time series are used as the upstream boundary conditions.

The maximum discharge at Dender (the second peak in the time series (Figure 131, Figure 132)) is put 15 hours after the maximum high water at Vlissingen. The maximum high water is selected based on the analysis of 1 year harmonic time series for 2013 and 2050 respectively.

Different spring-neap cycles are observed during the selected 3 months. Therefore, some of these tides represent average astronomical tide.

Figure 137 – Combination of the time series for the current state (for QN scenario)

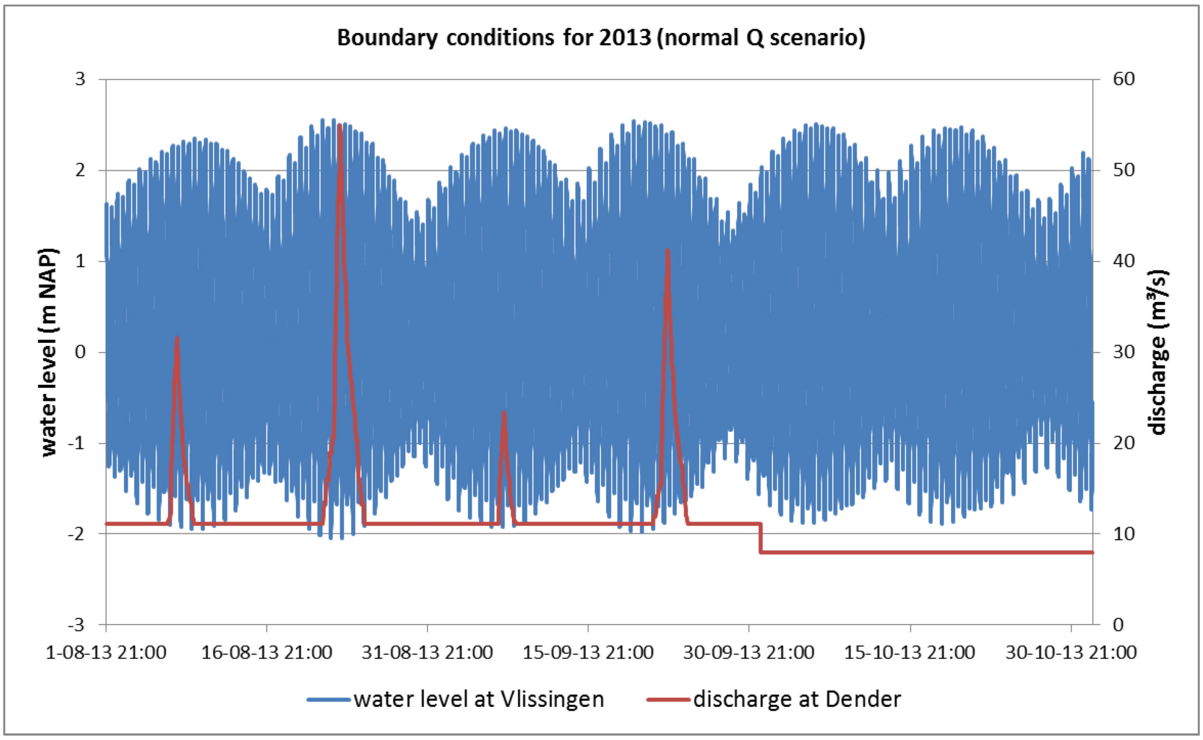
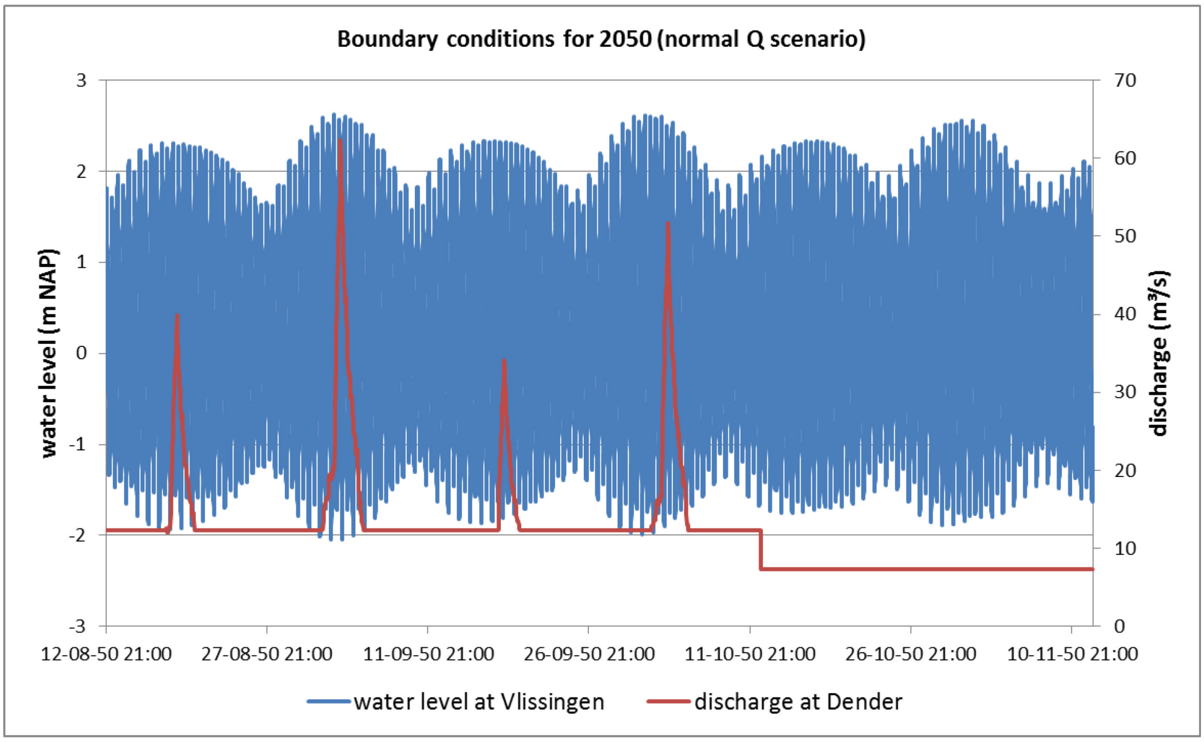


Figure 138 – Combination of the time series for 2050 (for QN scenario)



Simulation period

The selected periods for the analysis are:

- From 01/08/2013 22:20 to 01/11/2013 21:20 for the current state run;
- From 12/08/2050 22:00 to 12/11/2050 21:00 for the run for 2050.

Three days will be added to these periods for the spin up of the model.

6.2.2 Events discharge scenario (QE)

Description of scenario

The downstream boundary is a harmonic signal plus a storm surge signal. The typical storm surge was determined in a statistical way in IMDC (2015) and is described in §6.1.1.
The upstream boundary is a discharge time series that contain 2 discharge events with return periods of 1 year and 1/2 year.
The simulation period is 2 weeks (or a few days longer depending on the combination of the boundary condition upstream and downstream).

Implementation of boundary conditions

Downstream boundary condition

The water level at Vlissingen calculated in the harmonic ZUNO run is analyzed for the entire year 2013 (or 2050) and the maximum high water is found.

The peak of each storm surge (T1, T1/2, T1/3) should coincide with high water (conservative approach). The time series of the T1 surge is shifted so that the peak of T1 surge coincides with the highest high water at Vlissingen (23/08/2013 03:20 for the current state run, 03/09/2050 3:00 for 2050 run). The same surge time series are used for 2013 and 2050.

The time series of the surges with return periods T1/3 and T1/2 are made to coincide with high waters too. The surges are combined so that there are about 4.5 days between their peaks (Figure 139, Figure 140). To decrease the simulation period we let surges overlap for a limited time. When they overlap, the highest surge is taken for the calculation. The surge signal will be added to the harmonic water levels to get the downstream boundary of the TELEMAC model.

Upstream boundary condition

In total 14 days of discharge time series are available (7 days for T1 and 7 days for T1/2 return periods).

The maximum discharge at Dender is expected 15 hours after the maximum surge at Vlissingen (IMDC, pers. comm.). The peak of discharge T1 is therefore put 15 hours after the peak of surge T1 ; the peak of discharge T1/2 is put 15 hours after the peak of surge T1/2.

When no discharge is available (between Q T1 and Q T1/2) a constant average discharge is used upstream.

To decrease the simulation period we put the surge T1/3 between surges T1 and T1/2 (Figure 139, Figure 140).

