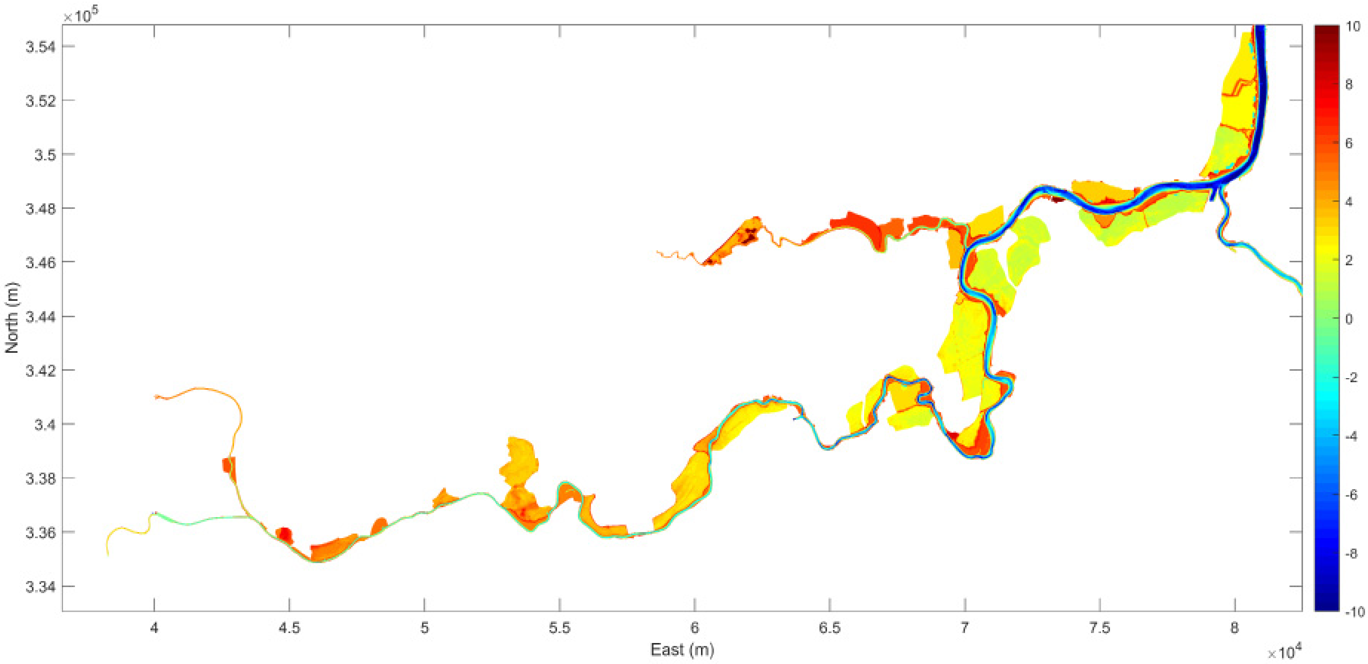

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Sub report 13
Implementation of C alternatives

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Sub report 13 – Implementation of C alternatives

Bi, Q.; Smolders, S.; Vanlede, J.; Mostaert, F.

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D/2020/3241/122

This publication should be cited as follows:

Bi, Q.; Smolders, S.; Vanlede, J.; Mostaert, F. (2020). Integraal Plan Bovenzeeschelde: Sub report 13 – Implementation of C alternatives. Version 1.0. FHR Reports, 13_131_13. Flanders Hydraulics Research: Antwerp.

Document identification

Customer:	dVW-RegioCentraal	Ref.:	WL2020R13_131_13
Keywords (3-5):	Scaldis-model, Scheldt estuary, Hydrodynamics, Telemac		
Knowledge domains	Water management > Hydraulics > Hydrodynamic model > Numerical modelling		
Text (p.):	54	Appendices (p.):	12
Confidentiality:	☒ No	☒ Available online	

Author(s):	Bi, Q.

Control

	Name	Signature
Reviser(s):	Smolders, S.; Vanlede, J.	Getekend door: Sven Smolders (Signature) Getekend op: 2020-06-25 12:38:21 +01:00 Reden: Ik keur dit document goed Sven Smolders Joris Vanlede
Project leader:	Vanlede, J.	Getekend door: Joris Vanlede (Signature) Getekend op: 2020-06-25 11:12:25 +01:00 Reden: Ik keur dit document goed Joris Vanlede

Approval

Head of Division:	Mostaert, F.	Getekend door: Frank Mostaert (Signature) Getekend op: 2020-06-25 08:09:25 +01:00 Reden: Ik keur dit document goed Frank Mostaert

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Abstract

This report details the implementation of the C alternatives in the Scaldis model. The definition of the C alternatives has three variations (C1 to C3), which have been described briefly in the memo ‘Towards the definition of C alternatives’ (IMDC, 2019) which has been discussed with international experts (EGIPUS) in a workshop 18th June 2019.

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1 Introduction

The most important objective in the project 'Integrated Plan for the Upper-Seascheldt' is to prepare the estuary for undesired evolutions as a consequence of climate change, cumulative effects of past and ongoing interventions downstream of the project area, and securing resilience of estuary functions such as nature, safety and navigability (Vansteenkiste and Adams, 2020). For achieving this goal, a numerical model chain is developed as an effective instrument to study the system response to the changes. This requires that the numerical models not only have the capability of describing the current estuarine functioning, but also the extrapolability of predicting reasonable effects with the future scenarios.

In the framework of the project 'Integrated Plan for the Upper-Seascheldt', a calibrated and validated 3D hydrodynamic - sediment transport model (the SCALDIS model) is developed with the TELEMAC modelling suite. The model adopts an unstructured high resolution grid and it covers the entire tidally influenced zone of the Scheldt estuary and the mouth area with a sufficient resolution in the upstream part, including the Upper Sea Scheldt and the other tributaries (Smolders et al., 2019).

For aligning with the goal of the project, the hydrodynamic - sediment transport model is used to study future (2050) scenarios/alternatives of the Scheldt estuary. An evaluation framework is developed, taking hydrodynamic, ecological, morphological and nautical aspects into account to quantify the effects in the different modelled future situations (Ref 2050, B and C alternatives – see Table 1).

Table 1 – Overview of studied estuarine situations (Vansteenkiste and Adams, 2020)

	2013	2050
Current channel	Current situation (ACT 2013)	Current situation + decided policy (mainly Sigma-plan) (REF 2050)
Future alternatives	n/a	B and C alternatives

The effects of B alternatives is studied and reported in Bi et al. (2019). This report details the implementation of the C alternatives in the Scaldis model. The definition of the C alternatives has three variations, which have been described briefly in the memo 'Towards the definition of C alternatives' (IMDC, 2019) which has been discussed with international experts (EGIPUS) in a workshop 18th June 2019.

2 Design principles of the C - alternatives

Based on the expert knowledge of the estuary, the lessons learnt from the previous study of B alternatives, the following principles are considered in the design of the C alternatives, for achieving the sustainable development of the estuary (Vansteenkiste and Adams, 2020):

- Limiting flow speed;
- Limiting tidal dynamics;
- Stimulating primary production;
- Limiting turbidity;
- Extra tidal flats, marsh and FCA/CRT;
- Improved water quality of the estuary;
- Buffering of peak flows;

Moreover, it is advised to spread the measures and make them diversified according to different locations.

Combining all these principles in the design, it is expected to a combination of measures that creates a more resilient system that is able to cope with expected and unknown changes in combination with an improved navigation channel aiming at nautical accessibility of ECMT class Va ships. To be more specific, the aim of designing the C alternatives is to tackle the bottlenecks caused by the B alternatives, and improve ecosystem functioning, creating better navigation conditions, safeguard (or even improve) the safety (against flooding) function, create habitat to provide better conditions for birds and fish.

A gradual approach is taken in building up the C alternatives in order to fully understand the extent, to which measures of a certain scale respond. Generally, in the C alternatives, different focuses are put between the up and downstream section. For the upstream, it is important to improve the riverine and safety functions, while for the downstream, it becomes crucial to improve the estuarine functions. The three alternatives are developed with the following mindset (Vansteenkiste and Adams, 2020):

- **C1 alternative**: Tackle the most prominent nautical bottlenecks (Km 0 – Ringvaart, km 10 – Wetteren, km 15 till 17 – Hoogland and Uitbergen, Km 30 – Kasteeltje, km 40 – Kramp). Looking for opportunities in the river and redefining the Sigma plan to improve habitat and reduce increase in tidal amplitude (from climate change and due to nautical changes).
- **C2 alternative**: Tackle also less prominent nautical bottlenecks and define additional measures for the most prominent bottlenecks. Include additional opportunities in the valley (depolderings, side channels) to improve habitat and reduce increase in tidal amplitude.
- **C3 alternative**: Yet additional nautical measures for a limited number of locations (Uitbergen, Paardenweide, Kasteeltje) and additional measures (larger derpolderings, additional depoldering at Weert, undeepening at Temse) aiming at providing extra (climate) resilience while also improving habitat conditions.

All the C alternatives are designed based on the sustainable bathymetry for 2050 (IMDC, 2015). In general, there are three types of measures incorporated in the design:

- Adaptations to the navigation channel;
- Adaptations to the channel bathymetry to allow for intertidal nature development;
- Definition of additional areas in the valley (depoldering, CRT, FCA).

The overview of the implemented measures is presented in Table 2.

Table 2 – Overview of all measures in the C alternatives

<table>
<tr><th rowspan="2"></th><th rowspan="2">Distance to Merelbeke [km]</th><th colspan="3">Overview measures</th><th>MHW</th><th>MLW</th></tr>
<tr><th>C1</th><th>C2</th><th>C3</th><th>[m TAW]</th><th>[m TAW]</th></tr>
<tr><td>Ringvaart</td><td>0-3</td><td colspan="3">Deepening and widening</td><td>5.05</td><td>2.44</td></tr>
<tr><td>Veerhoek</td><td>4</td><td>-</td><td colspan="2">Widening + pull back of dyke</td><td>5.05</td><td>2.44</td></tr>
<tr><td>Melleham</td><td>5</td><td>Limited tidal interaction</td><td>CRT without FCA</td><td>Depoldering</td><td>5.05</td><td>2.44</td></tr>
<tr><td>Bommels</td><td>6</td><td>-</td><td colspan="2">Widening + pull back of dyke</td><td>5.06</td><td>2.37</td></tr>
<tr><td>Voorde</td><td>8</td><td colspan="3">Bend modifications + intertidal nature</td><td>5.07</td><td>2.28</td></tr>
<tr><td>Wetteren</td><td>10-11</td><td>-</td><td colspan="2">Improved navigation (cfr VaG) by installing sheet piles</td><td>5.08</td><td>2.23</td></tr>
<tr><td>DS Wetteren</td><td>11</td><td colspan="3">Depoldering</td><td>5.08</td><td>2.23</td></tr>
<tr><td>FCA Wijmeers</td><td>13</td><td>-</td><td colspan="2">Additional FCA in the north</td><td>5.08</td><td>2.12</td></tr>
<tr><td>Wijmeers (Hoogland)</td><td>14</td><td colspan="3">Bend cut off (3 variants) + intertidal nature+FCA</td><td>5.10</td><td>2.10</td></tr>
<tr><td>Uitbergen</td><td>16</td><td colspan="3">Bend cut off + intertidal nature+depoldering
(3 variants)</td><td>5.10</td><td>2.02</td></tr>
<tr><td>Paardenweide (Wichelen)</td><td>18</td><td>-</td><td>-</td><td>Bend cut off+depoldering</td><td>5.10</td><td>1.95</td></tr>
<tr><td>Oude Broekmeer</td><td>23</td><td>-</td><td>Depoldering variant 1 + side channel</td><td>Depoldering variant 2 + side channel</td><td>5.17</td><td>1.63</td></tr>
<tr><td>Appels (Scheldebroek)</td><td>27</td><td colspan="3">Improved navigation (cfr Chafing)</td><td>5.20</td><td>1.50</td></tr>
<tr><td>Scheldebroek</td><td>27</td><td colspan="3">FCA Scheldebroek converted into FCA-CRT</td><td>5.20</td><td>1.50</td></tr>
<tr><td>Sint-Onolfspolder</td><td></td><td>-</td><td>Depoldering variant 1 + side channel variant 1</td><td>Depoldering variant 1 + side channel variant 2</td><td>5.20</td><td>1.50</td></tr>
<tr><td>Kasteeltje</td><td>30</td><td colspan="3">Bend smoothening + intertidal nature
(3 variants)</td><td>5.27</td><td>1.24</td></tr>
<tr><td>Dender</td><td>32</td><td>-</td><td colspan="2">Improved navigation by widening channel</td><td>5.3</td><td>1.12</td></tr>
<tr><td>Grembergen broek – Armenput</td><td>35-36</td><td>-</td><td colspan="2">Depoldering</td><td>5.34</td><td>1.02</td></tr>
<tr><td>Waterleiding</td><td>37</td><td colspan="3">Improved navigation (cfr Chafing) by widening channel</td><td>5.38</td><td>0.91</td></tr>
<tr><td>Roggeman</td><td>38</td><td>-</td><td>Depoldering variant 1</td><td>Depoldering variant 2</td><td>5.40</td><td>0.85</td></tr>
<tr><td>Kockham (Kramp)</td><td>39</td><td colspan="3">Bend cut off + intertidal nature
(C1: variant 1; C2-C3: variant 2)</td><td>5.44</td><td>0.75</td></tr>
</table>

	Distance to Merelbeke [km]	Overview measures			MHW	MLW
		C1	C2	C3	[m TAW]	[m TAW]
Wal-Zwijn	43	FCA	FCA with CRT	FCA with CRT	5.50	0.59
Blankaart	48	FCA	Depoldering variant 1	Depoldering variant 2	5.55	0.40
Akkershoofd	49	-	-	Depoldering together with Blankaart	5.54	0.38
Tielrode Broek	53	New connection with Durme + partly depoldering Tielrode Broek			5.52	0.31
Weert	50-57	-	-	Depoldering	5.52	0.31
Temse to Rupel	57-63	Local undeepening		Local undeepening + filling deep parts	5.46	0.15
Schouselbroek	59	-	Depoldering + new side channel		5.47	0.19
Schellandpolder	61	-	Depoldering + new side channel		5.47	0.16
Oudbroekpolder	62	-	Depoldering + new side channel		5.45	0.13

3 Methodology

3.1 Implementation of C alternatives

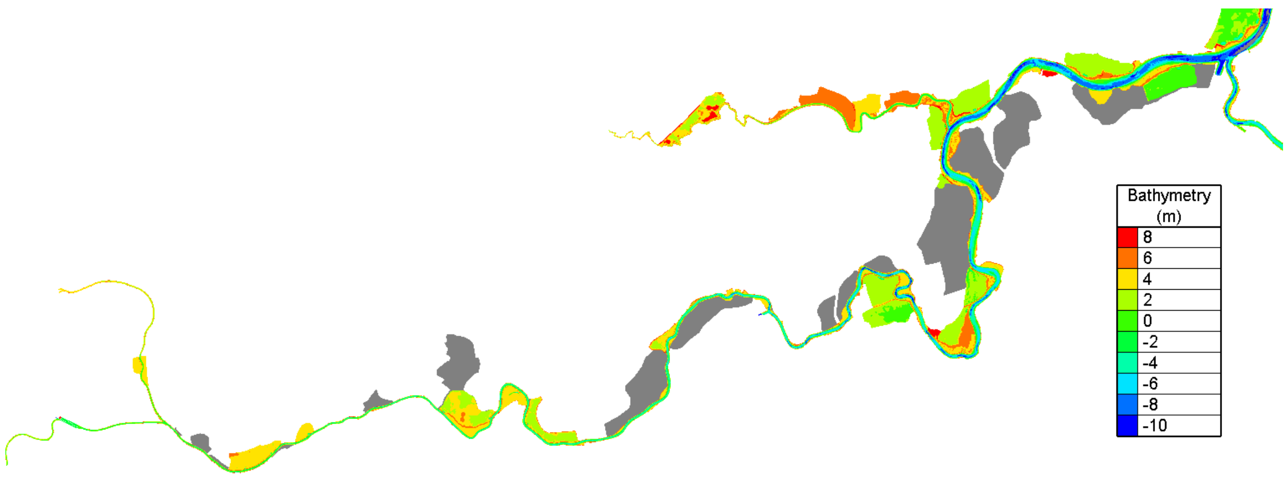
3.1.1 New reference grid

For implementing the three different C alternatives (C1, C2 and C3) in the SCALDIS model, a new reference grid is created based on the original 2050REF grid used in the B-alternatives (**2050REF_B**). This new reference grid, named **2050REF_C**, is then used as the basis for implementing the C alternatives.

The new reference grid is obtained by extending and refining the 2050REF_B mesh in the Upper Sea Scheldt in order to include the maximum outline of all C alternatives. For the rest of the domain except in the Ringvaart (a widened and deepend Ringvaart is applied to the 2050REF_C and all the C alternatives later), the grid remains unmodified, in order to allow the reuse of the boundary data. In the extended areas in the Upper Sea Scheldt, the finest grid resolution is about 7 m, and the coarsest resolution is about 50 m.

The new reference grid is able to accommodate the adaptations of the navigation channel, the new development of intertidal nature and the additional de-embankments and FCAs (with and without CRT), which are considered in any of the C alternatives.

Figure 1 – Overview of the extended grid in the Upper Sea Scheldt (the extended areas are indicated in grey)



3.1.2 New reference bathymetry

The sustainable bathymetry in the 2050REF_B grid with the deepening and widening of the Ringvaart is mapped to the new reference grid 2050REF_C (Figure 1), except for the newly extended areas (indicated in grey).

First a nautical design channel was introduced in all C alternatives – to include all measures to improve navigation, with a bottom depth to match the design depth correlated to the deepening of the Ringvaart as outlined in the feasibility study (IMDC, 2013).

For the extended areas, the background bathymetry without any modification from the C alternatives (provided by IMDC) is used as the data source. The background bathymetry does not contain any measure for 2050, it represents the current situation.