Figure 139 – Combination of the time series for the current state (for QE scenario)

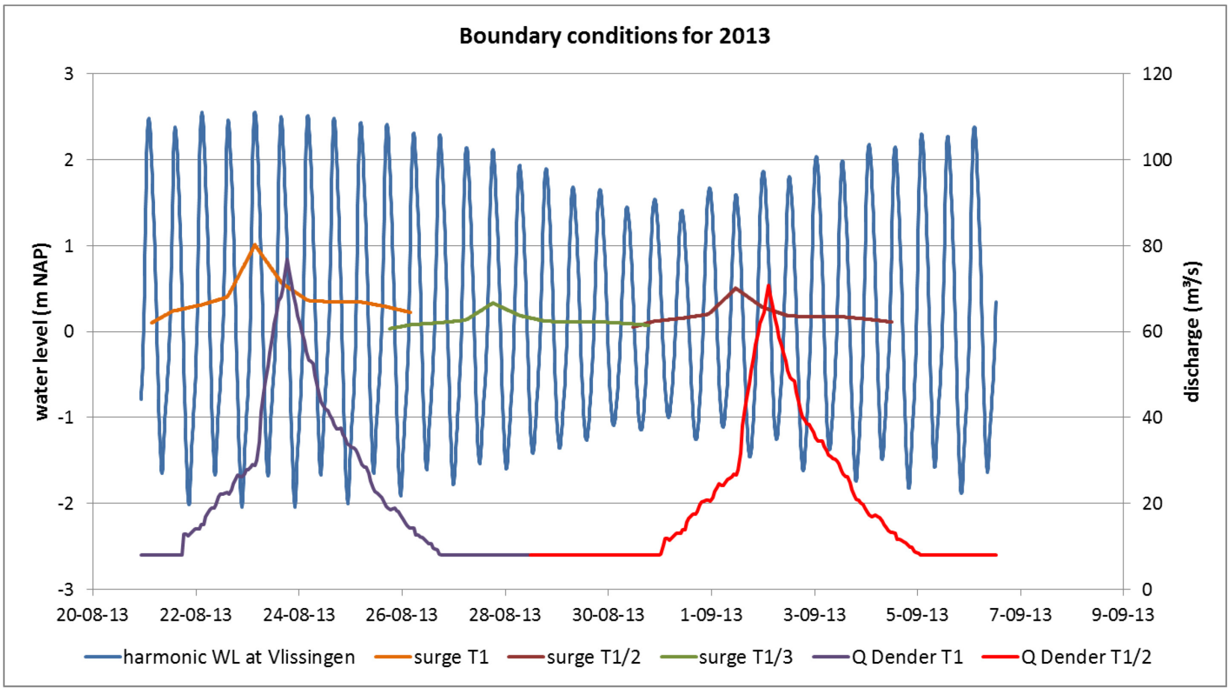
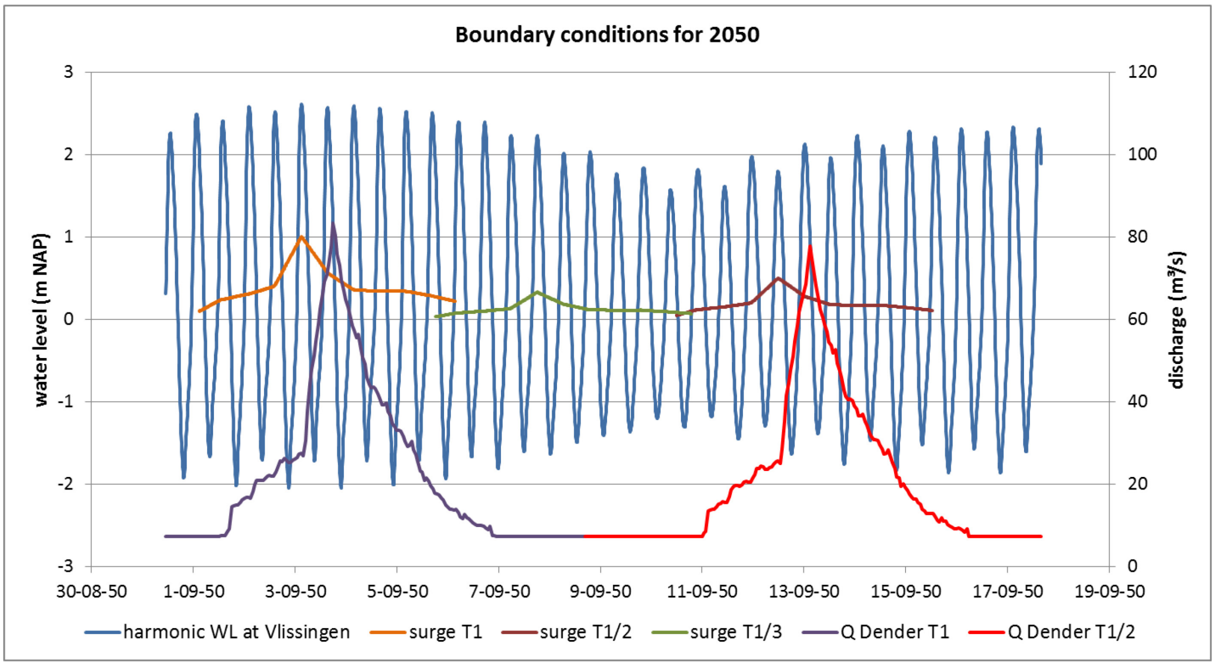


Figure 140 – Combination of the time series for 2050 (for QE scenario)



Simulation period

If the downstream and upstream boundary conditions are combined in the way shown in Figure 139 and Figure 140 the following periods should be included in the analysis:

- from 20/08/2013 22:20 to 06/09/2013 12:20;
- from 31/08/2050 11:00 to 17/09/2050 16:00.

The simulation period should also include 3 days of spin up time. Therefore, the simulation period is:

- 20 days for 2013 (from 17/08/2013 22:20 to 06/09/2013 12:20);
- 21 days for 2050 (from 28/08/2050 11:00 to 17/09/2050 16:00).

6.2.3 Tidal range scenarios

The 3D hydrodynamic model will be used to evaluate the effect of an increased and reduced tidal amplitude near Schelle and further upstream in the Upper Sea Scheldt. The increase and decrease of the amplitude will be enforced by changing the roughness in the Western Scheldt (in the polygon shown in Figure 141). By changing the roughness, the tidal propagation will be influenced, without simulating specific measures in the downstream parts of the estuary (e.g. creating additional flooding areas, deepening, etc.) (IMDC/INBO/UA/WL, 2015).

Tidal range scenarios A+, A0 and A- will be modeled. In these scenarios the tidal amplitude at Schelle is 5.70, 5.40 and 5.00 m respectively (Table 6).

A necessary change of the bed roughness in the Western Scheldt is found by the sensitivity analysis (Table 7, Figure 142). First, a modeled tide with a tidal amplitude of 5.40 m at Schelle was found in the calibrated model run. Afterwards a constant change of the roughness field of the Western Scheldt was applied (the polygon where roughness is changed is shown in Figure 141). Different values of the roughness correction were tested (Table 7).

When the bed roughness is decreased by 0.00426 $m^{-1/3}s$, the tidal amplitude at Schelle increases and becomes about 5.70 m. The increase of the roughness field by 0.00554 $m^{-1/3}s$ results in the tidal amplitude of about 5 m at Schelle.

Table 6 – Tidal range scenarios

Scenario	Tidal amplitude at Schelle (m)
A+	5.70
A0	5.40 (current tidal range)
A-	5.00

Table 7 – Model runs with different roughness correction

Model run	Roughness correction in Western Scheldt ($m^{-1/3}s$)	Tidal amplitude at Schelle 25/09/2013 (m)
RGH1	0	5.41
RGH2	0.01	4.69
RGH3	0.005	5.04
RGH4	-0.005	5.75
RGH5	0.0049	5.05
RGH6	-0.00426	5.71
RGH7	0.00554	5.01

Figure 141 – Bed roughness field of the Scaldis model (the polygon indicates the area where the bed roughness is adapted)

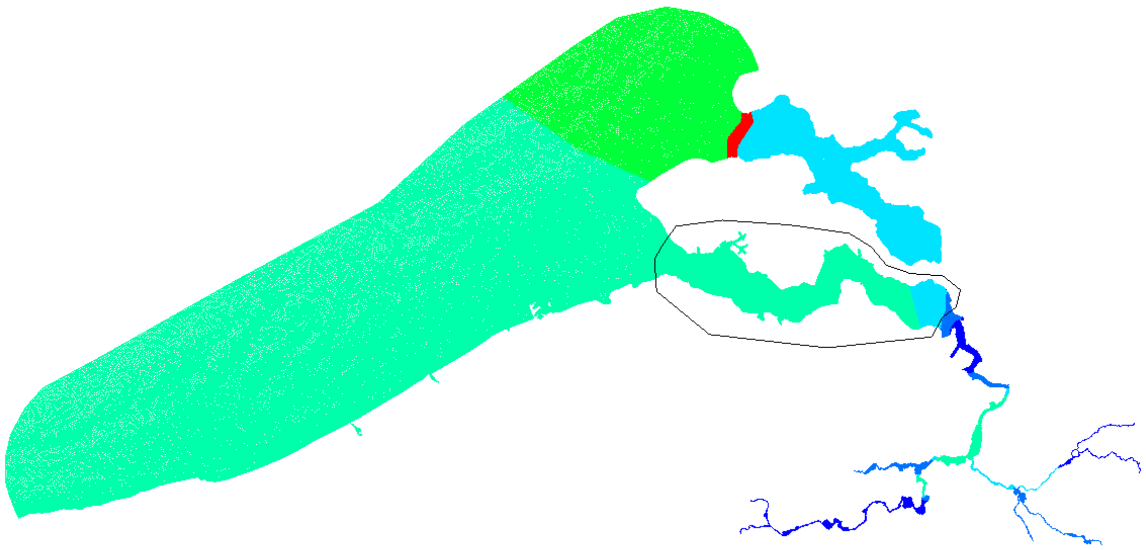
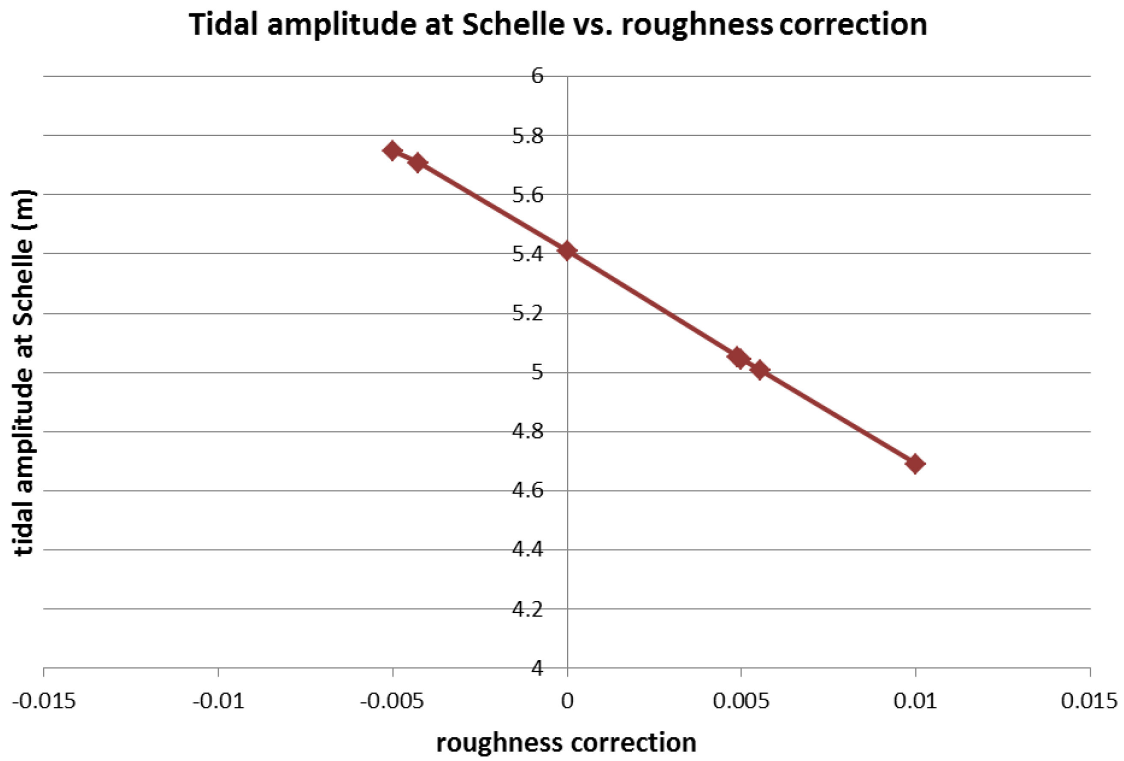


Figure 142 – Plot of the tidal amplitude vs. roughness correction



6.2.4 Sea level rise scenarios

The following sea level rise scenarios are modeled for 2050:

- the “low” scenario (CL, +15 cm in 2050);

- the “high” scenario (CH, +40 cm in 2050).

The downstream boundary conditions described in chapters 6.2.1 and 6.2.2 for year 2050 will be increased with these values.

The tidal range scenario A+ will be combined with the sea level rise CH. The tidal range scenario A- will be combined with the sea level rise CL. More information about the scenarios is given in IMDC/INBO/UA/WL (2015).

6.3 Harmonic water levels

Harmonic water levels (which are used for the calculation of the boundary conditions for scenarios) come from the ZUNO model for years 2013 and 2050. These data are corrected as described in Table 8.

This correction is calculated based on the comparison of the harmonic components of the ZUNO results and measurements for a period of 1 year (Maximova et al., 2015a). Differences in harmonic components (ZUNO vs. measurements) are found for stations in the Belgian and Dutch Coastal zone for the M2, M4, S2 phases and the Z0 component.

In the next step, the time series of the boundary conditions of the SCALDIS model are “harmonically corrected” with the obtained correction terms in Table 8. This means that the time series at the boundary locations of SCALDIS that are obtained out of ZUNO, are decomposed in harmonic components and a residual term. The harmonic components are corrected, and the signal is re-synthesized. Applying these corrected boundary conditions in SCALDIS makes that the hydrodynamics in SCALDIS does not have the systematic bias in harmonic components that is present in ZUNO.

Table 8 – Correction of harmonic components (Maximova et al., 2015a)

Harmonic component	Correction
Phase M2	+4°
Phase M4	-6°
Phase S2	+7°
Z0	-16 cm

6.4 Initial salinity field and salinity boundary in scenario analysis

6.4.1 Scenarios QN_2013 and QE_2013

The initial salinity field is defined based on the values provided by the University of Antwerp (taking into account the correction described in chapter 6.4.4).

For the North Sea and Eastern Scheldt (where UA values are not available) the salinity from ZUNO is used (salinity map for a certain moment). The ZUNO output is corrected based on comparison of the salinity at Vlissingen provided by UA and the average salinity at Vlissingen from the harmonic ZUNO run for 2013, in order to get one smooth initial salinity field. The difference is 3.4 psu.

The salinity boundary conditions are taken from the harmonic ZUNO run 2013. They are corrected similarly to the initial salinity field (correction by 3.4 psu).

6.4.2 Tracer runs 2050

The tracer run is a short run which has to be done before UA can provide the salinity data. Therefore, the initial salinity field for this simulation is defined based on the salinity from ZUNO (salinity map for a certain moment).

The salinity boundary conditions are taken from the harmonic ZUNO run (without correction).

The tracer run is done for a period from 20/08/2050 00:00 to 28/08/2050 00:00. Harmonic water levels are defined as downstream boundary conditions. Constant discharges are used upstream.

6.4.3 Scenarios QN_2050 and QE_2050

For QN and QE runs 2050 the salinity boundary conditions and the initial salinity field are defined based on the output of ZUNO model without correction (because there were no data for 2050 from the University of Antwerp).

6.4.4 Correction of the initial salinity

The initial salinity field of the 3D model is defined for different scenarios in 2013 based on the output of the 1D model of the University of Antwerp. However, this 1D model is tidally averaged. Therefore, it is necessary to take into account the tidal variation in salinity when applying the longitudinal salinity distribution in the 3D model (see memo ‘Afstemming model instrumentarium’ (IMDC/INBO/UA/WL, 2015)). It is necessary to use correction coefficients in local salinity.

This chapter describes the analysis of the measured time series of salinity for calculation of the correction coefficients.

Analysis of time series of measured salinity

Measured salinity time series are analyzed at different stations for year 2013 (Figure 143). These time series are transformed by subtracting the moving average (calculated by function moving_average_centered.m).

```
timewindow=48; %48 hours
dt=(SAL.Time{i,1}(2)-SAL.Time{i,1}(1))*24; %time step of time series
N=round(timewindow/dt/2); %size of a half timewindow in time steps
Mov_avg{i,1}=moving_average_centered(N,SAL.Data{i,1});
```

An example of plots for Baalhoek is presented in Figure 144 and Figure 145.