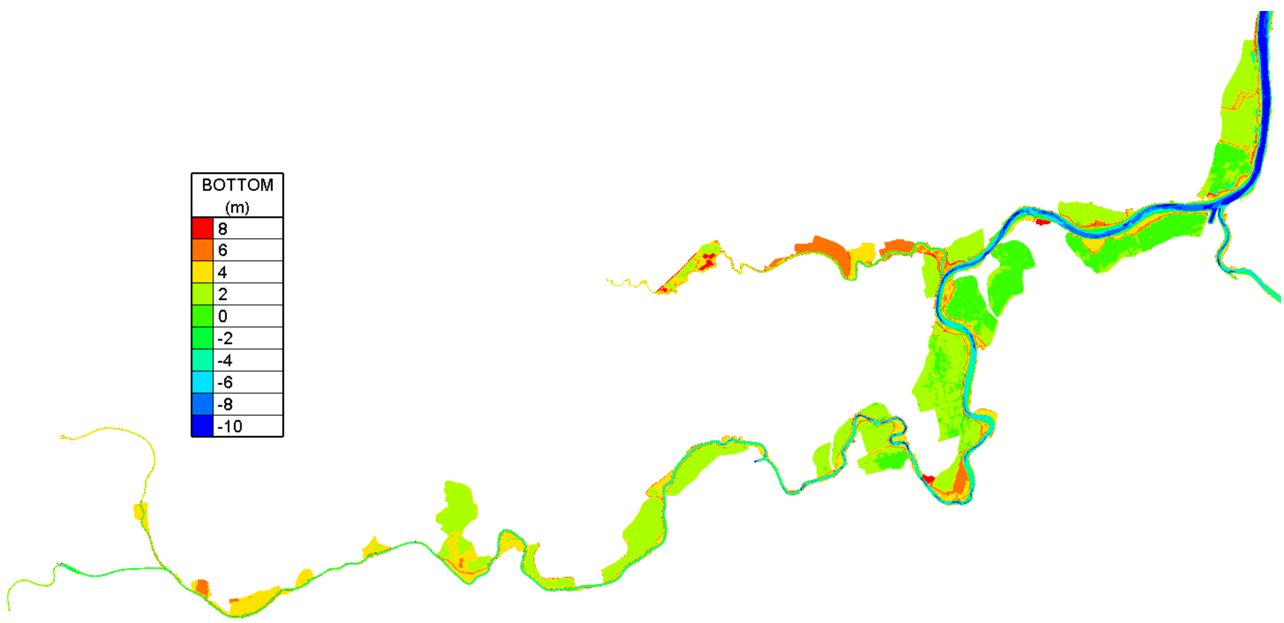
The following table gives an overview of the areas with the background bathymetry data.

Table 3 – The list of areas with the background bathymetry

Distance to Merelbeke [km]	Area
5	Melleham
12	Downstream Wetteren
13	Wijmeers (North)
23	Oude Broekmeer
27	Sint-Onolfspolder
35	Grembergen Broek
39	Roggeman
48	Blankaart-Akkershoofd
50-57	Depoldering Weert
59	Spierbroekpolder
60	Hingene Broekpolder

The final grid of 2050REF_C is shown in Figure 2.

Figure 2 – The new reference grid 2050REF_C with the combined bathymetric data



3.1.3 Adaptations of bathymetry

When incorporating the C alternatives, the new bathymetry from C1, C2 and C3 is mapped to the 2050REF_C grid, respectively. There are 3 main types of measures in the C alternatives, modification of navigation channels, creation of new side channels and additional depoldering and/or FCA areas. Those measures are implemented and result in three new grids for C1, C2 and C3.

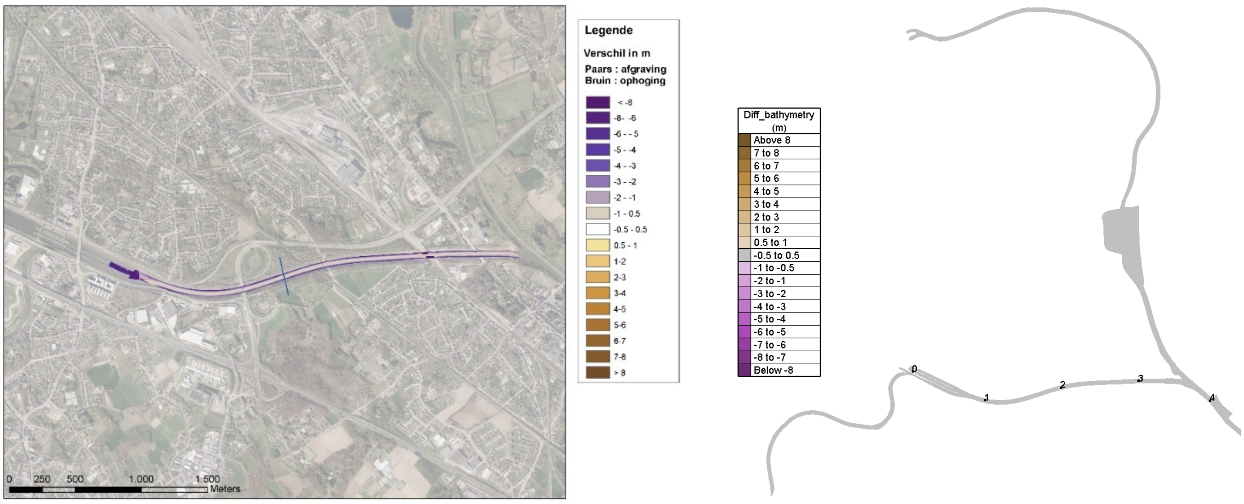
In order to check the implementation of the measures, a comparison is made. For each channel section, the map of bathymetry difference in the IMDC memo (Vansteenkiste and Adams, 2020) is compared with the bathymetric difference in Telemac. The bathymetry difference is calculated by subtracting the reference bathymetry in 2050REF_C grid from the bathymetry in the new grid after implementing the C alternatives.

The kilometre mentioned in this section for each measure is expressed as the distance from the of the downstream head of the lock of Merelbeke.

Km 0-4 : Deepening and widening of the Ringvaart (C1-C2-C3)

This measure is present already in some of the B alternatives. It will lead to an improved tidal window for navigation, and will be implemented in all the three C alternatives and the reference 2050REF_C.

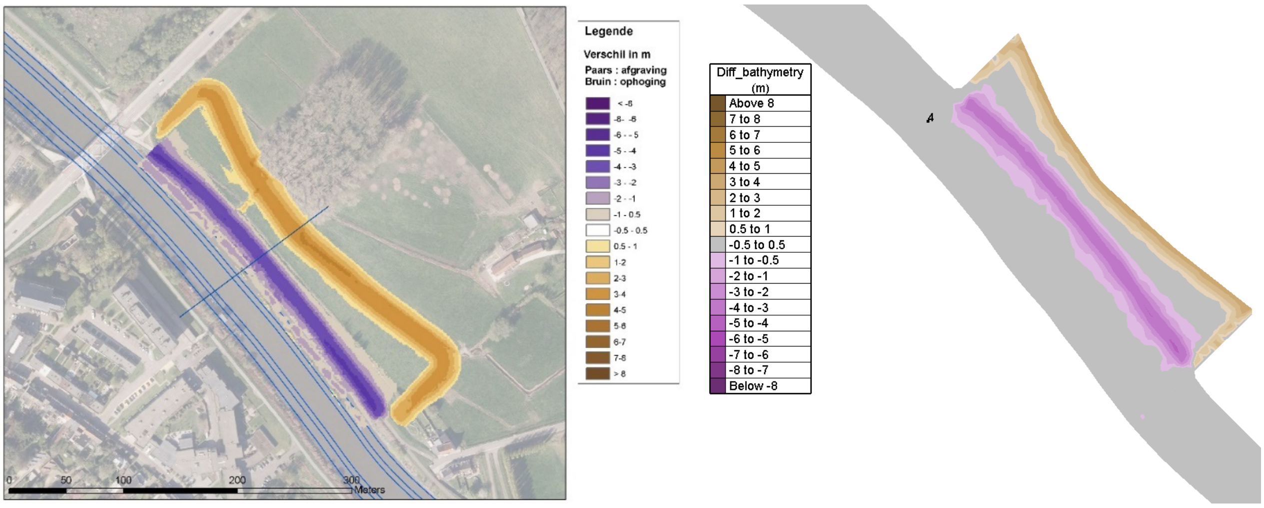
Figure 3 – Comparison of bathymetry difference in Ringvaart
(left: IMDC data, right: derived from Telemac grids)



Km 4 – 4.4 : Veerhoek dikes more inland (widening profile) (C2-C3)

The measure provides room for the development of tidal flats, but also to slightly widening the river profile (2 m to towards the left bank) to improve navigation conditions. This could also be considered as a small depoldering. This measure is only implemented in the C2 and C3-alternative since this location is no prominent nautical bottleneck.

Figure 4 – Comparison of bathymetry difference at km 4 – 4.4
(left: IMDC data, right: derived from Telemac grids)

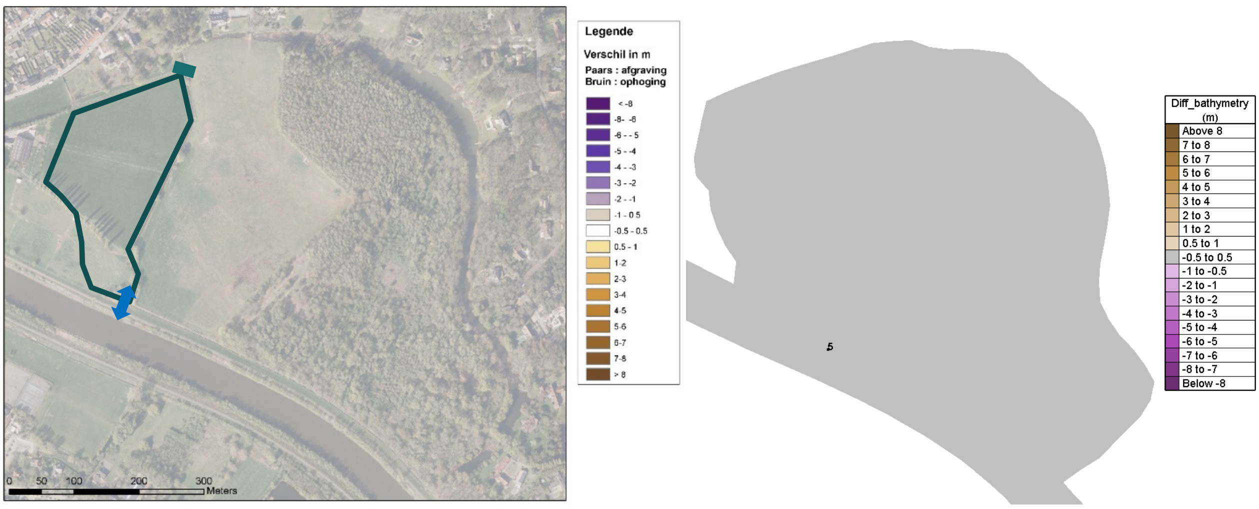


Km 5 : Extra depoldering Melleham

A new (non–Sigma) area between the confluence of the Ringvaart/Upper Seascheldt and Bastenakkers is suggested for depoldering (Melleham - km 5).

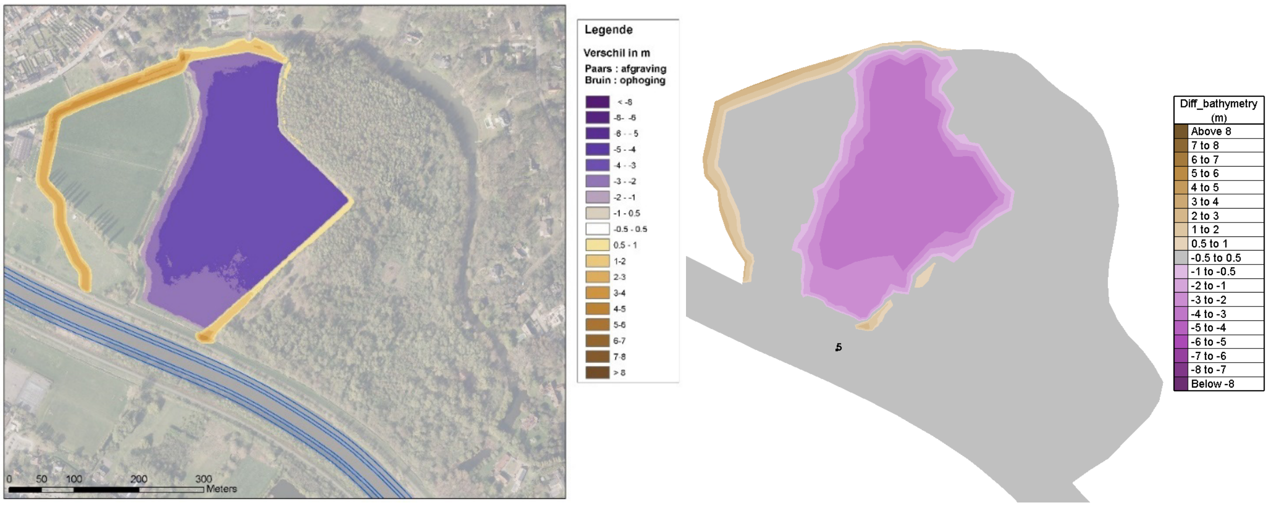
C1-alternative: one inlet structure to allow some exchange with the Scheldt – limited tidal action, no safety function, will be closed during high water (not to be included in the hydrodynamic simulation) + connection with lower area in the west. This measure mainly aims to be a stepping stone for nature development.

Figure 5 – Comparison of bathymetry difference at km 5 in C1 alternative
(left: IMDC data, right: derived from Telemac grids)



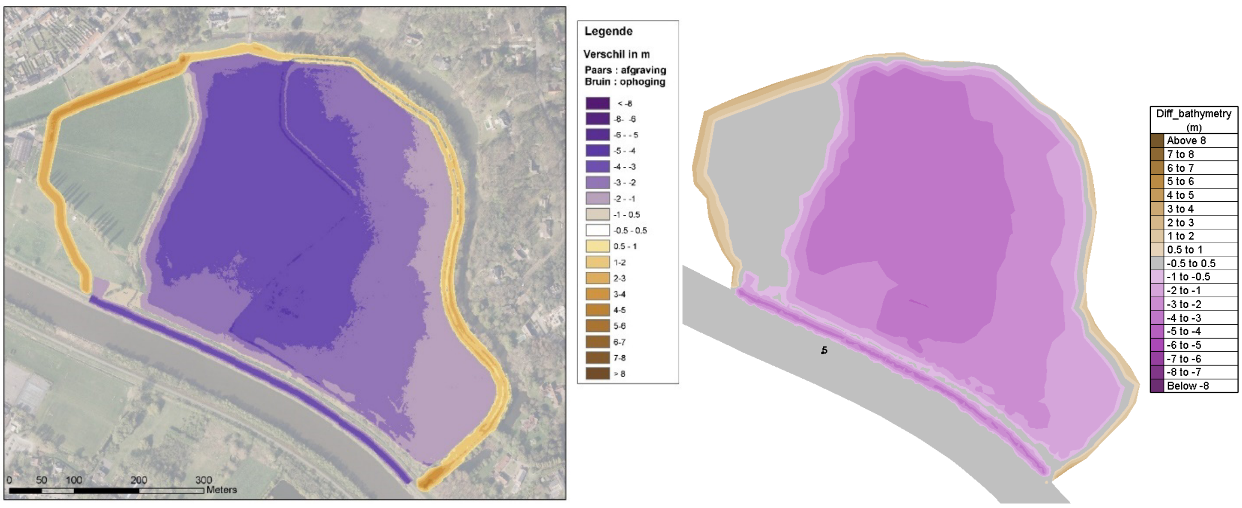
C2-alternative: C1-alternative + excavation of area in the east (till 4 m TAW) until trees are reached (CRT without FCA). (Maintain trees as a measure against midges). Inlet structure to be further defined by Flanders Hydraulics.

Figure 6 – Comparison of bathymetry difference at km 5 in C2 alternative
(left: IMDC data, right: derived from Telemac grids)



C3-alternative: C2-alternative + excavation to a level of 4 m TAW for the higher area in the east (depoldering).

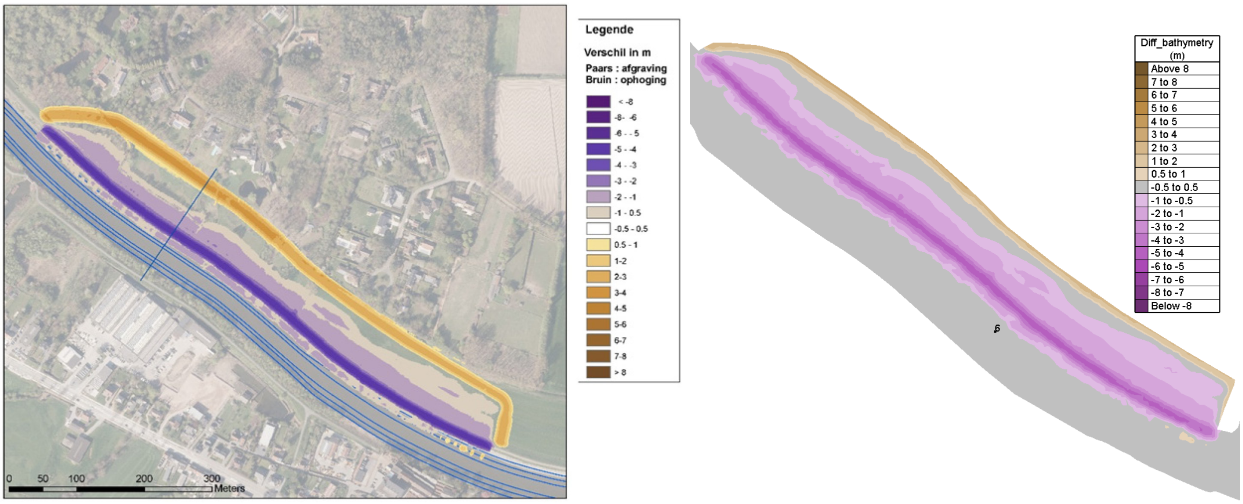
Figure 7 – Comparison of bathymetry difference at km 5 in C3 alternative
(left: IMDC data, right: derived from Telemac grids)



Km 6 : Bommels dikes more inland (widening profile) (C2-C3)

The measure provides room for the development of tidal flats, but also to slightly widening the river profile (2m towards the left bank) to improve navigation conditions. This measure is only implemented in the C2 and C3-alternative since this is not considered as a prominent nautical bottleneck.

Figure 8 – Comparison of bathymetry difference at km 6 in C2-C3 alternative
(left: IMDC data, right: derived from Telemac grids)



Km 8-9: Nautical bottleneck Voorde (C1-C2-C3)

The navigation profile is shifted towards the right bank and the slopes are altered to allow for intertidal nature development on left (tidal marshes) and right bank (tidal flats) according to the principles stated in section 4.1. This measure is implemented in all alternatives.