Figure 143 – Location of salinity measurements

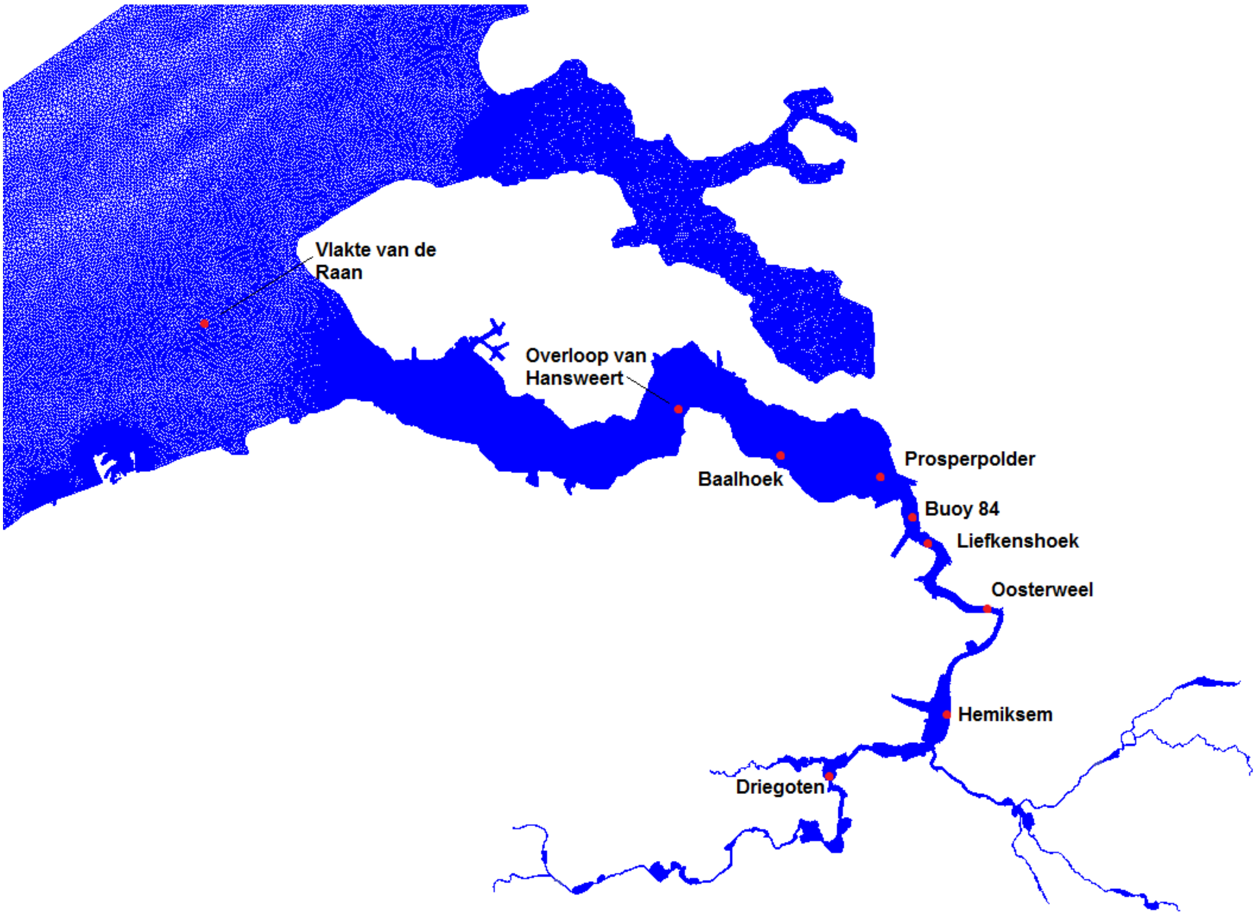


Figure 144 – Time series of measured salinity at Baalhoek

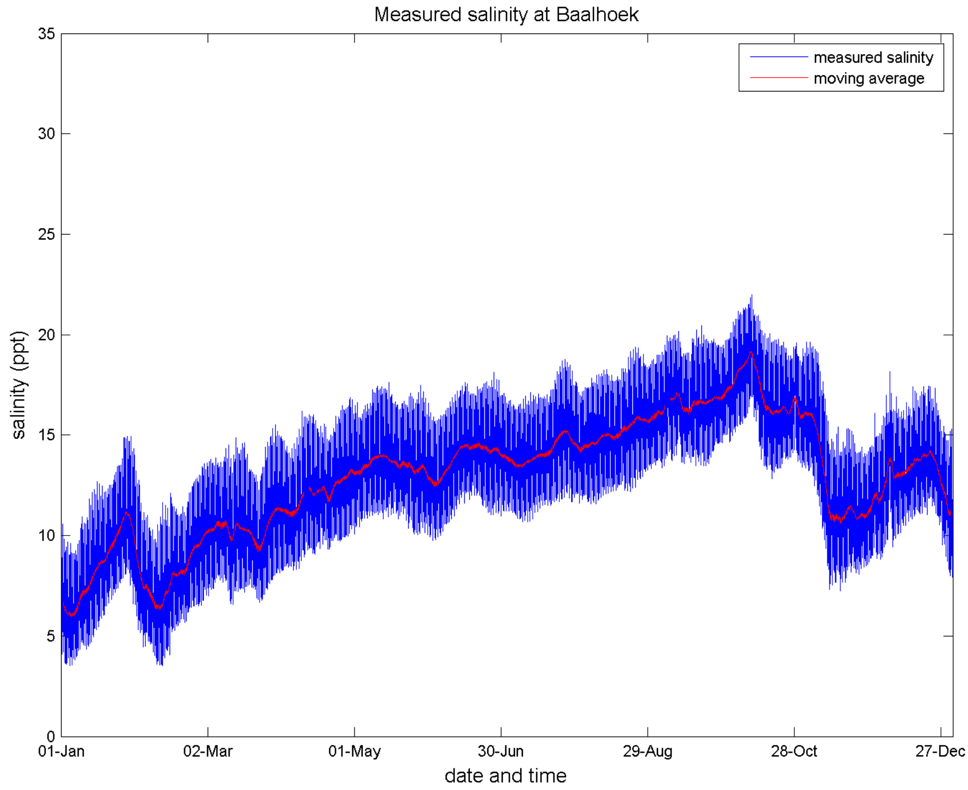
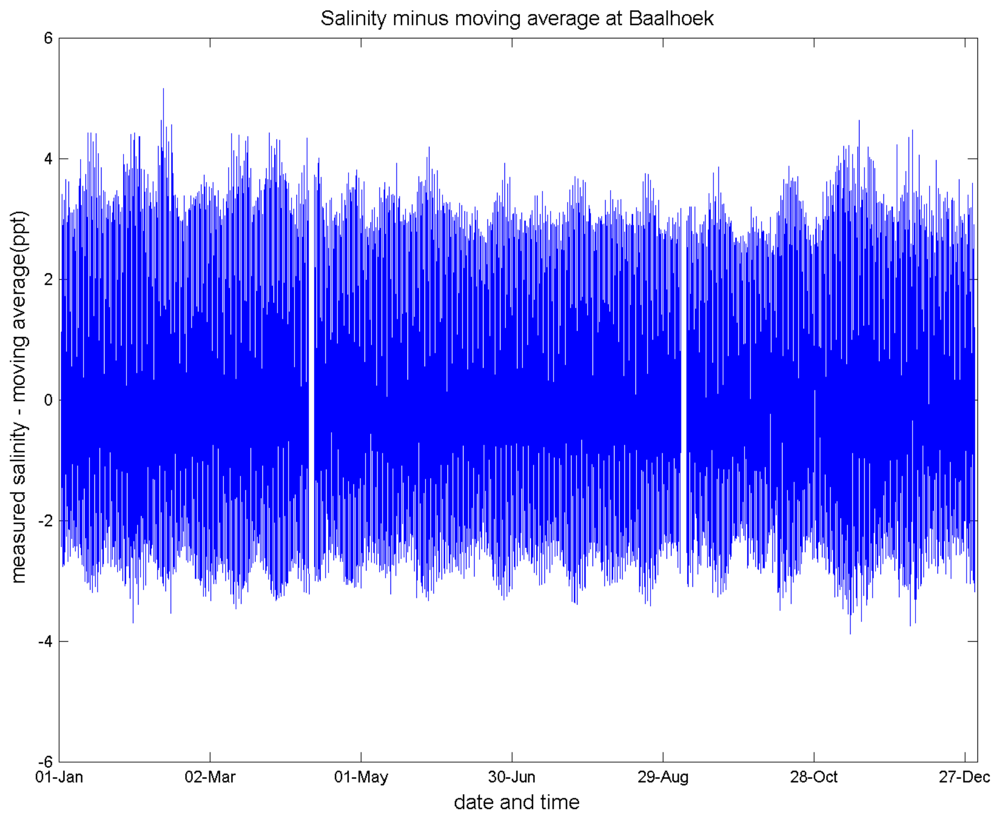


Figure 145 – Time series of salinity minus moving average at Baalhoek



Ensemble analysis

Figure 146 shows the time series of salinity at Baalhoek and water level at Vlissingen for one tide. The maximum salinity at Baalhoek is observed a bit less than 2 hours after high water at Vlissingen. The minimum salinity is about 3.5 hours before high water at Vlissingen.

In order to make characteristic curves of salinity distribution over the tidal cycle it is not sufficient to analyze only one selected tide. An ensemble analysis or phase averaging is used to analyze all the available tides. The measured salinities are split into individual tidal cycles and averaged out over neap, normal and spring tide.

Figure 147 shows an example of the ensemble analysis for Baalhoek. Black line in the figures represents the measurement. Grey shaded bar shows the standard deviation. X axis in the plots shows hours relative to the reference time (time of high water at Vlissingen).

The curves of salinity distribution calculated by ensemble analysis will be used for the correction of the salinity values provided by the University of Antwerp (see the next chapter).

Figure 146 – Plot of salinity at Baalhoek and water level at Vlissingen for one of the tides

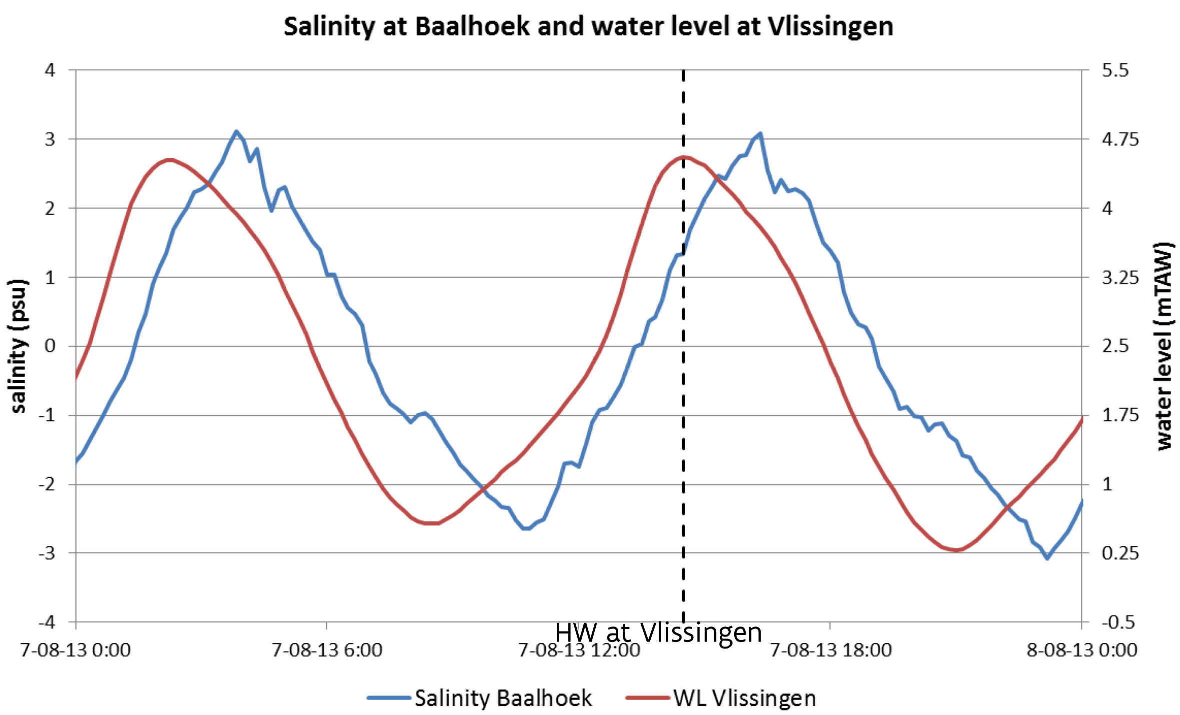
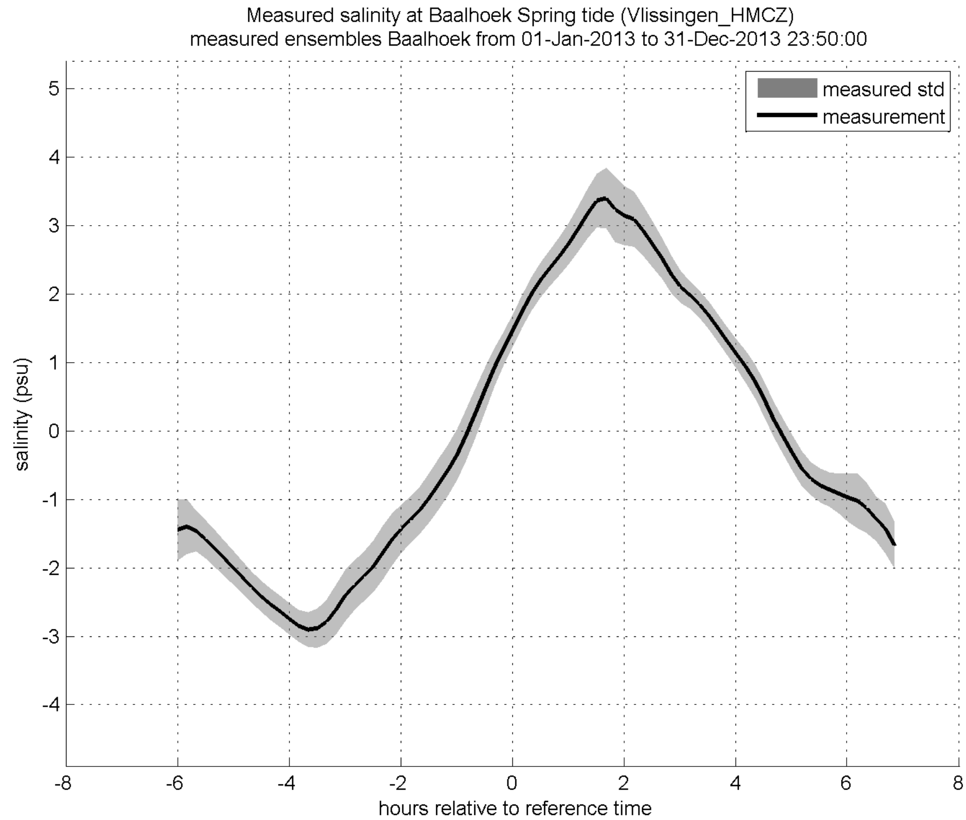


Figure 147 – Example of ensemble analysis of salinity variation around average salinity relative to HW at Baalhoek



Correction of the initial salinity field

The salinity distribution (calculated with the 1D model of the University of Antwerp) in the Scheldt estuary is presented in Figure 150 for 2013. The 1D model of UA is tidally averaged. Therefore, it is necessary to take into account the tidal variation in salinity when applying the longitudinal salinity distribution in the 3D model.

QN_2013 scenario starts on 29/07/2013 22:20 (3:30 after HW at Vlissingen) (Figure 148). It is an average tide (tidal coefficient k=0.96). More information about the tidal coefficients is given in Appendix 1.

QE_2013 scenario starts on 17/08/2013 22:20 (0:30 before HW at Vlissingen) (Figure 149). It is a neap tide (k=0.89).

Figure 148 – Water level at Vlissingen at the start of the QN_2013 run

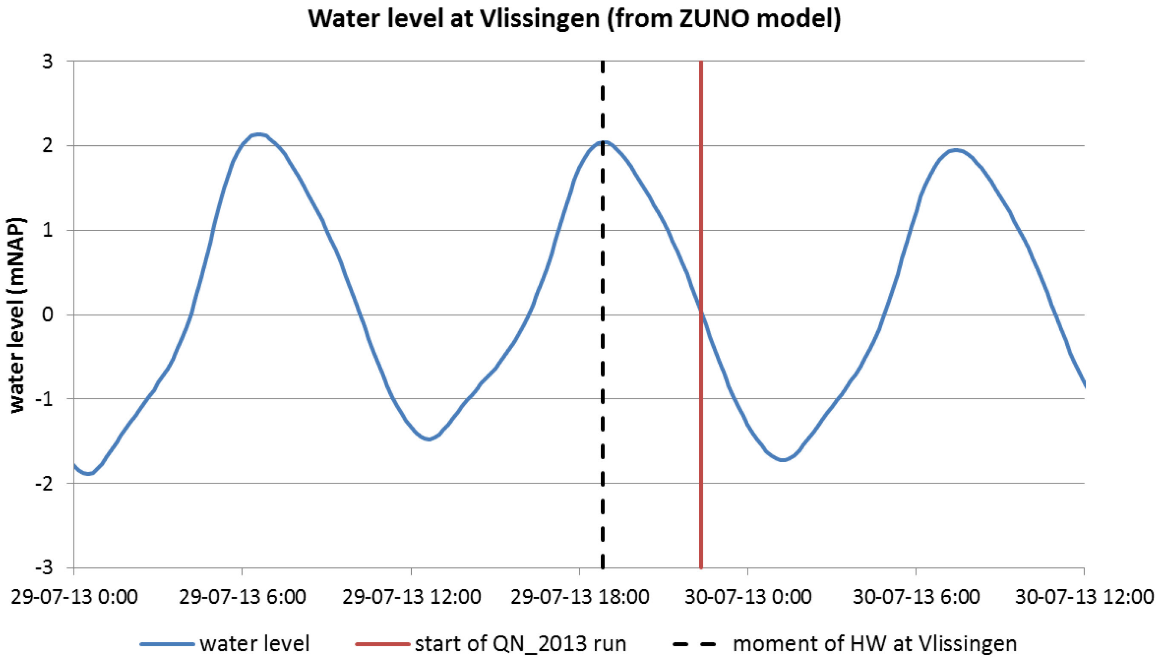
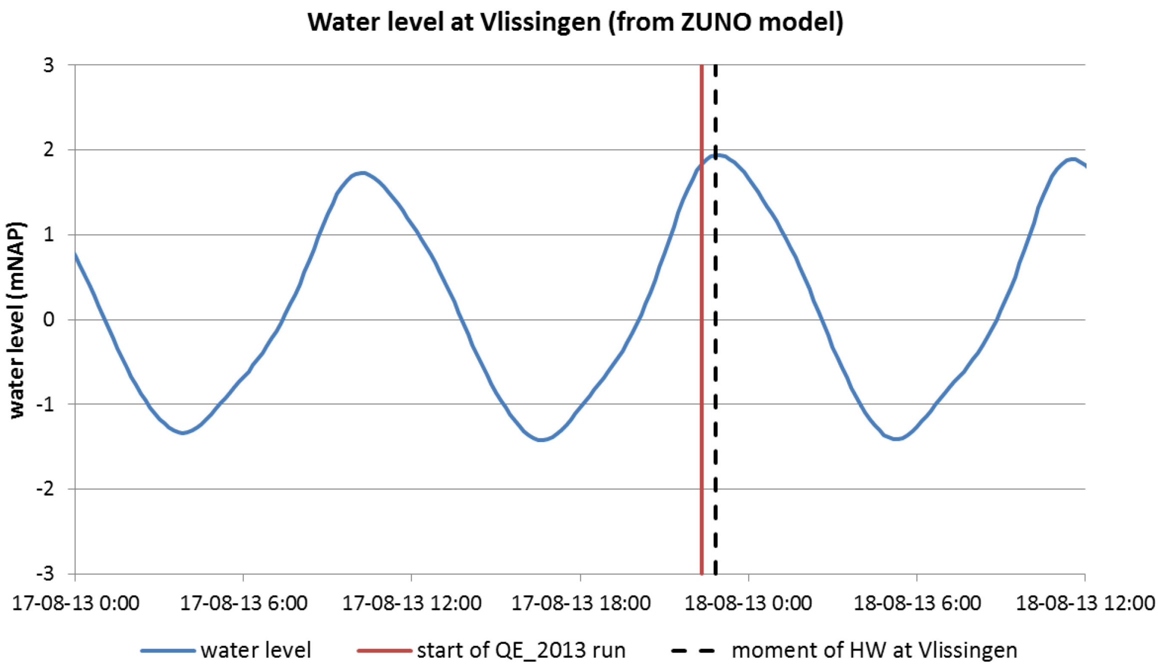


Figure 149 – Water level at Vlissingen at the start of the QE_2013 run



The ensemble analysis is done for the locations with available salinity measurements. These locations are plotted in brown colour in Figure 150.The salinity values provided by the University of Antwerp can be corrected based on the results of the ensemble analysis. The correction curve for 2013 is plotted in Figure 150.

The differences are calculated as:

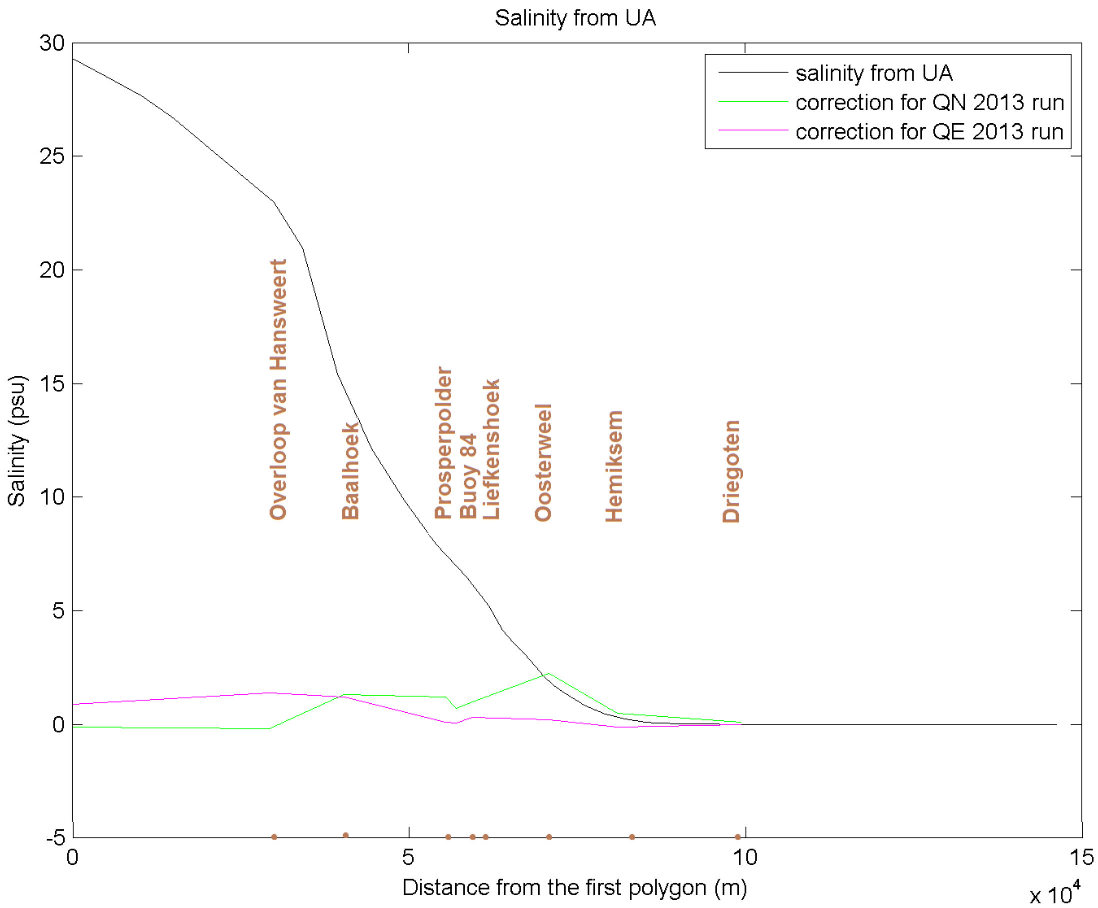
Difference at certain hour = Salinity at certain hour – Average salinity