Figure 9 – Comparison of bathymetry difference at km 8-9
(left: IMDC data, right: derived from Telemac grids)

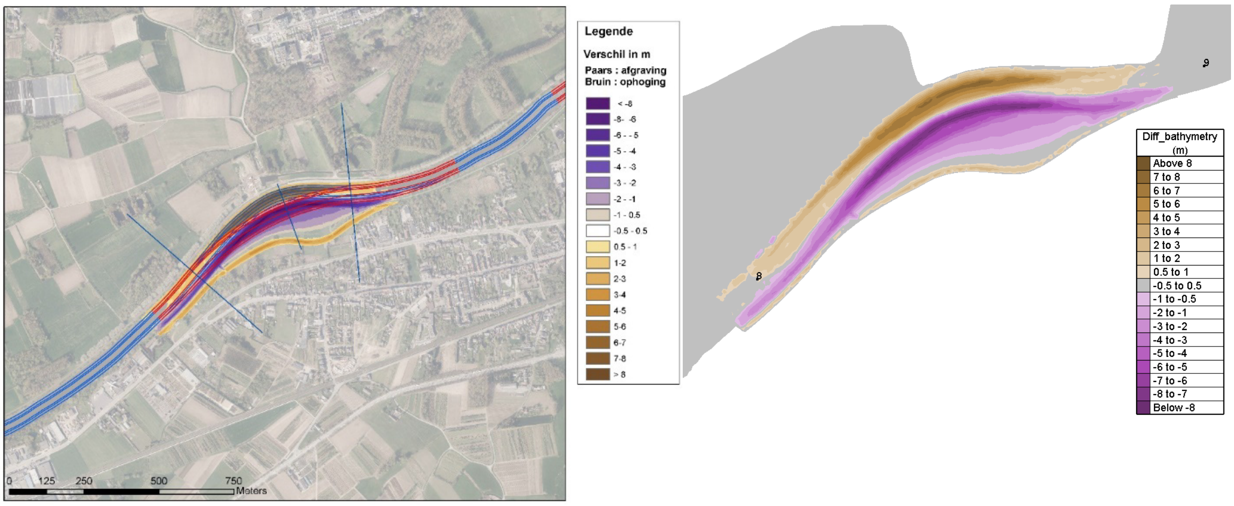
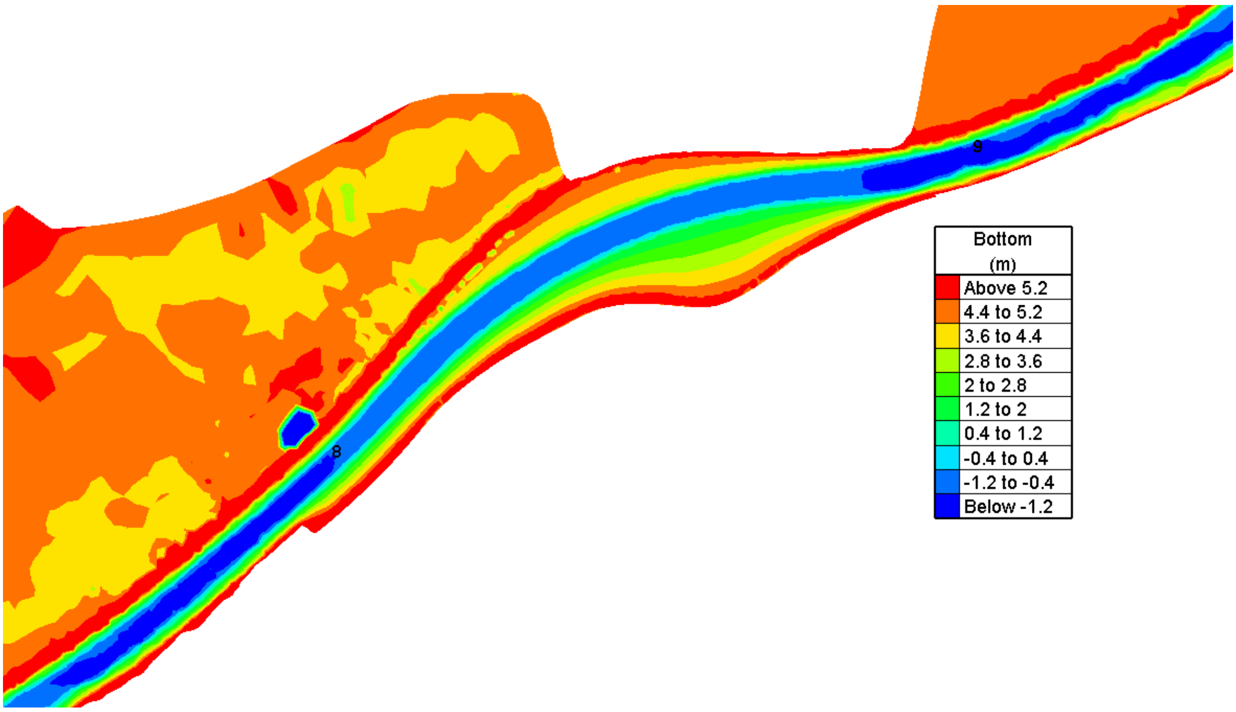


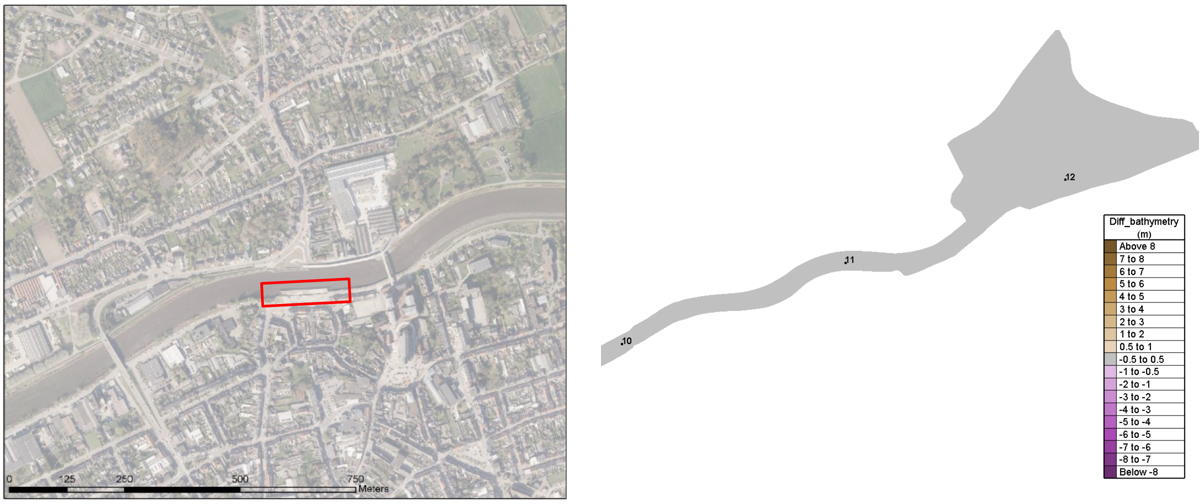
Figure 10 – The actual bathymetry in the Telemac grid at km 8-9 in the C1-C2-C3 alternatives



Km 10-11: Nautical bottleneck Wetteren (C1-C2-C3)

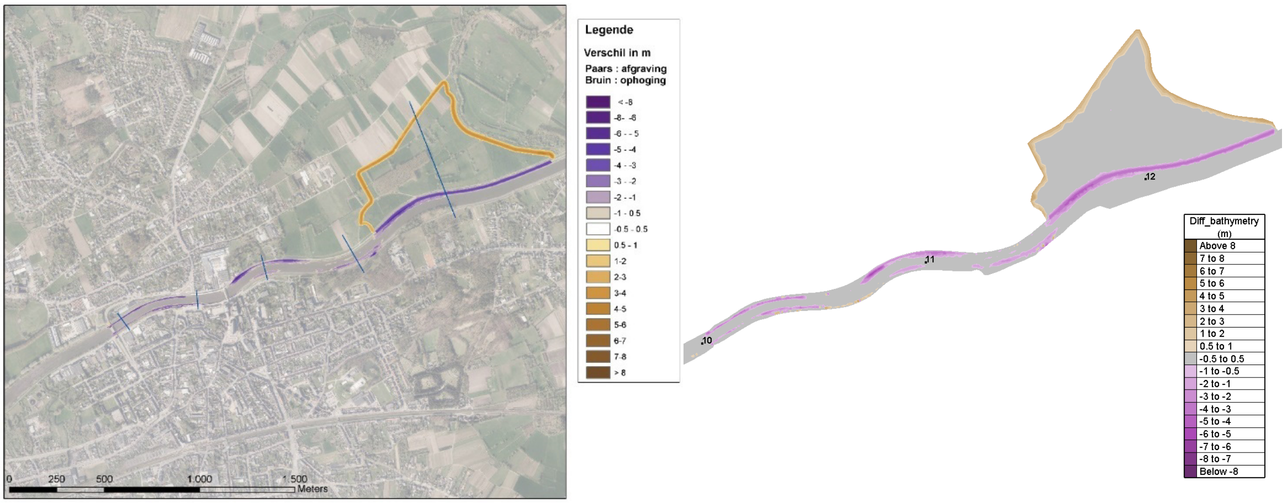
In the C1 alternative the jetty will be removed to improve nautical conditions. This has no impact on the bathymetry since the jetty is not represented in the bathymetry.

Figure 11 – Comparison of bathymetry difference at km 10-11 in C1 alternative
(left: IMDC data, right: derived from Telemac grids)



In the C2 and C3 alternatives, sheet piles are used on the left bank and right bank to improve the nautical conditions.

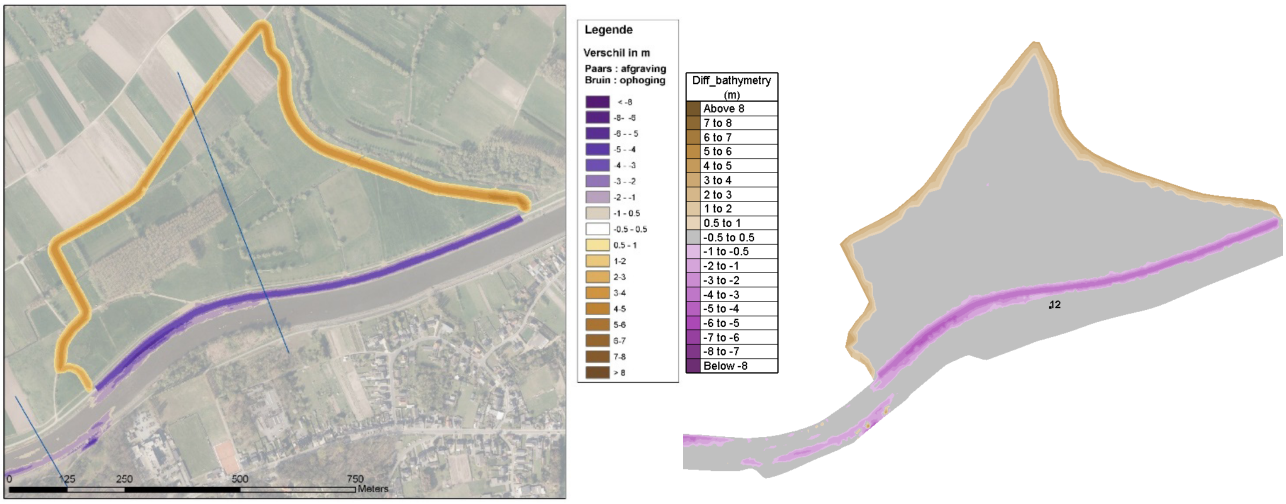
Figure 12 – Comparison of bathymetry difference at km 10-11 in C2-C3 alternative
(left: IMDC data, right: derived from Telemac grids)



Km 12 : Depoldering area downstream of Wetteren (C1-C2-C3) - **Kastenmeersen**

Part of the ‘Kalkense Meersen Wetland’ as defined in the Sigma plan is redefined as depoldered area (ca 38 ha). This will act as a new stepping stone for the higher trophic levels. The delineation of this area is an altered version of the delineation in the Sigma plan. The eastern dyke of this depoldered area is defined in such a way that the existing connection between the Scheldt and the unclassified watercourse is maintained.

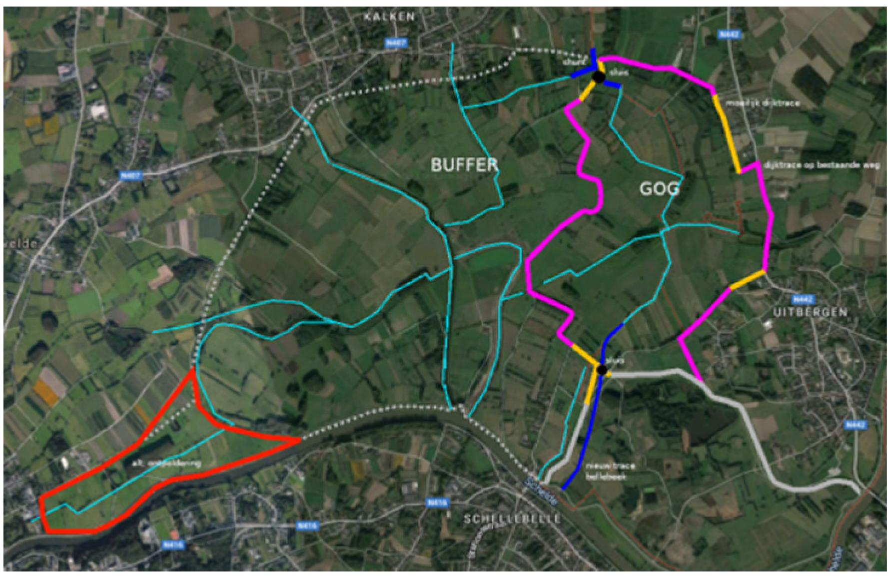
Figure 13 – Comparison of bathymetry difference at km 12
(left: IMDC data, right: derived from Telemac grids)



Km 13 : FCA Wijmeers (C2-C3)

Connect FCA Wijmeers to a more northerly FCA (lower frequency FCA) in the Kalkense Meersen Wetland. Based upon topography, nature goals and flow direction a proposal of an extension of FCA Wijmeers is made by ANB. The Bellebeek gets partly a new trajectory in this alternative. This measure is implemented in the C2 and C3 alternative.

Figure 14 – Conceptual design of extension FCA WIjmeers
(pink : existing dikes – orange : new dikes – dark blue : new trajectory Bellebeek, source: communication with ANB)



Km 15-17 : Channel cut off at Hoogland – Uitbergen - Paardenweide (C1-C2-C3)

C1-alternative : In Hoogland the new channel will remain in the already depoldered area, and follow closely the planned side channel constructed in the IMMERSE project. The designed bathymetry from the IMMERSE project is made available through De Vlaamse Waterweg. The old channel will be filled up and used for intertidal nature development. The Uitbergen bend will be smoothened by a new channel in the Bergenmeersen FCA-CRT area. The latter will be completely depoldered (40 ha), safety against flooding function compensation through the new FCA in Kalkense Meersen (175 ha). The main channel is filled to MLW-0.5 m. No change for the channel at Paardeweide.

Figure 15 – Comparison of bathymetry difference at km 15-17 in C1 alternative
(left: IMDC data, right: derived from Telemac grids)

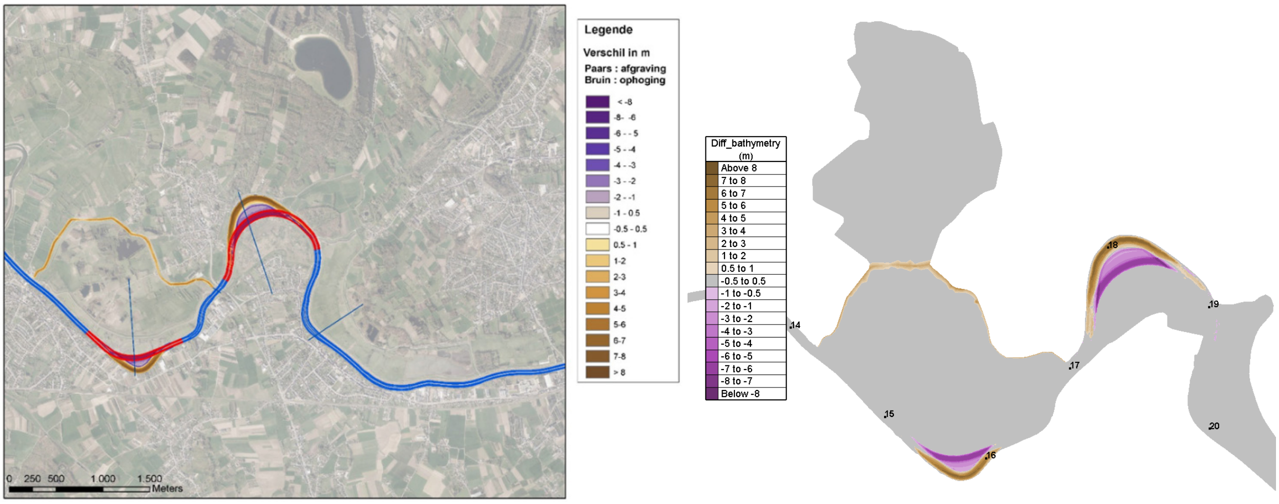
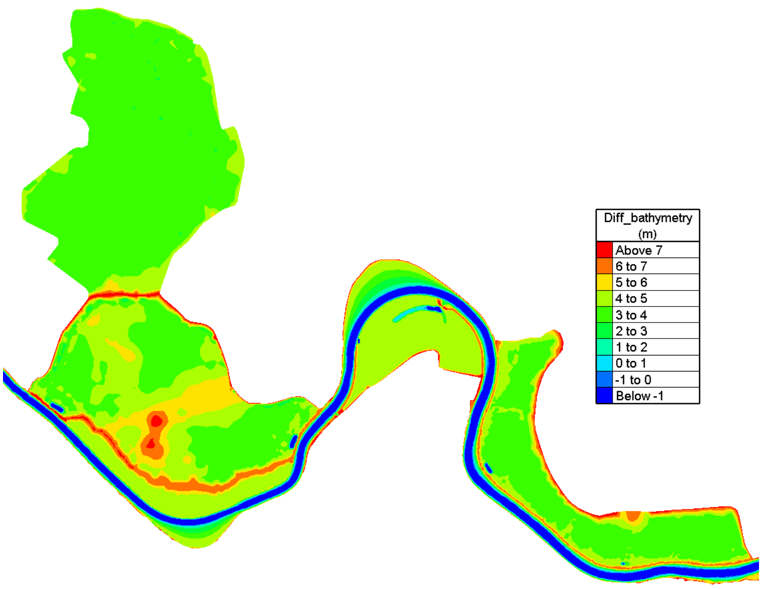


Figure 16 – The actual bathymetry in the Telemac grid at km 15-17 in the C1 alternative



C2-alternative: In Hoogland the new channel will be placed south of the current northern dyke of the Wijmeers depoldered area. The old channel is used for intertidal nature development, the section is drawn from the channel at -0.5m MLW to MHW with a slope of 3 to 5%. The Uitbergen bend will be smoothened by a new channel in the Bergenmeersen FCA-CRT area (following the old meander). The existing channel will remain, but filled to 0.5 m below MLW. The FCA-CRT will be completely depoldered (40 ha), safety against flooding function compensation through the new FCA in Kalkense Meersen (175 ha). No change for the channel at Paardeweide.