Therefore, the salinity values from the University of Antwerp should be corrected as:

Corrected salinity $_{QN\ 2013}$ *= Average salinity (from UA)*$_{2013}$ *+ Difference* $_{(3:30\ after\ HW\ Vlissingen)\ average\ tide}$

Corrected salinity $_{QE\ 2013}$ *= Average salinity (from UA)*$_{2013}$ *+ Difference* $_{(0:30\ before\ HW\ Vlissingen)\ neap\ tide}$

Figure 150 – Salinity along the estuary from the University of Antwerp for runs 2013 and correction curves



The Scheldt estuary is divided in polygons and salinity is provided by the University of Antwerp for each polygon. The correction values are available only at 8 stations (Figure 151). The correction values in all other polygons are found by linear interpolation (Figure 152).

Figure 151 – Polygons from UA and available locations with the correction values

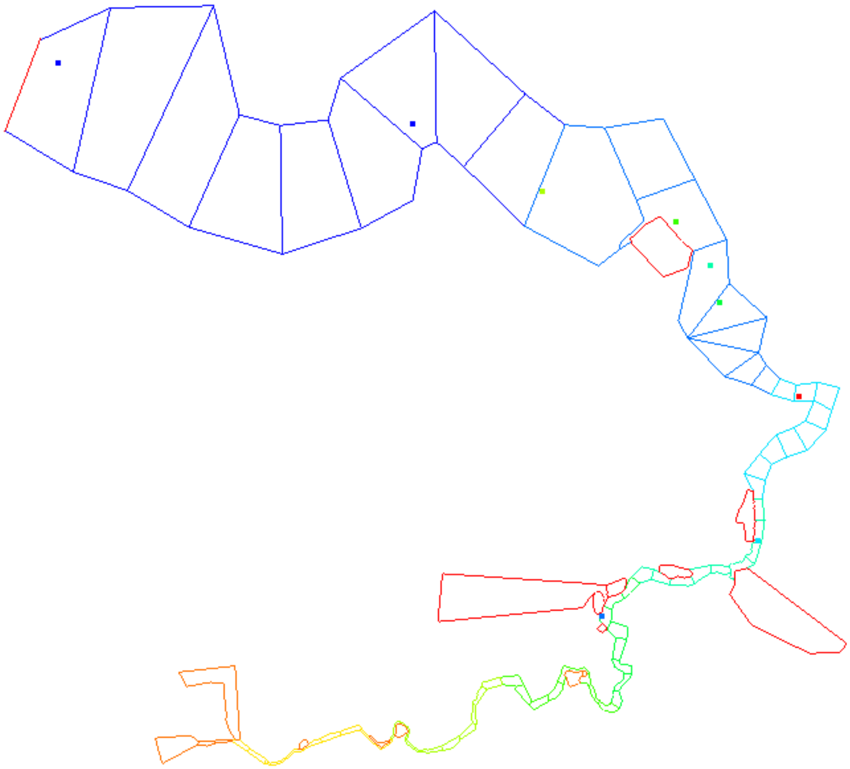
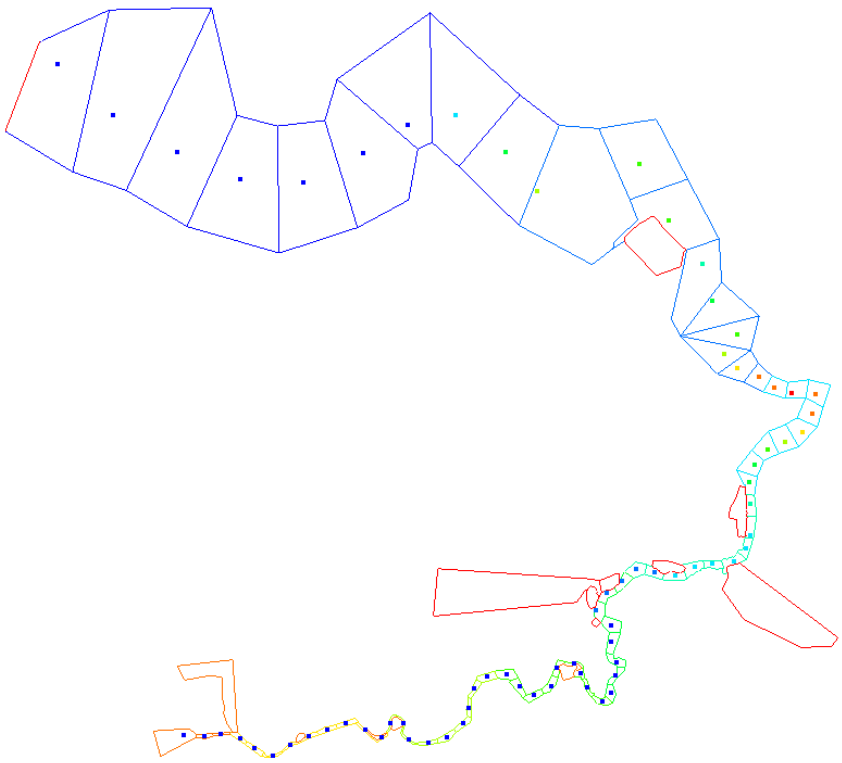


Figure 152 – Polygons from UA with correction values in each polygon (after interpolation)



7 Effect of the changes in Scaldis 2050 (compared to Scaldis 2013)

Three runs are analyzed to see the effect of changes in Scaldis 2050 (Table 9).

To see the effect of the boundary conditions (sea level rise in 2050) it was necessary to compare two runs for the same periods. Therefore, the sea level rise was implemented in the boundary conditions from 2013 in run **Scaldis_2050_RVW2013plus40**. The model developed for the year 2050 is run for the same period as the model for 2013. The boundary conditions from 2013 are increased with the sea level rise of 40 cm. All other setting are the same as in the 2050 model (grid, bathymetry, culverts).

In order to better understand the changes in the model, the changes in the schematization are done in two steps. In run **Scaldis_041_0_bathy_clvrt2050** the model grid and bathymetry for 2050 are implemented in the model run for 2013. The differences between this run and the run for 2013 are analyzed to see the effect of the grid and bathymetry change.

Table 9 – Model runs for the analysis of changes in 2050

Parameter	**Model run**		
	Scaldis_041_0_sis	**Scaldis_041_0_bathy_clvrt2050**	**Scaldis_2050_RVW2013plus40**
		Effect of grid and bathymetry	**Combined effect**
Bathymetry	2013	2050	2050
Grid	Grid of Scaldis 2013	Adapted grid for 2050	Adapted grid for 2050
Boundary conditions	2013	2013	Boundary conditions from 2013 + 40 cm
Culverts	2013	2050	2050

Figure 153 to Figure 155 show differences in high waters, low waters and complete water level times series.

There is no effect of the grid and bathymetry adaptation (in run **Scaldis_041_0_bathy_clvrt2050**) in the Western Scheldt. This is expected because most changes are implemented in the upstream part of the estuary. High waters decrease by 2 to 8 cm between Bath and Schoonaarde. They increase by 1 and 6 cm at Wetteren and Melle.

Low waters increase by 1 to 8 cm between Baalhoek and Melle. Bias in the complete water level time series is only 1 to 2 cm.

In run **Scaldis_2050_RVW2013plus40** we see the combined effect of the change of boundary conditions, grid and bathymetry. High waters increase by about 40 cm in the Western Scheldt (effect of sea level rise) and 25 to 55 cm more upstream (combined effect of all changes). Low waters increase by 33 to 46 cm. Differences in the complete water level time series are 37 to 44 cm.