Figure 17 – Comparison of bathymetry difference at km 15-17 in C2 alternative
(left: IMDC data, right: derived from Telemac grids)

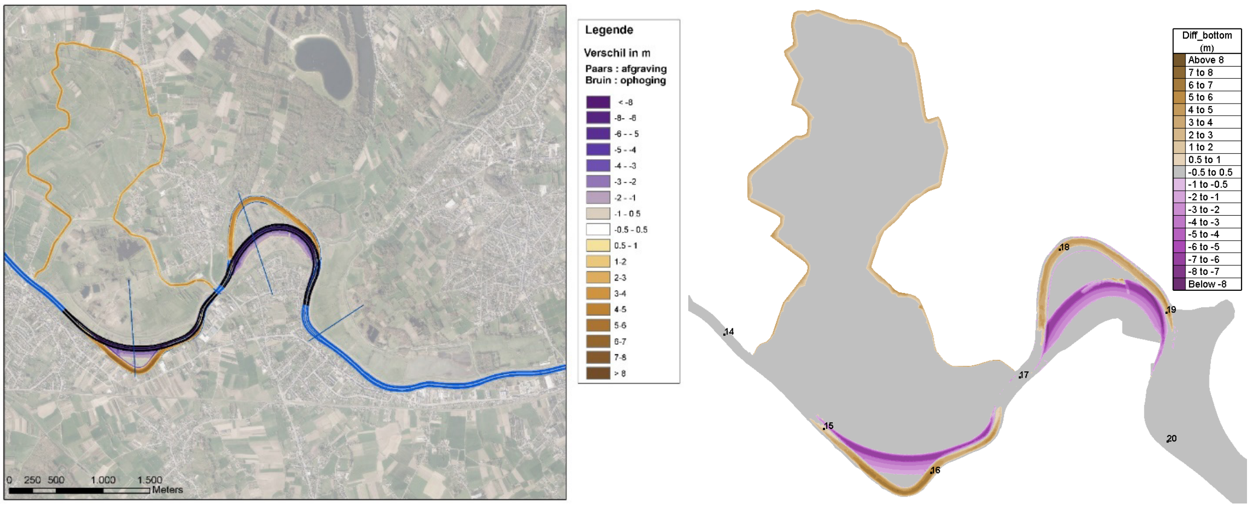
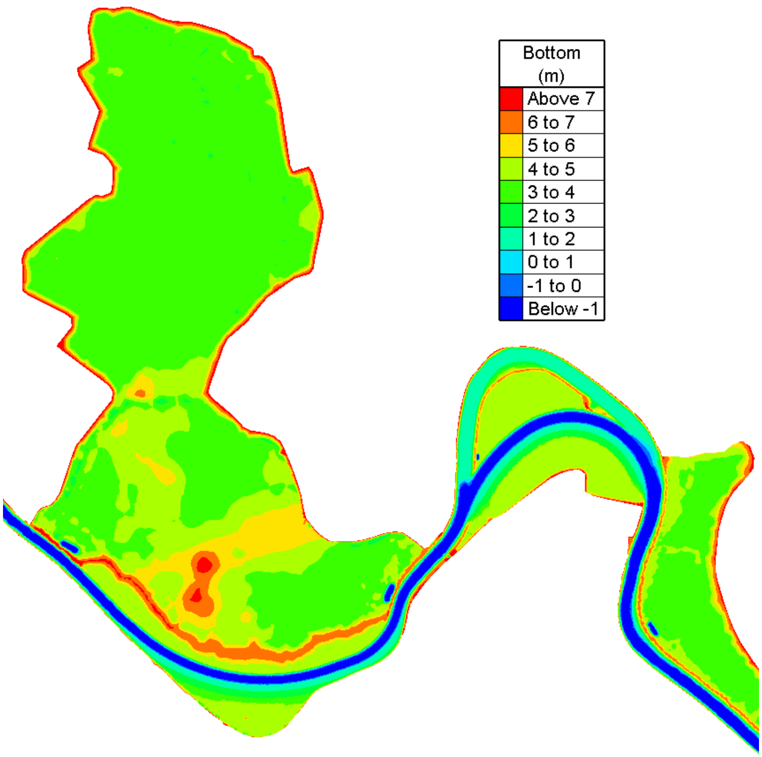
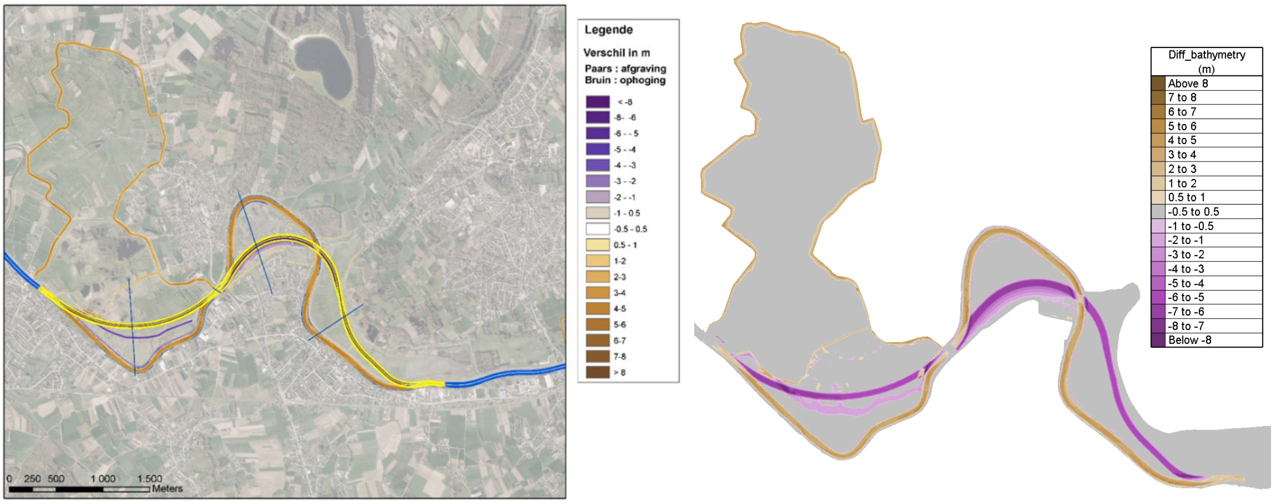


Figure 18 – The actual bathymetry in the Telemac grid at km 15-17 in the C2 alternative



C3-alternative: In Hoogland the new channel will cut through the Wijmeers FCA and depoldered area. The old channel is filled up to 0.5 below MLW. The existing dyke in the Wijmeers FCA is lowered to the surrounding ground level (4.15 m TAW). Due to this measure it is necessary to implement a new overflow dyke that makes connection to the new FCA north of Wijmeers. A ring dyke is created north of the new channel. The Uitbergen bend will be further smoothened by a new channel in the Bergenmeersen FCA-CRT area (south of the old meander). The existing channel will remain, but filled to 0.5 m below MLW. The FCA-CRT will be completely depoldered (40 ha), safety against flooding function compensation through the new FCA in Kalkense Meersen (175 ha). An new navigation channel will be created at Paardeweide. The existing channel will remain, but filled up to 0.5 m below MLW. The Sigma FCA surrounding this measure is depoldered. Safety is compensated by the extension of the Wijmeers FCA into the Kalkense Meersen.

Figure 19 – Comparison of bathymetry difference at km 15-17 in C3 alternative
(left: IMDC data, right: derived from Telemac grids)



As seen in Figure 19, the main discrepancy between the left and right figures is located in the tidal flat between the main channel and side channel in Hoogland, roughly from km 15 – 16.5. The reason is that, in the 2050REF_C grid, the bathymetry of the 2050REF_B grid is applied in the area. When implementing the C3 alternative, the channel modifications are applied exactly as designed. However, with the new channel cuting through the FCA Wijmeers, the old dike is supposed to be removed in the C3 alternative. The old dike was wider in the 2050REF_C grid, resulting in a wider “purple” band in the right figure after removing it. This can be clearly seen in Figure 20.

Figure 20 – Comparison of bathymetry between the 2050REF_C grid (left) and C3 grid (right)

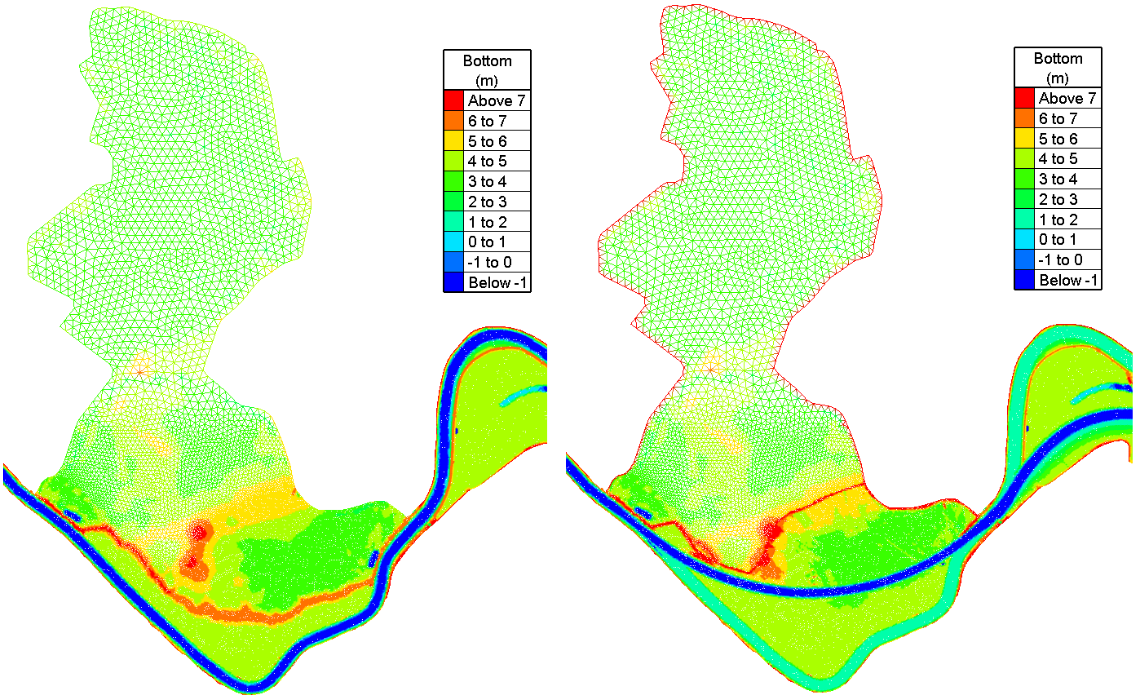
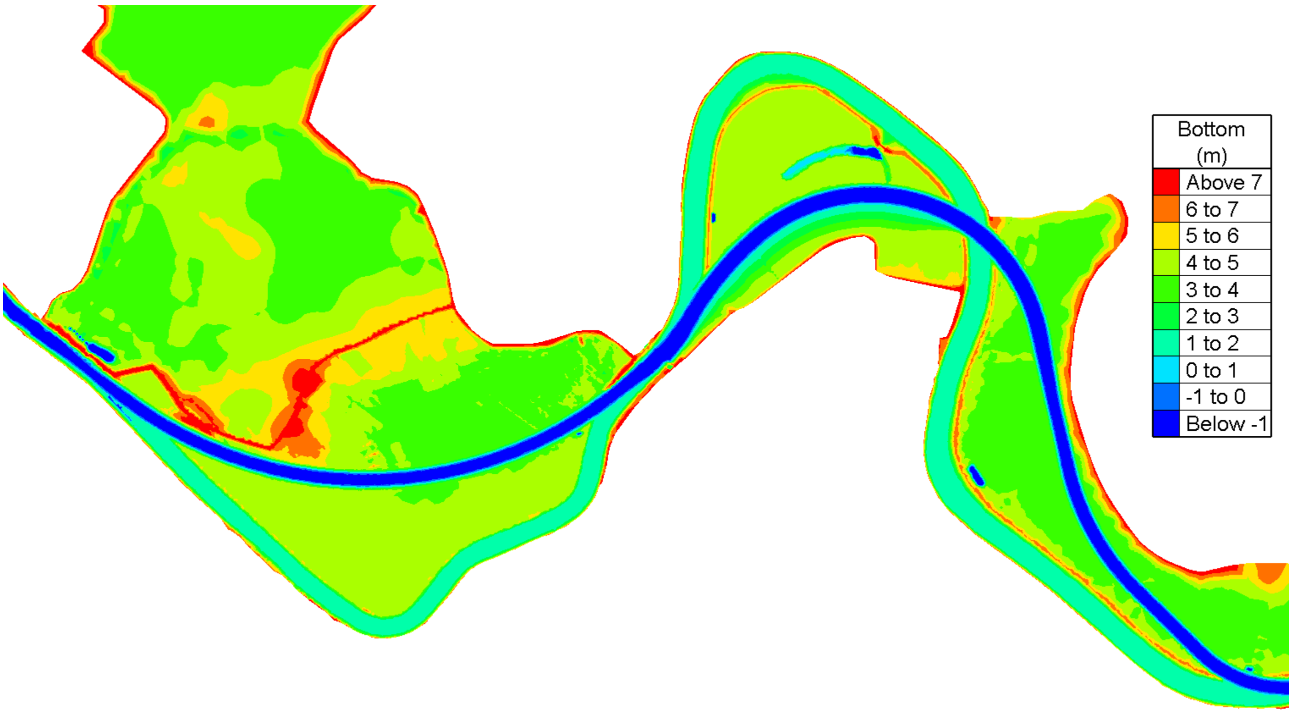


Figure 21 – The actual bathymetry in the Telemac grid at km 15-17 in the C3 alternative



Km 23-27 : Oude Broekmeer - Scheldebroek – Sint-Onolfspolder (C1-C2-C3)

- Depoldering and side channel Oude Broekmeer : C2 – C3 : two variants in depoldered area. Side channel same for the two alternatives. The tidal marsh between km 25 and 26 on the left bank is not altered in the C alternatives.
- FCA Scheldebroek converted into FCA with CRT : C1 – C2- C3
- Depoldering and side channel Sint-Onolfspolder: C2-C3 : two variants in depoldered area and side channel.

The depoldering and side channel in **Oude Broekmeer** (km 23-27) are larger in C3 than in C2. The side channels have a bottom level of 0.5 m below average low water and a slope of 4.5%.
Scheldebroek FCA (km 27) converted into FCA with CRT, as a next stepping stone for nature. The design parameters for the inlet and outlet structures need to be defined by Flanders Hydraulics. Nautical conditions are improved by smoothening the **bend at Scheldebroek (Appels-km 27)** in all alternatives as in the Chafing B alternative.
The depoldering and side channel in **Sint-Onolfspolder** (km 27-30) are larger in C3 than in C2. The side channels have a bottom level of 0.5 m below average low water and a slope of 4.5%. In the C3 alternative the downstream part of the new side channel is connected with tht bend at Kasteeltje (km 30).

No bathymetry changes in C1.

C2 alternative

Figure 22 – Comparison of bathymetry difference at km 23-27 in C2 alternative
(left: IMDC data, right: derived from Telemac grids)

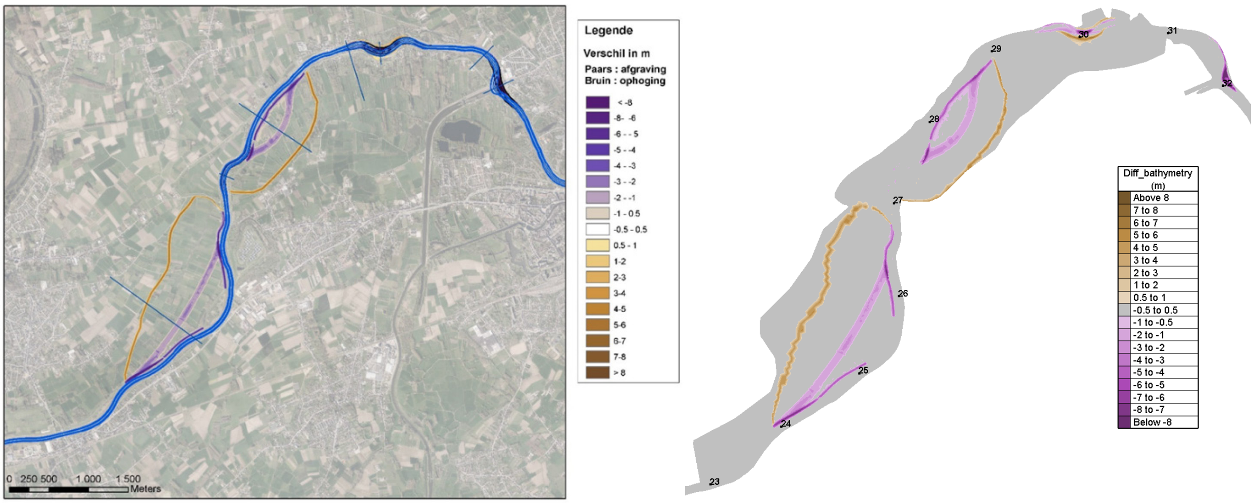
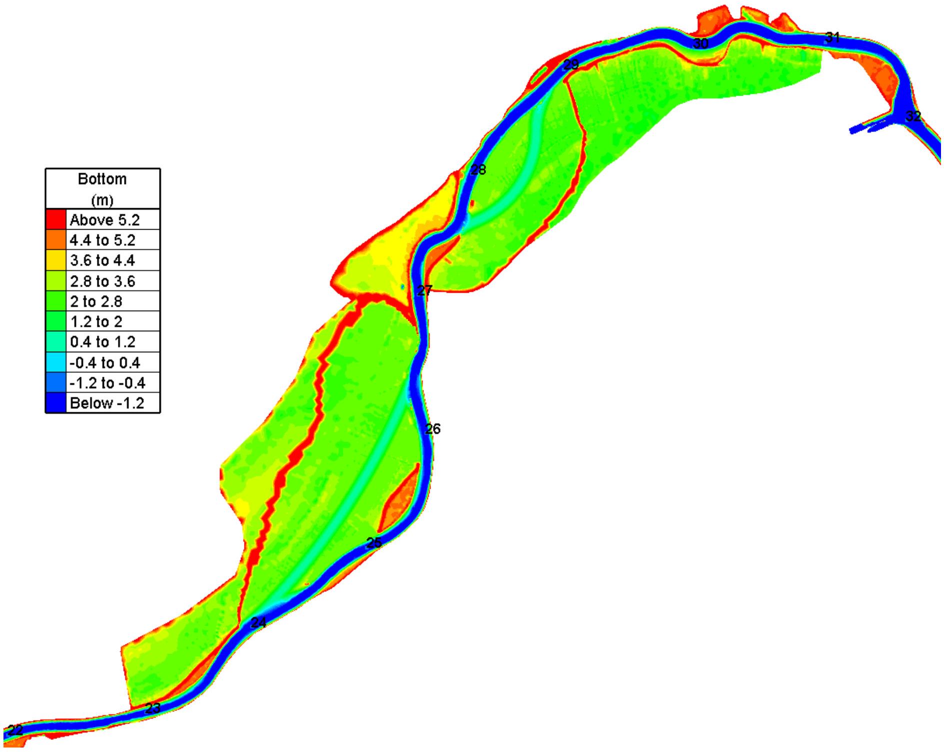


Figure 23 – The actual bathymetry in the Telemac grid at km 23-27 in the C2 alternative



C3 alternative

Figure 24 – Comparison of bathymetry difference at km 23-27 in C3 alternative
(left: IMDC data, right: derived from Telemac grids)

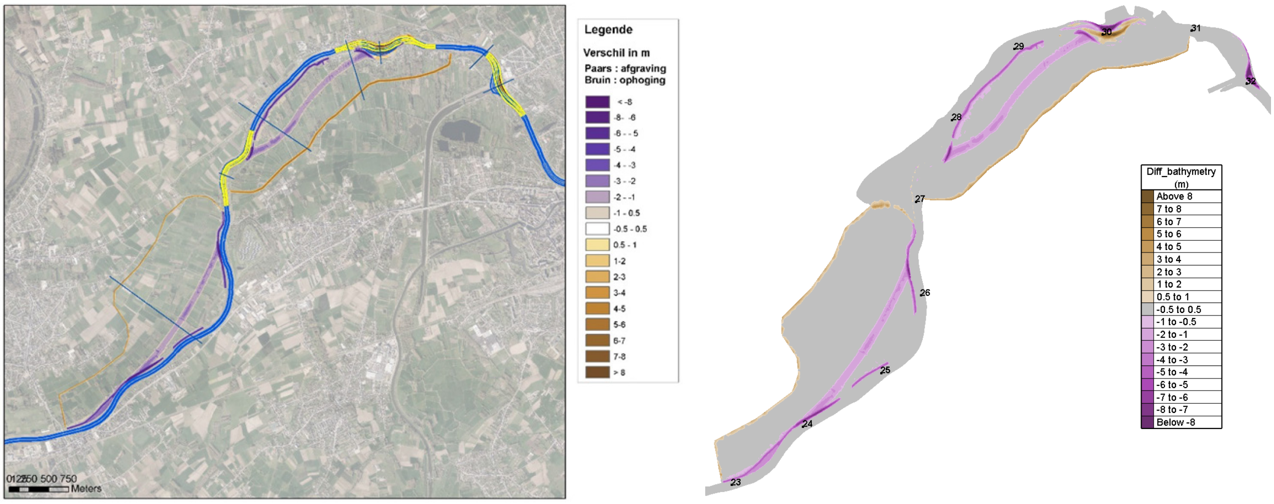
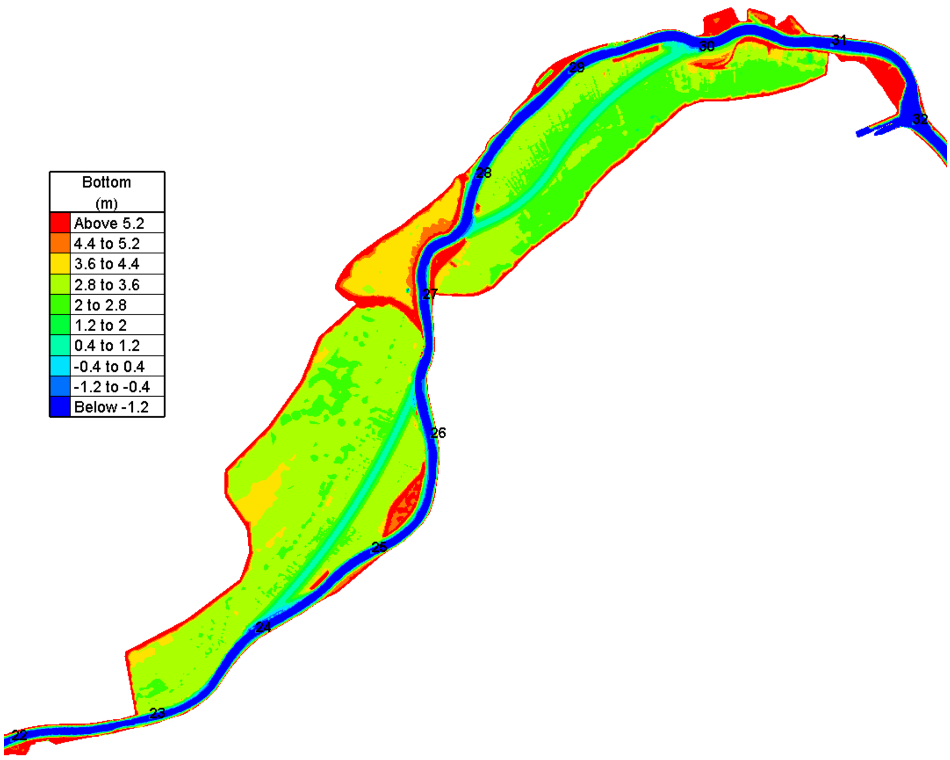


Figure 25 – The actual bathymetry in the Telemac grid at km 23-27 in the C3 alternative

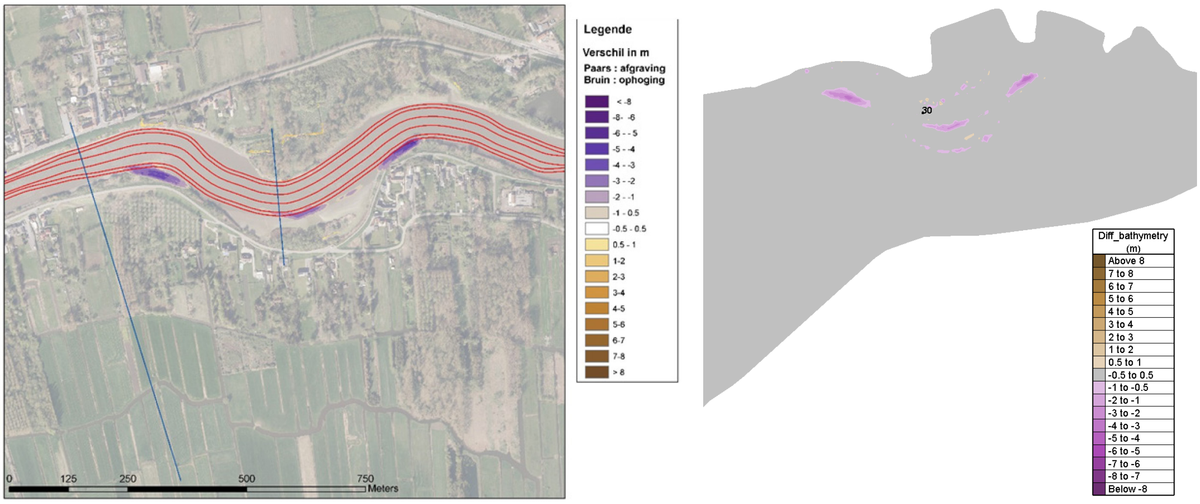


Km 30 : Kasteeltje (C1-C2-C3)

The bend at Kasteeltje (km 30) is widened in a gradual approach. At the same time, conditions for development of tidal marshes and flats are created.

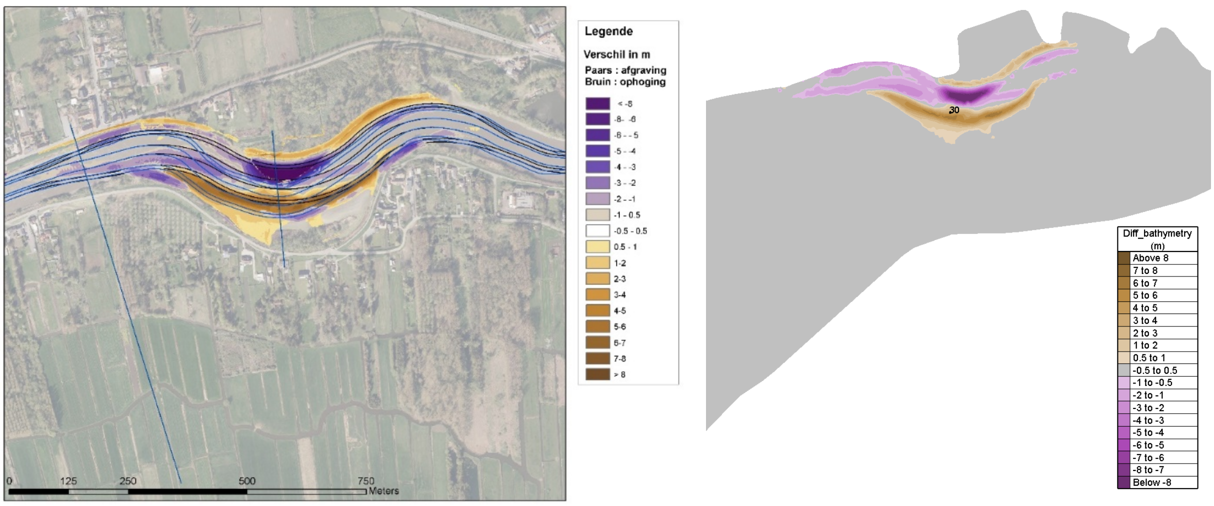
C1- alternative: Chafing principle;

Figure 26 – Comparison of bathymetry difference at km 30 in C1 alternative
(left: IMDC data, right: derived from Telemac grids)



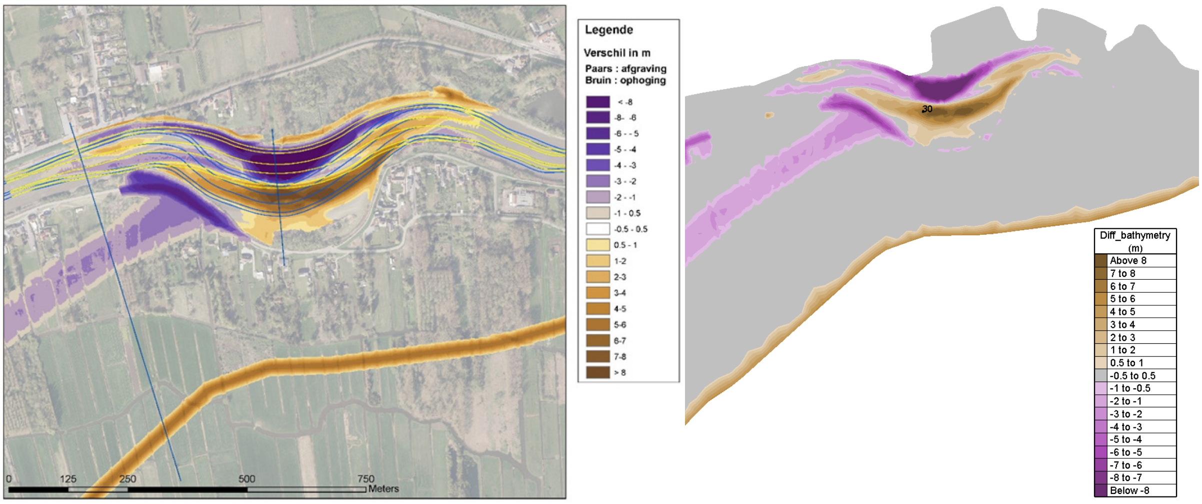
C2-alternative: Straightening;

Figure 27 – Comparison of bathymetry difference at km 30 in C2 alternative
(left: IMDC data, right: derived from Telemac grids)



C3-alternative: More extreme straightening (VaG alternative with adaptations for intertidal nature development).

Figure 28 – Comparison of bathymetry difference at km 30 in C3 alternative
(left: IMDC data, right: derived from Telemac grids)



Km 34: Straightening bend Dender and maintaining marsh (C2-C3)

The bend in the Upper Sea Scheldt at km 32 (in front of the Dender lock, bend) is straightened (implying cutting through industrial zone), using sheet piles on the left bank for C2 and C3. Upstream on the right bank the existing marsh is maintained.

Figure 29 – Comparison of bathymetry difference at km 34 in C2-C3 alternative
(left: IMDC data, right: derived from Telemac grids)

Km 35-38 : Grembergen Broek + Armenput + Waterleiding + Roggeman (C1 – C2 – C3)

Two new depoldered areas from C2 alternative onwards : Grembergen Broek (km 35) with a total area 52 ha of and Armenput (km 36-37) with a total area of 47 ha. These are considered necessary to compensate for the applied bend straightening in these alternatives and contribute to the general goal of reducing the tidal amplitude. It is not included in the C1 alternative because the focus in the C1 alternative is mainly on possibilities within the main channel. The implementation of the two depoldered areas is the same for the C2 and C3 alternative.

For the bend at Waterleiding (km 37-38) a bend smoothening is suggested for all alternatives (same in all three alternatives) . This is done since Waterleiding is considered as an prominent nautical bottleneck. This part of the bathymetry is taken from the Chafing alternative. An additional undeepening is applied so that the cross sectional area is maintained (see Figure 4 48).

For the Roggeman (km 38) a gradual set of measures is proposed :

- C1-alternative: no measure defined
- C2-alternative: depoldering of Roggeman with dykes more south, connecting smoothly to the existing dykes.
- C3-alternative: depoldering of Roggeman with dykes more north, connecting smoothly to the existing dykes.

C1 alternative

Figure 30 – Comparison of bathymetry difference at km 35-38 in C1 alternative
(left: IMDC data, right: derived from Telemac grids)

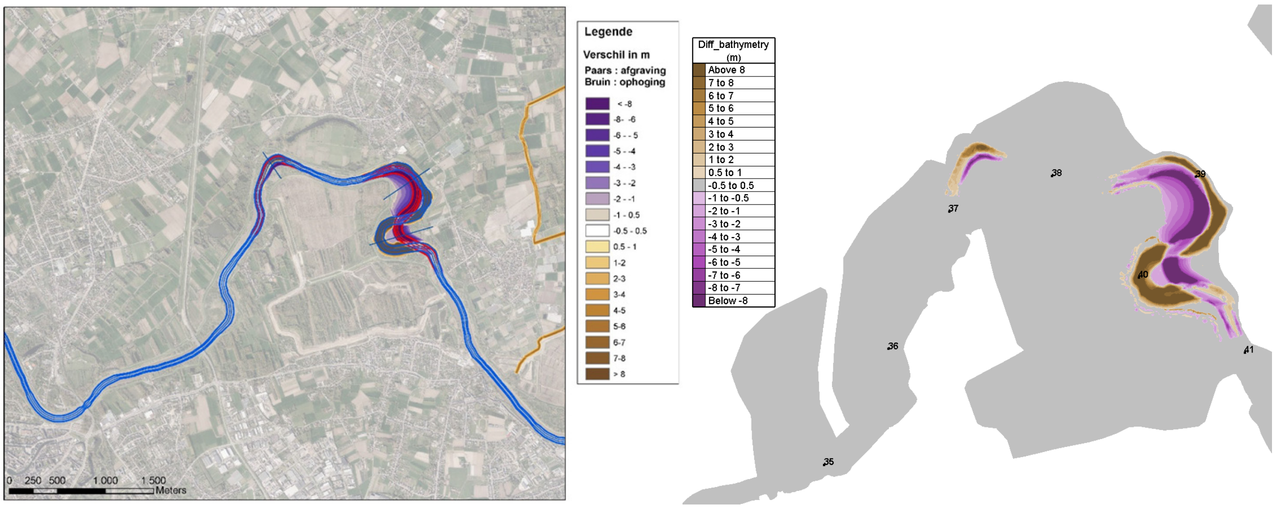


Figure 31 – The actual bathymetry in the Telemac grid at km 35-38 in the C1 alternative

C2 alternative

Figure 32 – Comparison of bathymetry difference at km 35-38 in C2 alternative
(left: IMDC data, right: derived from Telemac grids)