Figure 153 – Differences in high water for runs with different bathymetry, grid and boundary conditions

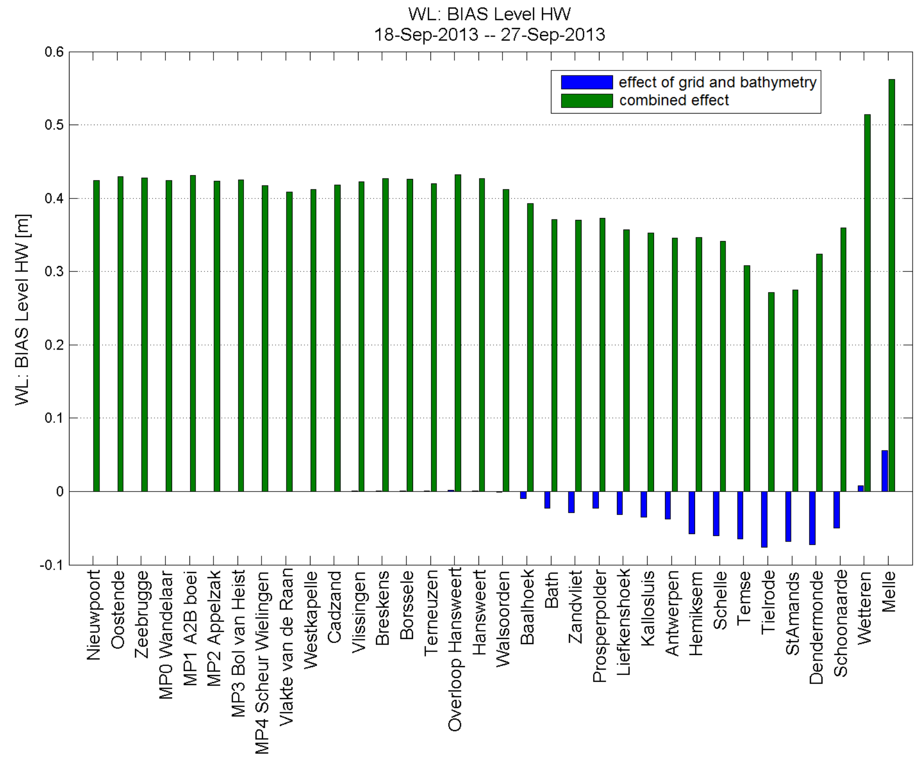


Figure 154 – Differences in low water for runs with different bathymetry, grid and boundary conditions

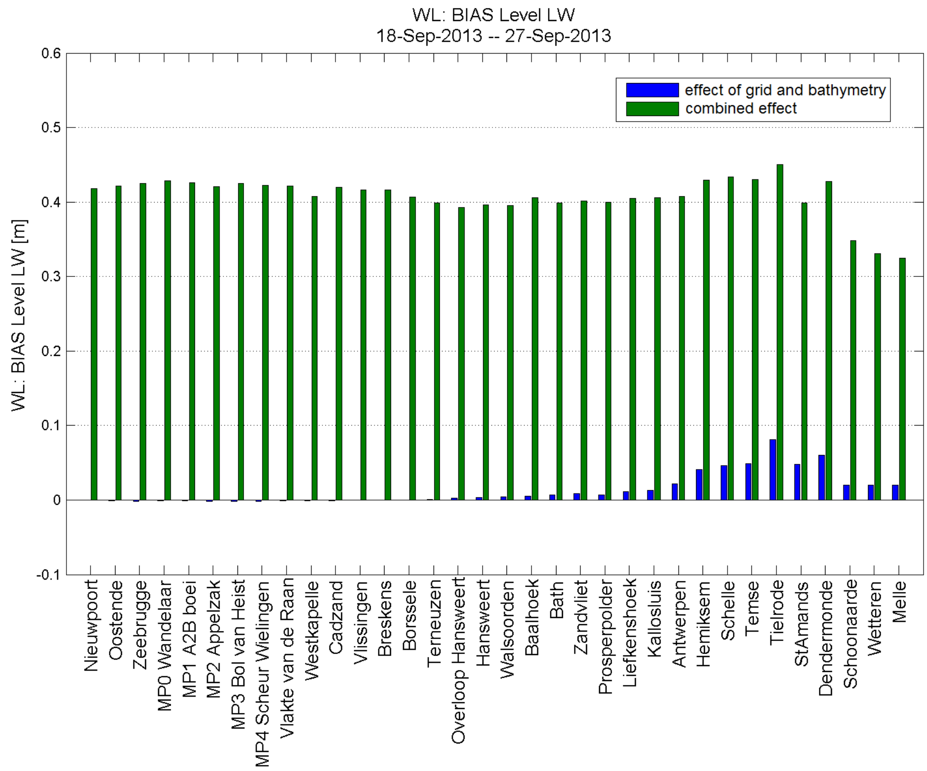
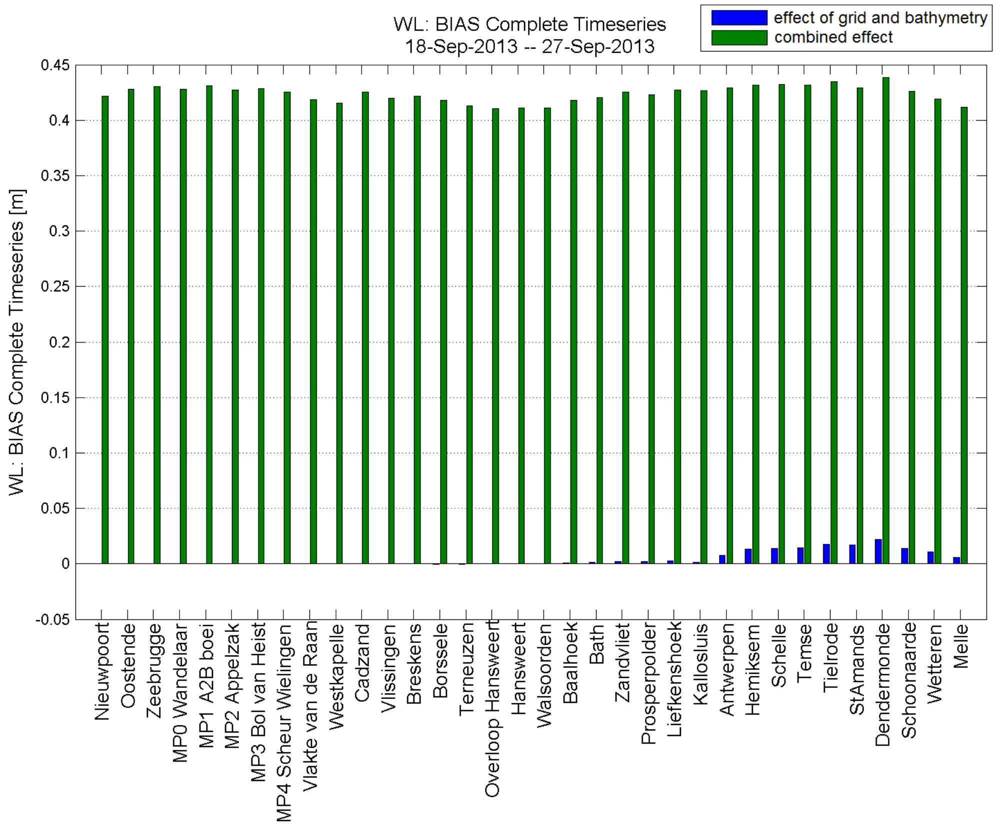


Figure 155 – Differences in the complete water level time series for runs with different bathymetry, grid and boundary conditions



8 List of scenarios

The TELEMAC model is used to evaluate the effects of different alternatives (specified morphology of the Scheldt river in a specific state and at a specific time), under different scenarios (a range of boundary conditions to take into account climate change, sea level rise, increasing or decreasing tidal amplitude, high or low discharge). The list of the scenario runs is presented in Table 10.

The model runs for the year 2013 are done with the TELEMAC model for 2013 described in Smolders et al., (2016). For the simulations of 2050 we use the model described in this report.

More detailed information about the alternatives and scenarios, model sequence and an overview of the data flow are given in the memo 'Afstemming Modelinstrumentarium' (IMDC, INBO, UA, WL, 2015).

Table 10 – List of scenario runs

Code	Year	Bathymetry (alternatives)	Type	Amplitude correction	Climate Scenario	Duration of run [days]
2013_Current_TR_A0_CN	2013	Current	TR	A0	CN	3
2013_Current_QN_A0_CN	2013	Current	QN	A0	CN	95
2013_Current_QE_A0_CN	2013	Current	QE	A0	CN	20
2050_Reference_TR_A0_CL	2050	Reference	TR	A0	CL	3
2050_Reference_QN_A0_CL	2050	Reference	QN	A0	CL	95
2050_Reference_QE_A0_CL	2050	Reference	QE	A0	CL	20
2050_Reference_TR_A0_CH	2050	Reference	TR	A0	CH	3
2050_Reference_QN_A0_CH	2050	Reference	QN	A0	CH	95
2050_Reference_QE_A0_CH	2050	Reference	QE	A0	CH	20
2050_Reference_TR_A-_CL	2050	Reference	TR	A-	CL	3
2050_Reference_QN_A-_CL	2050	Reference	QN	A-	CL	95
2050_Reference_QE_A-_CL	2050	Reference	QE	A-	CL	20
2050_Reference_TR_A+_CH	2050	Reference	TR	A+	CH	3
2050_Reference_QN_A+_CH	2050	Reference	QN	A+	CH	95
2050_Reference_QE_A+_CH	2050	Reference	QE	A+	CH	20
2050_Chafing_TR_A0_CL	2050	Chafing	TR	A0	CL	3
2050_Chafing_QN_A0_CL	2050	Chafing	QN	A0	CL	95
2050_Chafing_QE_A0_CL	2050	Chafing	QE	A0	CL	20
2050_Chafing_TR_A0_CH	2050	Chafing	TR	A0	CH	3
2050_Chafing_QN_A0_CH	2050	Chafing	QN	A0	CH	95
2050_Chafing_QE_A0_CH	2050	Chafing	QE	A0	CH	20
2050_Chafing_TR_A-_CL	2050	Chafing	TR	A-	CL	3
2050_Chafing_QN_A-_CL	2050	Chafing	QN	A-	CL	95
2050_Chafing_QE_A-_CL	2050	Chafing	QE	A-	CL	20

2050_Chafing_TR_A+_CH	2050	Chafing	TR	A+	CH	3
2050_Chafing_QN_A+_CH	2050	Chafing	QN	A+	CH	95
2050_Chafing_QE_A+_CH	2050	Chafing	QE	A+	CH	20
2050_VaH_TR_A0_CL	2050	VaH	TR	A0	CL	3
2050_VaH_QN_A0_CL	2050	VaH	QN	A0	CL	95
2050_VaH_QE_A0_CL	2050	VaH	QE	A0	CL	20
2050_VaH_TR_A0_CH	2050	VaH	TR	A0	CH	3
2050_VaH_QN_A0_CH	2050	VaH	QN	A0	CH	95
2050_VaH_QE_A0_CH	2050	VaH	QE	A0	CH	20
2050_VaH_TR_A-_CL	2050	VaH	TR	A-	CL	3
2050_VaH_QN_A-_CL	2050	VaH	QN	A-	CL	95
2050_VaH_QE_A-_CL	2050	VaH	QE	A-	CL	20
2050_VaH_TR_A+_CH	2050	VaH	TR	A+	CH	3
2050_VaH_QN_A+_CH	2050	VaH	QN	A+	CH	95
2050_VaH_QE_A+_CH	2050	VaH	QE	A+	CH	20
2050_VaG_TR_A0_CL	2050	VaG	TR	A0	CL	3
2050_VaG_QN_A0_CL	2050	VaG	QN	A0	CL	95
2050_VaG_QE_A0_CL	2050	VaG	QE	A0	CL	20
2050_VaG_TR_A0_CH	2050	VaG	TR	A0	CH	3
2050_VaG_QN_A0_CH	2050	VaG	QN	A0	CH	95
2050_VaG_QE_A0_CH	2050	VaG	QE	A0	CH	20
2050_VaG_TR_A-_CL	2050	VaG	TR	A-	CL	3
2050_VaG_QN_A-_CL	2050	VaG	QN	A-	CL	95
2050_VaG_QE_A-_CL	2050	VaG	QE	A-	CL	20
2050_VaG_TR_A+_CH	2050	VaG	TR	A+	CH	3
2050_VaG_QN_A+_CH	2050	VaG	QN	A+	CH	95
2050_VaG_QE_A+_CH	2050	VaG	QE	A+	CH	20
Total duration (days)						2006

TR : a short tracer run used for the calculation of the tracer data for the University of Antwerp .

QN : normal discharge scenario (more information is given in chapter 6.2.1) .

QE : events discharge scenario (more information is given in chapter 6.2.2).

Different tidal range scenarios (A0, A+, A-) and sea level rise scenarios (CN, CL, CH) are described in chapter 6.2.3 and chapter 6.2.4.

Estimation of computation time :

All tracer simulations together account for 51 days to be simulated. On the FHR linux cluster an average speed up time for tracer simulations is 0.019/cpu. If we use the complete Reynolds cluster (our newest and fastest cluster with 8 nodes of 16 cpu = 128 cpu) we will need 21 days to simulate all tracer runs.

All QN scenarios together account for 1520 days to be simulated. On the FHR linux cluster an average speed up time for QN simulations with the Scaldis 2050 model is 0.138/cpu. If we use the complete Reynolds cluster (our newest and fastest cluster with 8 nodes of 16 cpu = 128 cpu) we will need 86 days to simulate all QN runs.

All QE scenarios together account for 320 days to be simulated. On the FHR linux cluster an average speed up time for QN simulations with the Scaldis 2050 model is 0.138/cpu. If we use the complete Reynolds cluster (our newest and fastest cluster with 8 nodes of 16 cpu = 128 cpu) we will need 18 days to simulate all QE runs.

9 List of references

Bodhaine, G.L., 1968. Measurement of peak discharge at culverts by indirect methods: U.S. Geological Survey, Techniques of Water-Resources Investigations, book 3, chapter A3 60p

Coen, L.; Verelst, K.; Vercruysse, J.; Peeters, P.; Mostaert, F. (2014). Sigmaplan - gereduceerde getijdegebieden - schaalmodelproeven gecombineerde in- en uitwateringsconstructies: deelrapport 6. Aanpassing debiet/hoogte-relaties GGG-inwateringen in MIKE11 op basis van resultaten schaalmodelproeven. Versie 3.0. WL Rapporten, 00_075. Waterbouwkundig Laboratorium: Antwerpen. IV, 42 pp.

Cox, T., Maris, T., De Vleeschauwer, P., De Mulder, T., Soetaert, K., Meire, P. (2006). Flood control areas as an opportunity to restore estuarine habitat. Ecological Engineering 28, 55–63.

IMDC (2015). Bepalen van randvoorwaarden voor de referentiesituatie (2050) m.b.t. debiet en waterstand. I/NO/11448/15.128/TFR/

IMDC (2015a). Duurzaam Beheerplan Boven-Zeeschelde. Duurzame bathymetrie. I/RA/11448/14.240/JFA/

IMDC/INBO/UA/WL (2015). Modelling instruments for Integrated Plan Upper Sea Scheldt. I/NO/11448/14.165/DDP

Maris, T., Cox, T., Temmerman, S., De Vleeschauwer, P., Van Damme, S., De Mulder, T., Van den Bergh, E., Meire, P. (2007). Tuning the tide: creating ecological conditions for tidal marsh development in a controlled inundation area. Hydrobiologia 588, 31–43.

Maximova, T.; Vanlede, J.; Verwaest, T; Mostaert, F. (2015a). Vervolgonderzoek bevaarbaarheid Bovenzeeschelde: Subreport 4 – Modellentrein CSM – ZUNO: validatie 2013. Version 3.0. WL Rapporten, 13_131. Flanders Hydraulics Research: Antwerp, Belgium

Maximova, T.; Smolders, S.; Schramkowski, G.; Verwaest, T.; Mostaert, F. (2015b). Verkennende studie kribben Fort Filip: Deelrapport II. aanvullende scenario's. Versie 1.0. WL Rapporten, 15_042. Waterbouwkundig Laboratorium: Antwerpen, België.

Peeters, P.; Claeys, S.; Michielsen, S.; De Schutter, J.; Temmerman, S.; Meire, P.; Vandenbruwaene, W.; Maris, T.; Chen, M.; Wartel, S. (2009). Sediment behaviour within a flood control area with a controlled reduced tide - pilot project Lippenbroek = Processus sédimentologiques dans un zone de contrôle d'inondations et de marée réduite controlée - projet pilote Lippenbroek, in: (2009). Congrès SHF-31ième Journées de l'hydraulique: "Morphodynamiques et débits solides dans les estuaires, les baies et les deltas" Paris, 22-23 septembre 2009 [CD-ROM]. pp. [1-15]

Smolders, S.; Maximova, T.; Vanlede, J.; Verwaest, T.; Mostaert, F. (2016). Integraal Plan Bovenzeeschelde: Subreport 1 – 3D Hydrodynamisch model Zeeschelde en Westerschelde. Version 3.0. WL Rapporten, 13_131. Flanders Hydraulics Research: Antwerp, Belgium.

Temmerman, S., Govers, G., Meire, P., Wartel, S. (2003). Modelling long-term tidal marsh growth under changing tidal conditions and suspended sediment concentrations, Scheldt estuary, Belgium. Marine Geology 193, 151–169.

Temmerman, S.; Govers, G.; Wartel, S.; Meire, P. (2004). Modelling estuarine variations in tidal marsh sedimentation: response to changing sea level and suspended sediment concentrations. Mar. Geol. 212(1-4): 1-19. dx.doi.org/10.1016/j.margeo.2004.10.021

Vandenbruwaene, W.; Maris, T.; Cox, T.J.S.; Cahoon, D.R.; Meire, P.; Temmerman, S. (2011). Sedimentation and response to sea-level rise of a restored marsh with reduced tidal exchange: Comparison with a natural tidal marsh. Geomorphology (Amst.) 130(3-4): 115-126. dx.doi.org/10.1016/j.geomorph.2011.03.004

Vandenbruwaene, W.; Vanlede, J.; Plancke, Y.; Verwaest, T.; Mostaert, F. (2015a). Inrichtingsplan Hedwige-Prosperpolder: Deelrapport 3 – Empirisch ophogingsmodel. Versie 6.0. WL Rapporten, 13_166. Waterbouwkundig Laboratorium: Antwerpen, België.

Vandenbruwaene, W.; Vanlede, J.; Plancke, Y.; Verwaest, T.; Mostaert, F. (2015b). Slibbalans Zeeschelde: Deelrapport 4 – Historische evolutie SPM. Versie 5_0. WL Rapporten, 00_029. Waterbouwkundig Laboratorium & Antea: Antwerpen, België.

Wang, C. & Temmerman, S. (2013). Does biogeomorphic feedback lead to abrupt shifts between alternative landscape states?: An empirical study on intertidal flats and marshes. Journal of Geophysical Research-Earth Surface 118(1): 229-240

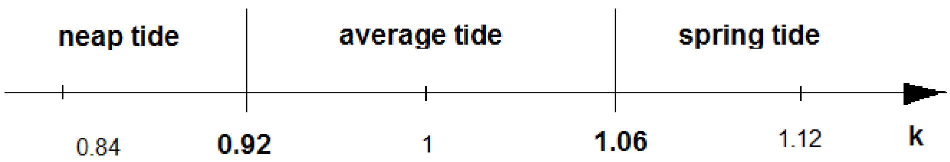
Wang, C.; Temmerman, S.; Vanlede, J.; Vandenbruwaene, W.; Verwaest, T.; Mostaert, F. (2014). Mud balance Sea Scheldt: Subreport 6 - Historical evolution (1930-2011) of mud deposition/erosion in the intertidal areas of the Scheldt estuary. Version 4.0. WL Rapporten, 00_029. Flanders Hydraulics Research & University of Antwerp, Ecosystem Management research group: Antwerp, Belgium.

Appendix 1. Tidal coefficients

A tidal coefficient is calculated as a ratio of the tidal amplitude during the analyzed period to the amplitude of the average tide for the period from 1991 to 2000. Tidal coefficients are calculated for all analysed tides based on the measured water levels at Antwerp.
Table 11 shows the typical values of the tidal coefficients corresponding to the neap, average and spring tides. Tides with coefficients higher than 1.06 are considered to be spring tides; tides with coefficients lower than 0.92 are neap.

Table 11 – Typical values of the tidal coefficients for neap, average and spring tides

Tide	Amplitude at Antwerp (m)	k
Neap	4.43	0.84
Average	5.29	1
Spring	5.95	1.12



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