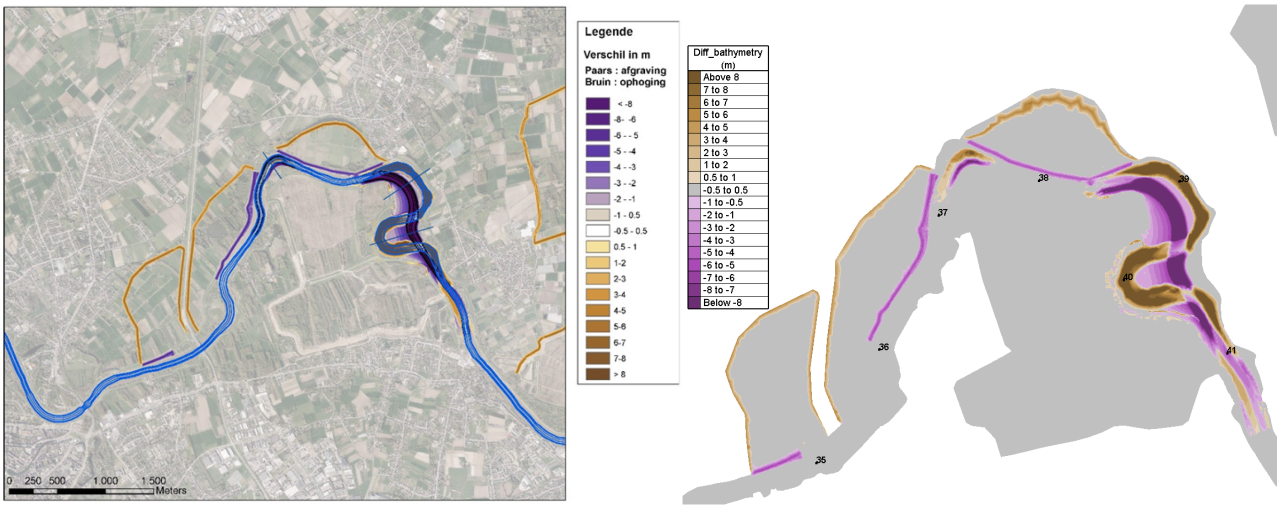
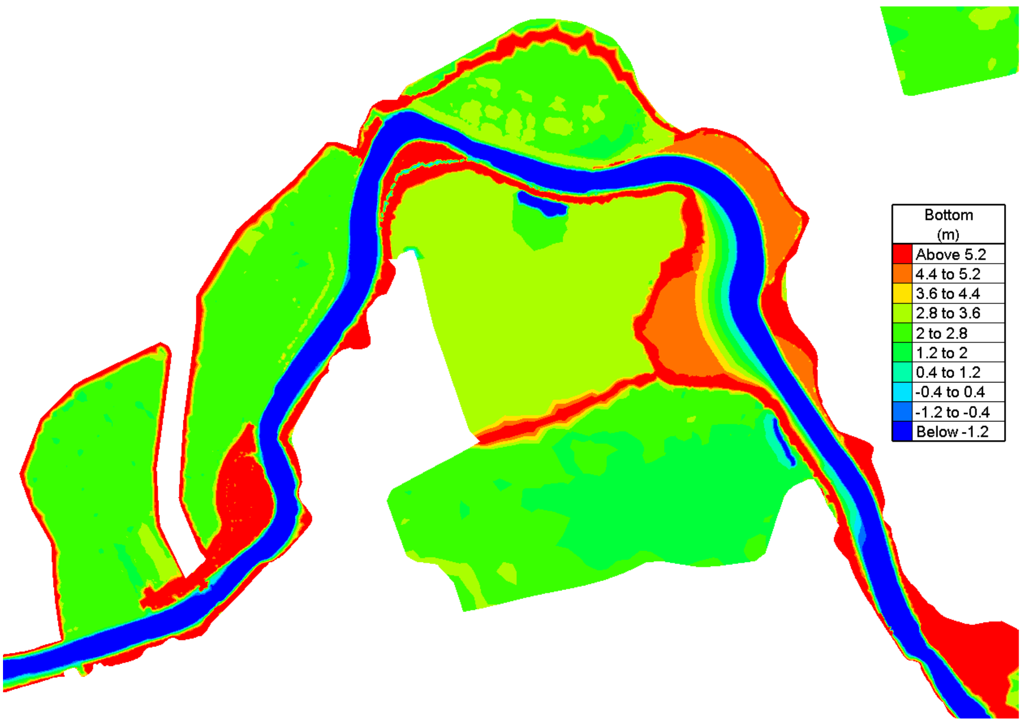


Figure 33 – The actual bathymetry in the Telemac grid at km 35-38 in the C2 alternative



C3 alternative

Figure 34 – Comparison of bathymetry difference at km 35-38 in C3 alternative
(left: IMDC data, right: derived from Telemac grids)

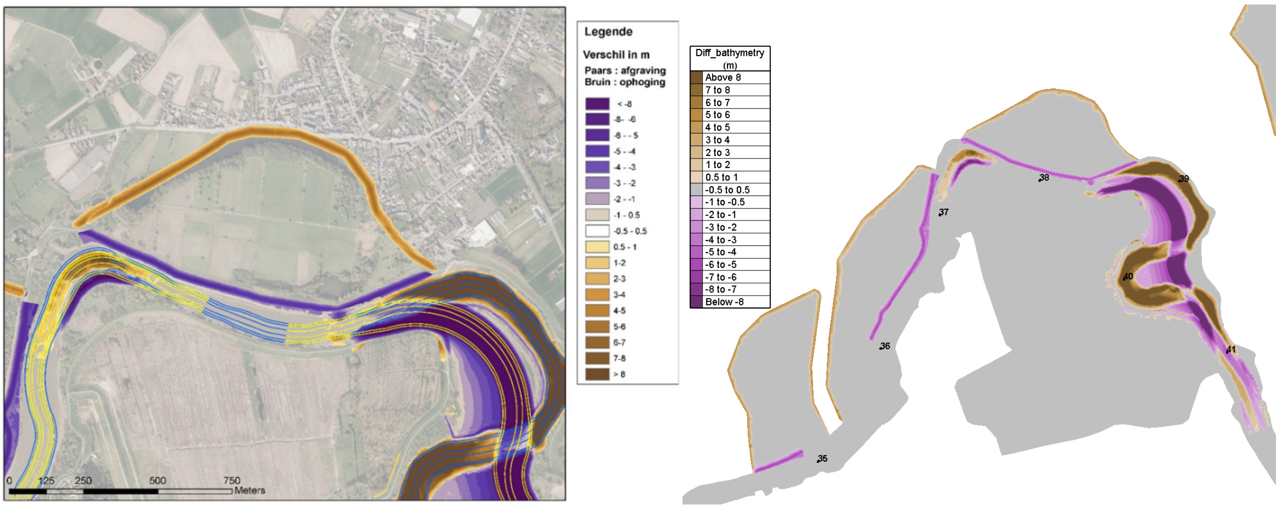
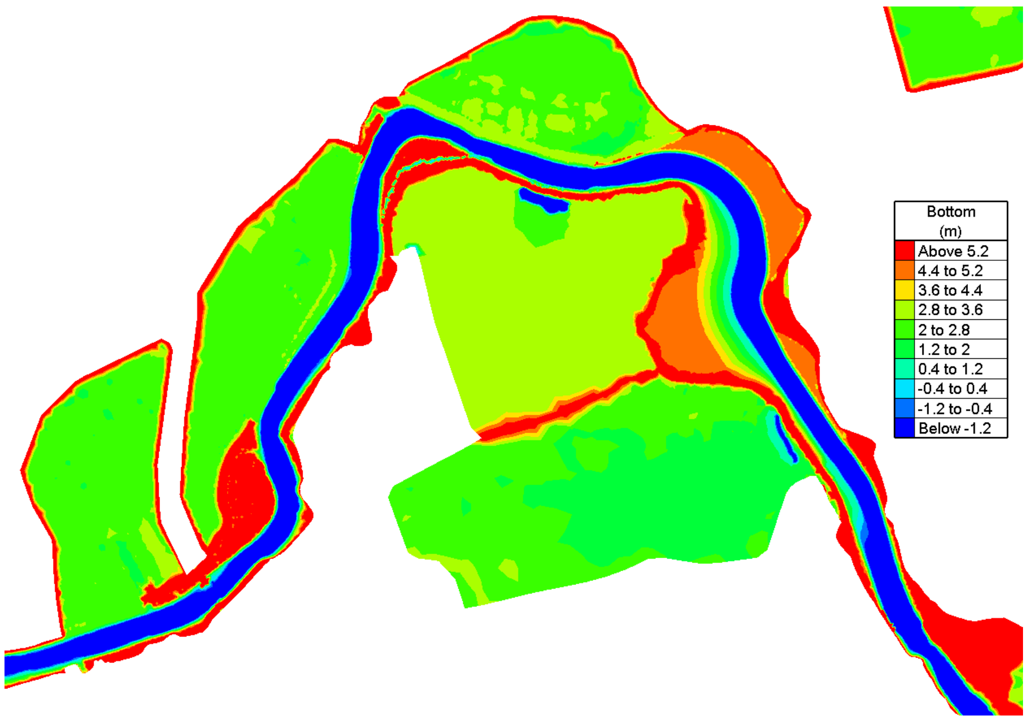


Figure 35 – The actual bathymetry in the Telemac grid at km 35-38 in the C3 alternative



Km 40: Kramp (C1-C2-C3)

Two variants of the bend straightening at km 40 (Kramp) are defined. In the C1 alternative a milder straightening is included when compared to the variant in the C2-C3 alternative. Based upon the experience from the B alternatives, it is known that this measure has a significant impact on the tidal amplitude. Depoldering and other measures are necessary to compensate for this straightening.

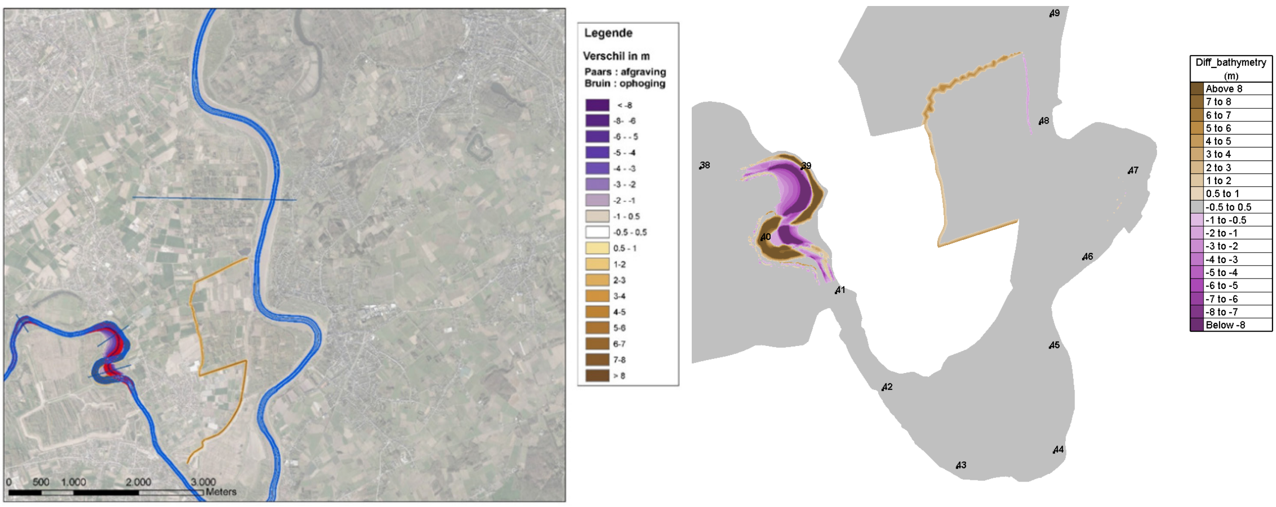
The main channel that is no longer used for navigation is filled up to a level of GHW – 1. For the C1 alternative, the bend straightening is combined with a slope of 3-5 % in the inner bend to allow for the development of intertidal nature. For the C2 and C3 alternative, a slope between 3-5 % on the right bank is implemented.
Comparison of bathymetry can be seen above.

Km 48 : Blankaart-Akkershoofd (C1-C2-C3)

For the Blankaart (km 48) and Akkershoofd (km 49-51) a gradual set of measures is proposed that reflect a larger effect on reducing the tidal amplitude:

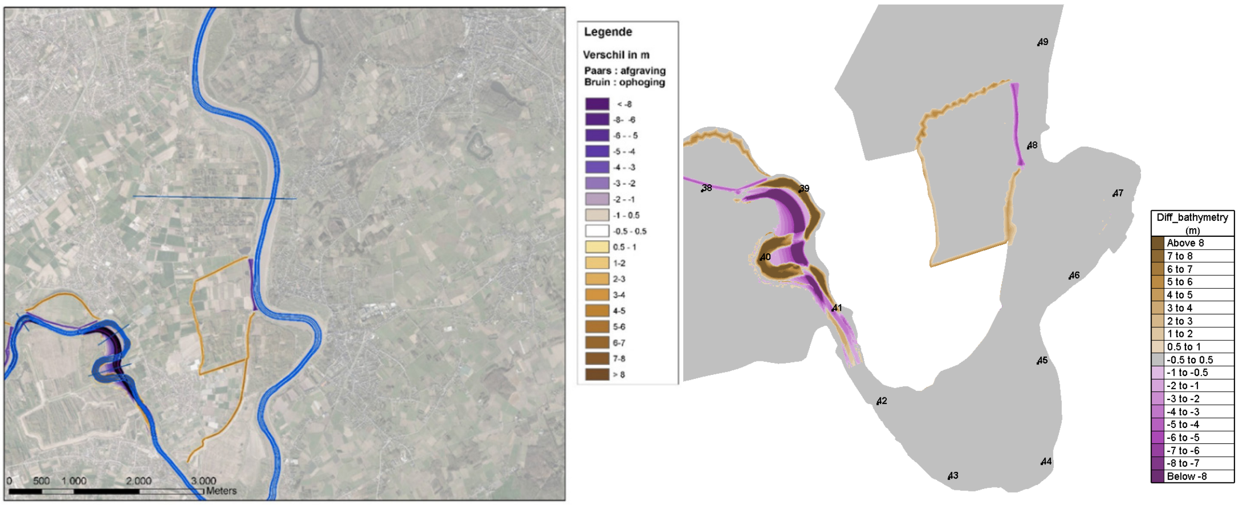
C1-alternative: FCA Blankaart in combination with Wal-Zwijn (no dyke in between). Connection with the FCA by lower dyke level to 6.7 m TAW. This is similar to the dyke levels in Wal-Zwijn, which is present in 2050REF_C and all the three C alternatives.

Figure 36 – Comparison of bathymetry difference at km 48 in C1 alternative
(left: IMDC data, right: derived from Telemac grids)



C2-alternative: depoldering Blankaart. Wal-Zwijn as CRT (with dyke in between both). In and outlet structures of the CRT to be defined by Flanders Hydraulics.

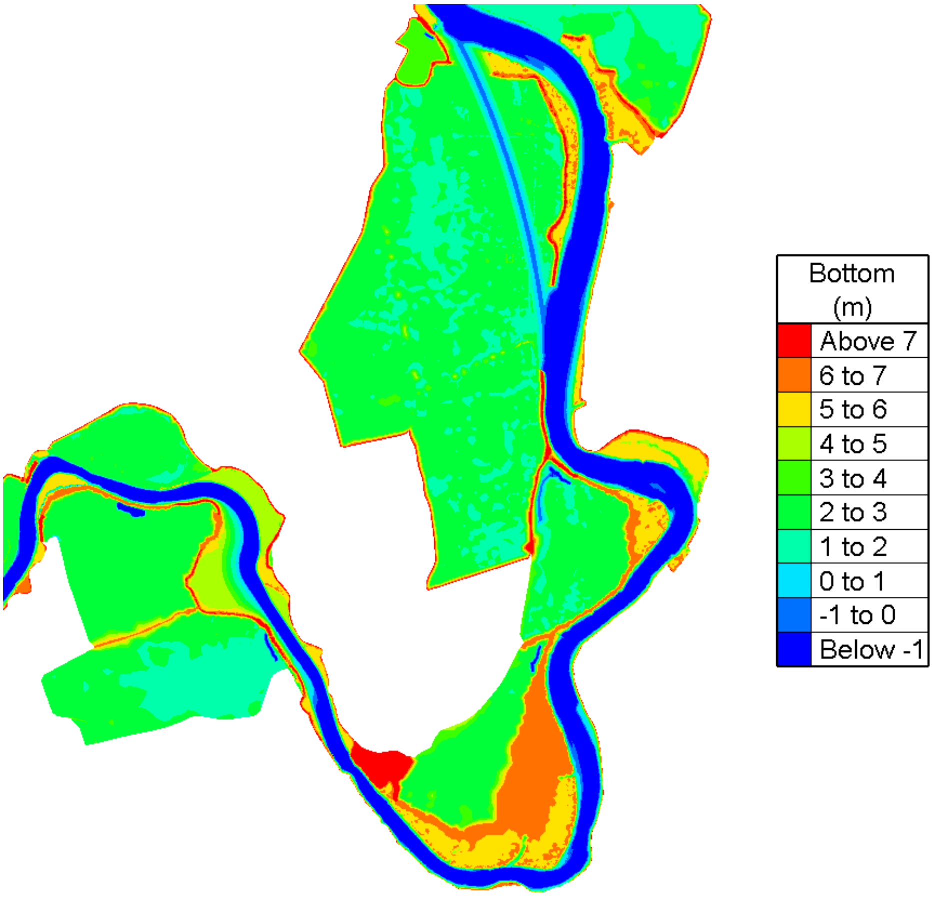
Figure 37 – Comparison of bathymetry difference at km 48 in C2 alternative
(left: IMDC data, right: derived from Telemac grids)



C3-alternative: depoldering Blankaart and Akkershoofd with a new side channel. Wal-Zwijn as CRT. In and outlet structures to be defined by Flanders Hydraulics.

Figure 38 – Comparison of bathymetry difference at km 48 in C3 alternative
(left: IMDC data, right: derived from Telemac grids)

Figure 39 – The actual bathymetry in the Telemac grid at km 48 in the C3 alternative



Km 53: New connection with Durme (C1-C2-C3)

Secondary branch to Durme (km 53) in combination with depoldering southern section of FCA-CRT area Tielrode broek (loss in safety compensated by Blankaert – km 48) – aiming at improving dynamics at river mouth and reducing siltation rate. With this operation ca 6 ha of the original FCA/CRT area is converted into the side channel. Ca fifteen ha of the FCA-CRT is converted to depoldered area. The total depoldered area is 27 ha. The northern part of this area keeps the original function as FCA/CRT. The bed level in the FCA-CRT zone is 2.76 mTAW in the ACT2013 simulation. Estimated level of FCA-CRT in 2050 is 3 mTAW. Connection with the Tielrode Broek FCA-CRT is suggested to keep the same implementation as in the 2050 reference situation (2 culverts with bottom level 4.2 m TAW, length 18 m, 3 3 m wide, 2.2 m high, weir height 0.2 m, trash screen present). This measure is implemented in all C-alternatives. The overflow dyke is at 6.6 mTAW.

Figure 40 – Comparison of bathymetry difference at km 53
(left: IMDC data, right: derived from Telemac grids)

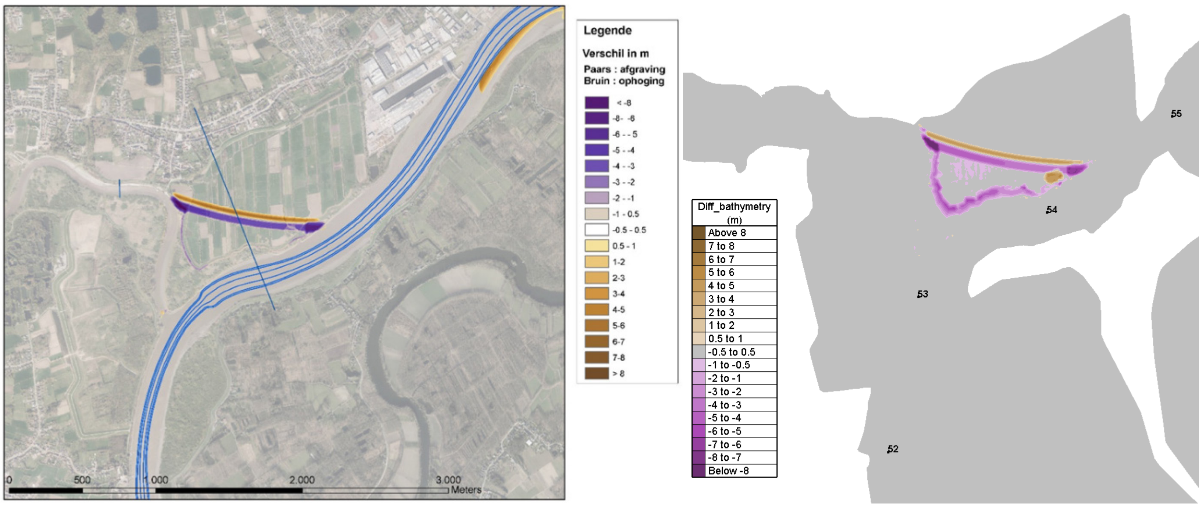
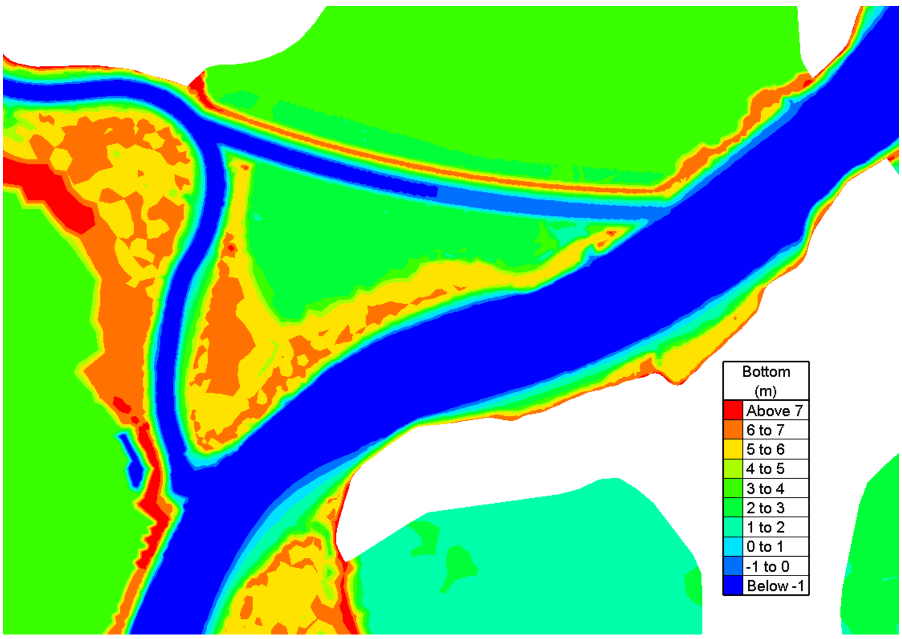


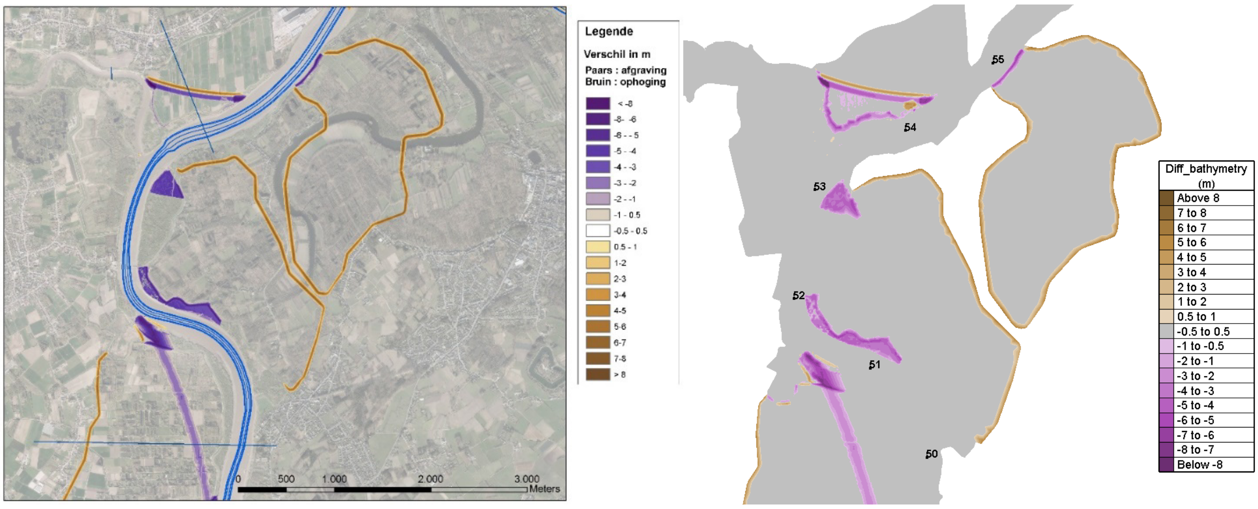
Figure 41 – The actual bathymetry in the Telemac grid at km 53 in the C1-C2-C3 alternative



Km 50- 57 : Depoldering Weert: C3

Looking for depoldering an area of ca 500 ha, try to find a relation with the existing meander and limit the number of house to expropriate. This measure is only implemented in the C3-alternative since in the C3 alternative the maximum potential of the valley is investigated to reduce the tidal amplitude. The connection between the depoldered area is made at three locations. For the southern depoldered area two connections are foreseen: one with a length of 300m and one with a length of 1 km. For the northern depoldered area only one connection is foreseen over a length of ca 400 m.

Figure 42 – Comparison of bathymetry difference at km 50-57 in C3 alternative
(left: IMDC data, right: derived from Telemac grids)



km 57 – km 64: Bornem (Temse to mouth Rupel) (C1-C2-C3)

C1-alternative: Local undeepening (cfr Baasrode pilot) at 5 locations between km 56 and 65 to a level not higher than 0.5 m below MLW, in order to preserve the valuable tidal flats of this area.

Figure 43 – Comparison of bathymetry difference at km 57-64 in C1 alternative
(left: IMDC data, right: derived from Telemac grids)

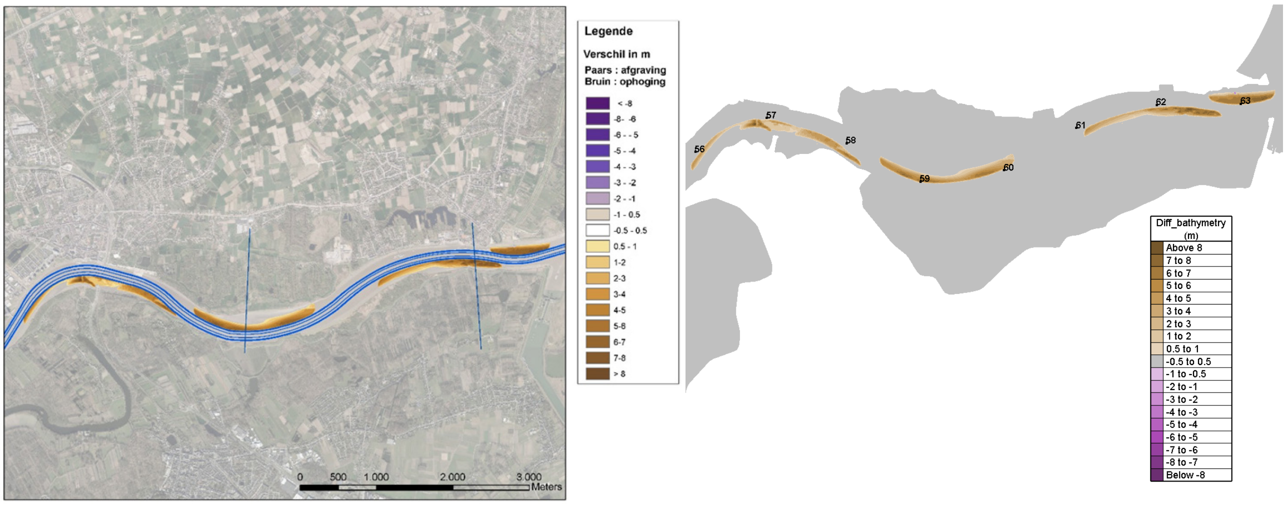
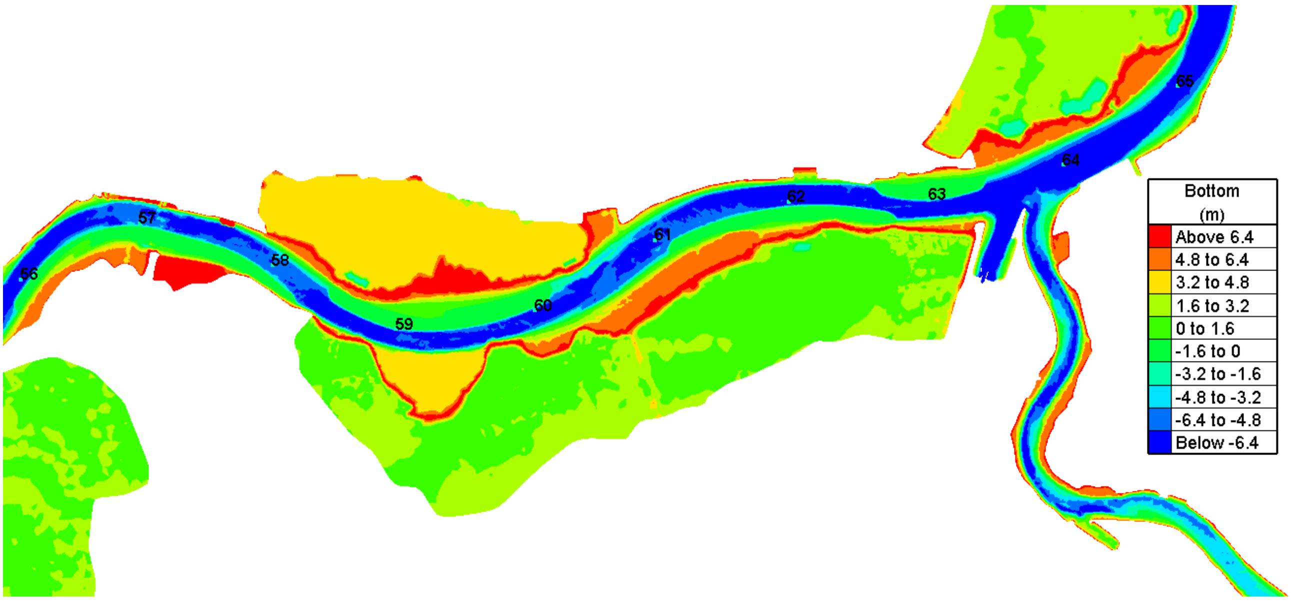


Figure 44– The actual bathymetry in the Telemac grid at km 56 in the C1 alternative



C2-alternative: In addition to the C1 alternative, two new side channels: one through Schouselbroek and one through Schelland/Oudbroekpolder are defined. To compensate for the loss of Sigma areas with safety function, the reserve areas Spierbroekpolder and Hingene Broekpolder are activated as a FCA with CRT, in order to maximise the surface of estuarine nature. The new side channels have a bottom width of 30 m, top width is 100 m. Bottom level is considered to be 0.5 m below average low water and thus -0.35 m TAW. Slope of the side channel is ca 0.045 m/m to get an even slope towards the ground level of 1.1 m TAW.

Figure 45 – Comparison of bathymetry difference at km 57-64 in C2 alternative
(left: IMDC data, right: derived from Telemac grids)

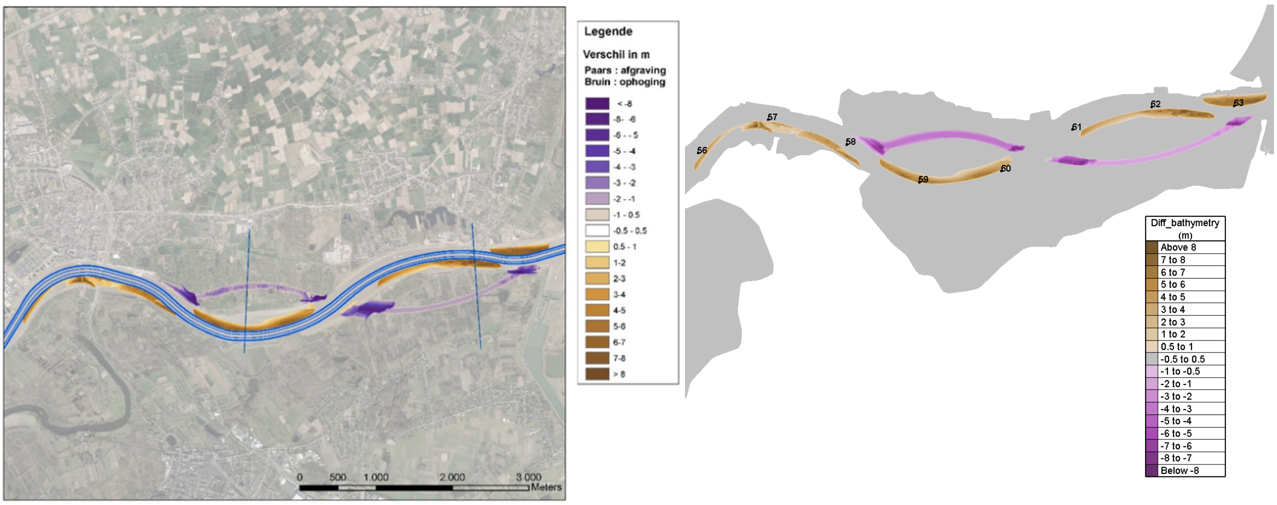
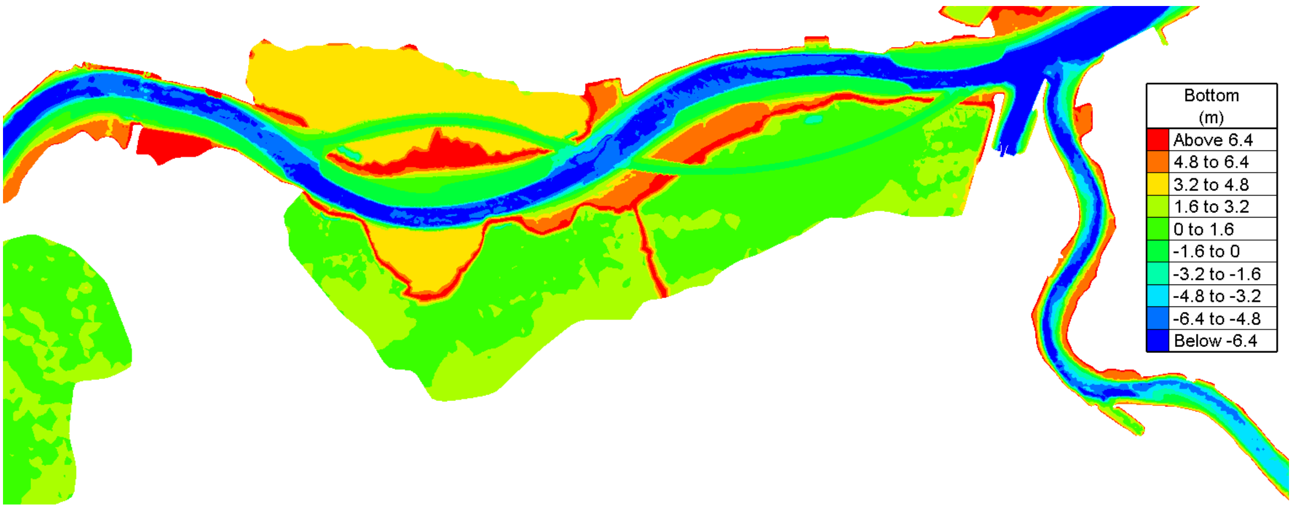


Figure 46 – The actual bathymetry in the Telemac grid at km 56 in the C2 alternative



C3-alternative: same as C2, but with an extra undeepening to a level of -5.3 m TAW in the main channel. These measures assume that current bathymetry is still not in equilibrium after sand exploitation in the past, hence it is expected that deposition of sand will largely remain in place.

Figure 47 – Comparison of bathymetry difference at km 57-64 in C3 alternative
(left: IMDC data, right: derived from Telemac grids)

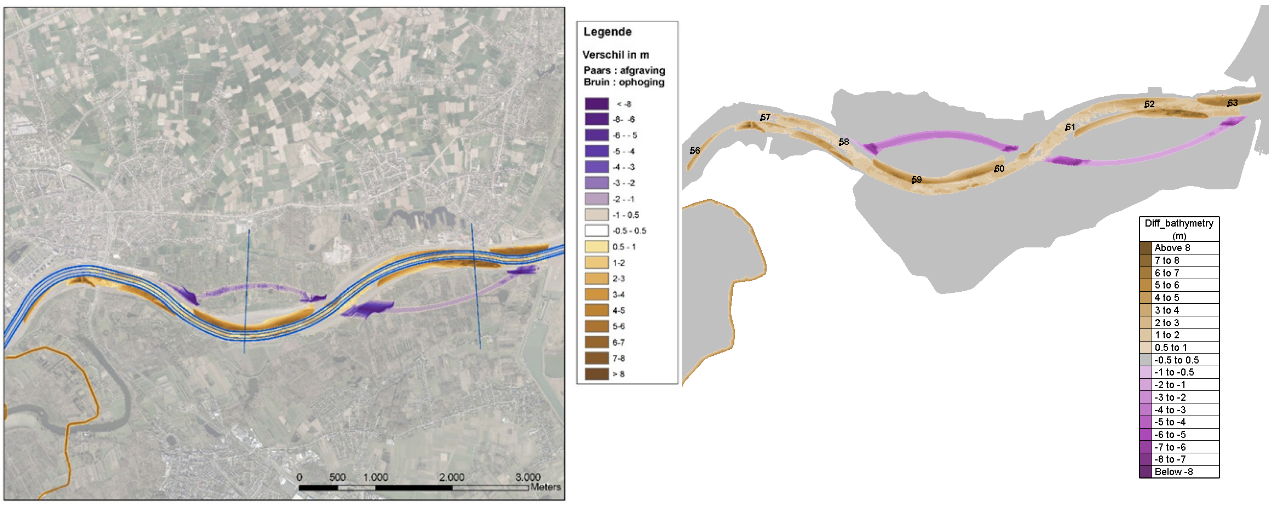
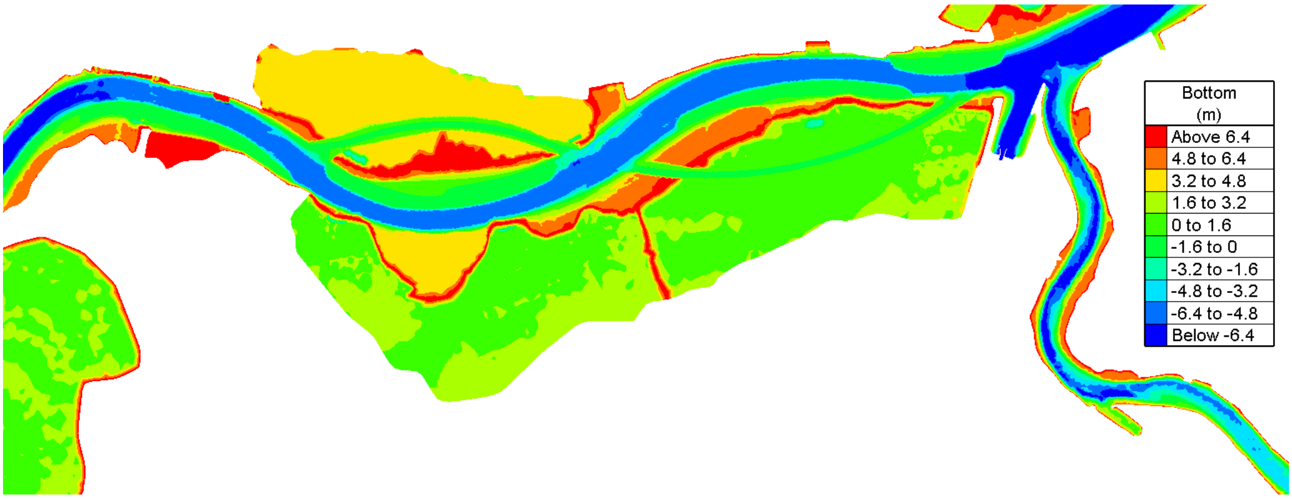


Figure 48 – The actual bathymetry in the Telemac grid at km 56 in the C3 alternative

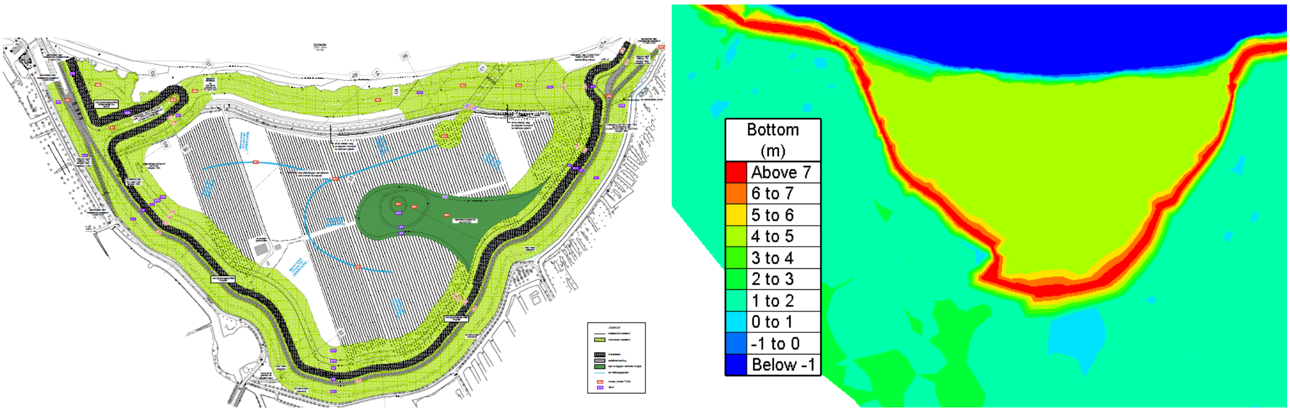


These measures assume that current bathymetry is still not in equilibrium after sand exploitation in the past, hence it is expected that deposition of sand will largely remain in place.

km 59: Groot Schoor

The Groot Schoor will have a new structure according to the plan of De Vlaamse Waterweg. In the current model (2050REF_C and C1-C2-C3 alternatives), however, the additional structure stretching from east dike to the middle of the depoldering area is not present. Instead, the Groot Schoor in the model is a depoldering area with relatively flat bottom surrounding by the dike.

Figure 49 – The Plan of the Groot Schoor prodived by De Vlaamse Waterweg
(left) and the bathymetry used in the model (right)



3.1.4 Adaptations of FCA/FCA-CRT

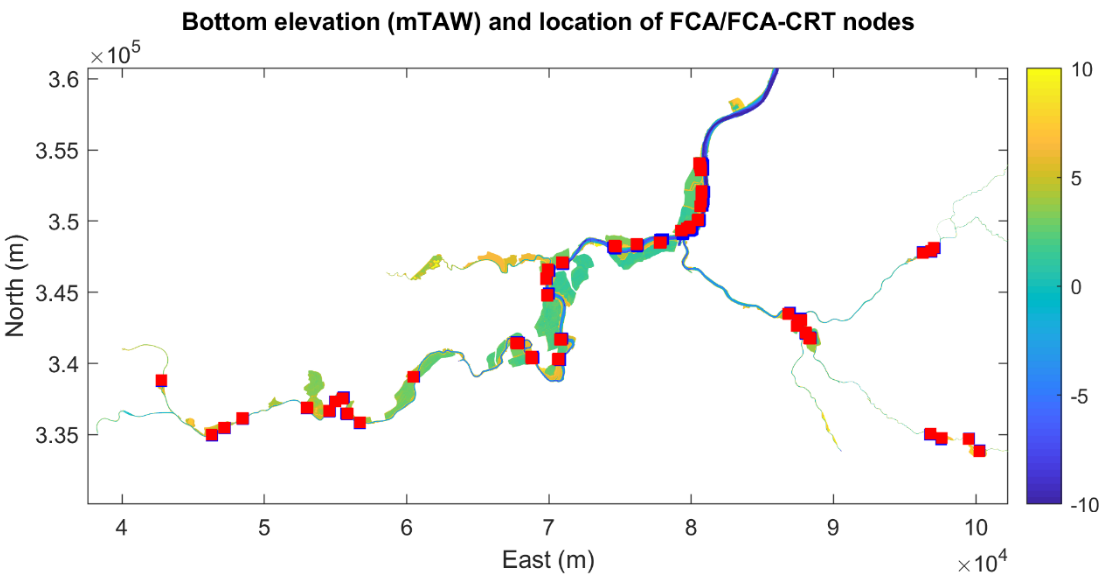
The FCAs/FCA-CRTs were implemented in the previous 2050REF_B grid, using the culvert functionality in TELAMC modelling suite (Smolders et al. 2015). The inlets and outlets of the structures are defined as pairs of nodes, connecting the FCAs/FCA-CRTs with the main channel. Water is allowed to move through the culvert nodes, and the discharge at the inlets and outlets are computed according to the characteristics of the structure and the water level difference.

In the previous 2050REF_B grid, there are 252 culvert nodes in total. Due to the change of the reference grid from 2050REF_B to 2050REF_C, the numbering of the nodes has changed as well. In the Scaldis model, the culvert node numbers have to be provided in an input file. In order to define the culvert nodes correctly in the new reference grid 2050REF_C, the following steps are taken:

1. Use the culvert node numbers in the 2050REF_B grid to find their corresponding coordinates;
2. With the coordinates of each culvert node, search its nearest point in the new reference grid 2050REF_C;
3. The new node numbers in the 2050REF_C grid is put in to the culvert node list.

The overview of the locations of the culvert nodes in the 2050REF_C grid can be found in Figure 50.

Figure 50 – Overview of the locations of the culvert nodes in the 2050REF_C grid for the Upper Sea Scheldt



Due to the new measures present in the C alternatives, the implementations of the FCAs/FCA-CRTs have to be adapted in the C alternative grids, namely 2050_C1, 2050_C2 and 2050_C3. This means some of the culverts will be removed, relocated and new culverts will be added, depending on the locations.

There are 21 main parameters that have to be defined for each culvert in Telemac-3D. The overview of the parameters and their meanings are shown in Appendix I. For simplicity, only the key characteristics of the new culverts will be mentioned in the following sections, the technical parameters used in the modelling will be put in Appendix II.

Km 5: Extra depoldering Melleham

A new (non–Sigma) area between the confluence of the Ringvaart/Upper Seascheldt and Bastenakkers is suggested to include in the C alternatives in three variants to allow for nature development.

C1 alternative

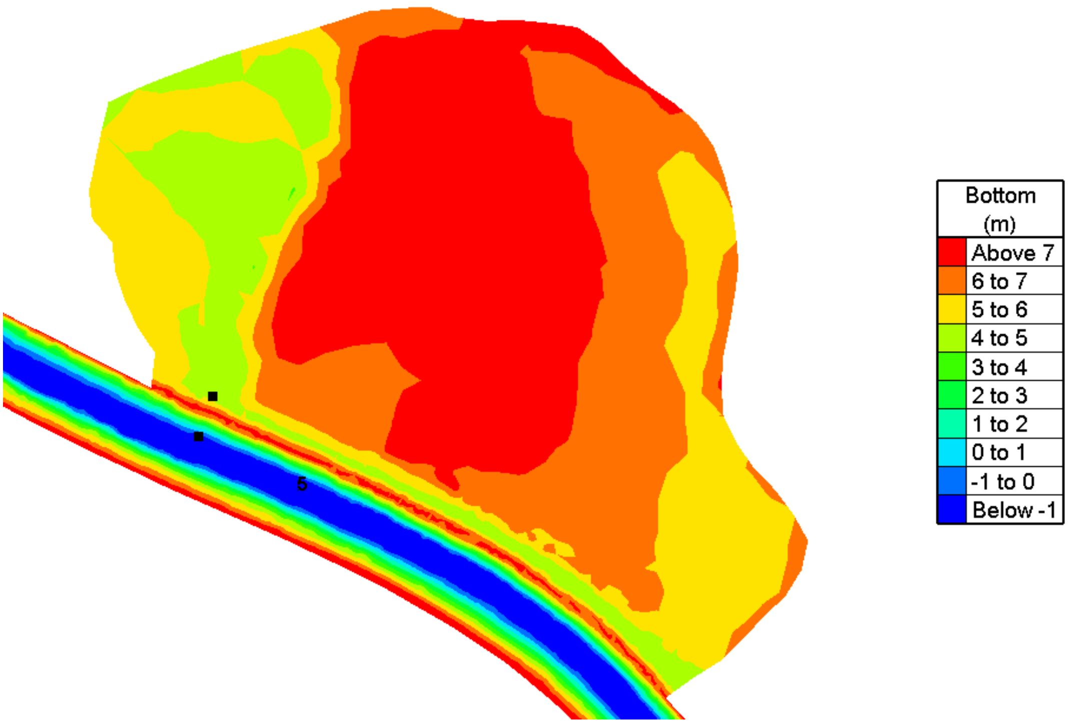
In the C1 alternative, one inlet structure to allow some exchange with the Scheldt – limited tidal action, no safety function, will be closed during high water (not to be included in the hydrodynamic simulation) + connection with lower area in the west. This measure mainly aims to be a stepping stone for nature development.

In the 2050_C1 grid, one culvert is added as the inlet structure for allowing water exchange between the main channel and the depoldering area Melleham. The definition of the new culvert is shown in Table 4, and the location of the culvert nodes in Figure 51. It is worth noting it has different implementation compared to the 1D model. In 1D model, the measure in C1 is not implemented.

Table 4 – Definition of the new culvert in Melleham (C1 alternative)

Type of culvert	Number of culvert	Ground level (mTAW)	Length (m)	Width (m)	Height (m)
Inlet	1	4.4	20	3	2.2

Figure 51 – The location of the culver nodes in Melleham in the C1 alternative
(black square: new inlet culvert)



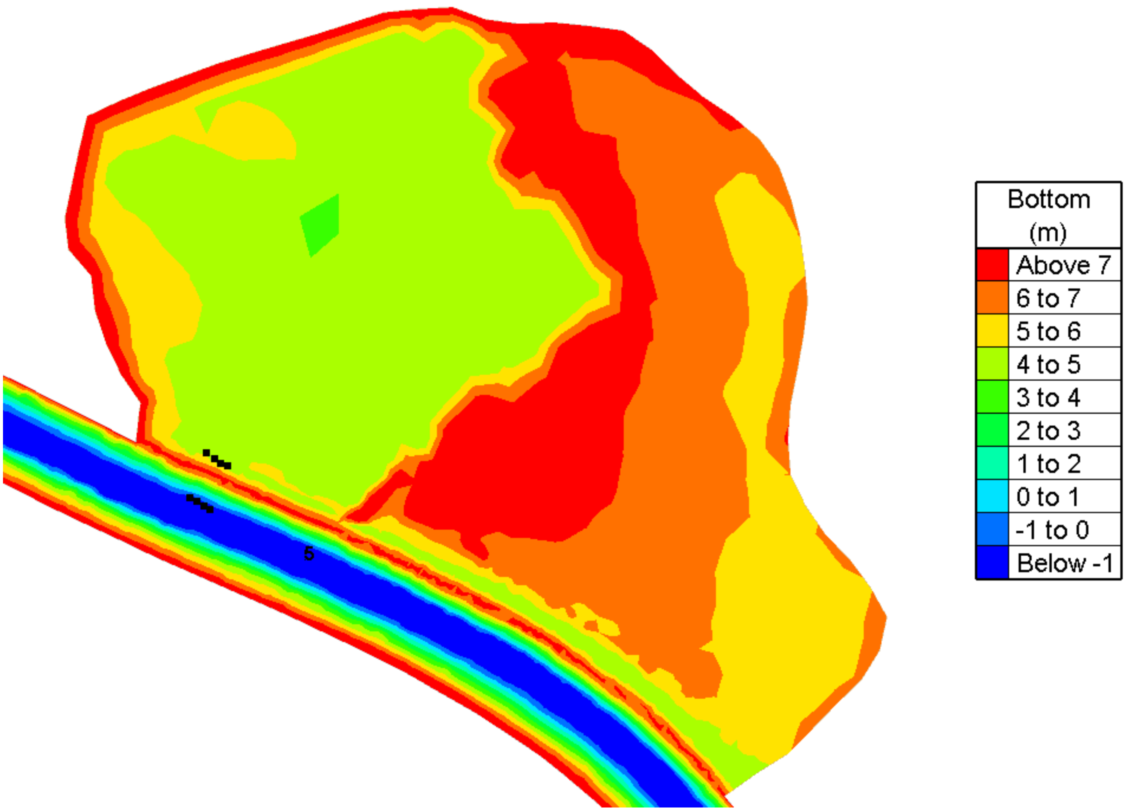
The parameters chosen for modelling this inlet structure in Telemac-3D are shown in Table 15.

C2 alternative

Measures of C1 alternative with and additional excavation of area in the east (till 4 m TAW) until trees are reached (CRT without FCA). A sigma dyke is foreseen at the border of the area. The trees are maintained as a measure against midges.

New culverts consisting of 2 inlets and 2 outlets will be implemented in the area (Figure 52).

Figure 52 – The location of the culver nodes in Melleham in the C2 alternative
(black square: new culverts)



The new inlets and outlets for this area are proposed and listed in Table 16Table 5.

Table 5 – Definition of the new culvert in Melleham (C2 alternative)

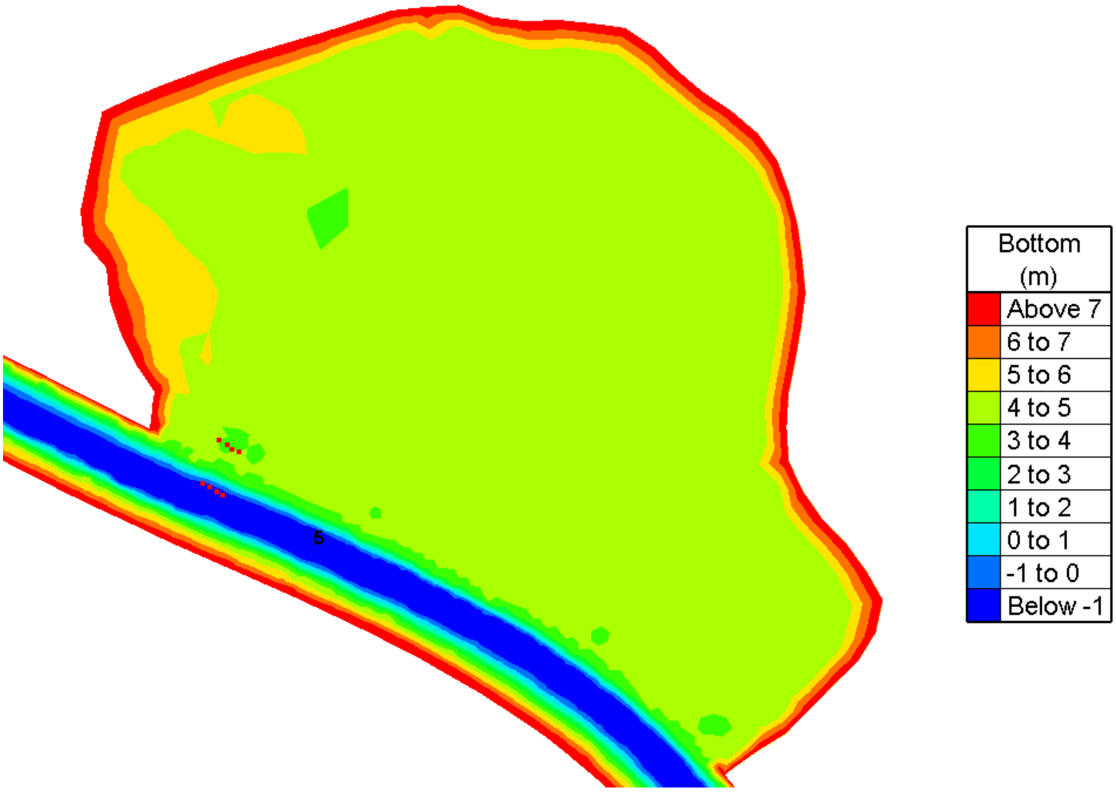
Type of culvert	Number of culvert	Ground level (mTAW)	Length (m)	Width (m)	Height (m)
Inlet	2	4.4	20	3	2.2
Outlet	2	2.5	20	3	2.2

The parameters for the proposed new culverts are listed in.

C3 alternative

Measures of C2 alternative with an additional excavation to a level of 4 m TAW for the higher area in the east. The current dyke at this location is also lowered to 4 m TAW and a new safety dyke around the area is created.

Figure 53 – The location of the removed culver nodes in Melleham in the C3 alternative
(red square: the culverts in the C2 alternative, will be removed in the C3 alternative)



The culverts predefined in the C2 alternative are removed since this area will become depoldering area after removing the dike.

Km 13 : FCA Wijmeers

Connect FCA Wijmeers to a more northerly FCA (lower frequency FCA) in the Kalkense Meersen Wetland. Based upon topography, nature goals and flow direction a proposal of an extension of FCA Wijmeers is made by ANB. This measure is implemented in both the C2 and C3 alternatives.

An overflow dike is proposed with crest level at 3.8 mTAW between the southern part and the northern part of the FCA Wijmeers. However, the bathymetry in this region is above the proposed level of dike. Hence, the dike is not implemented for now.

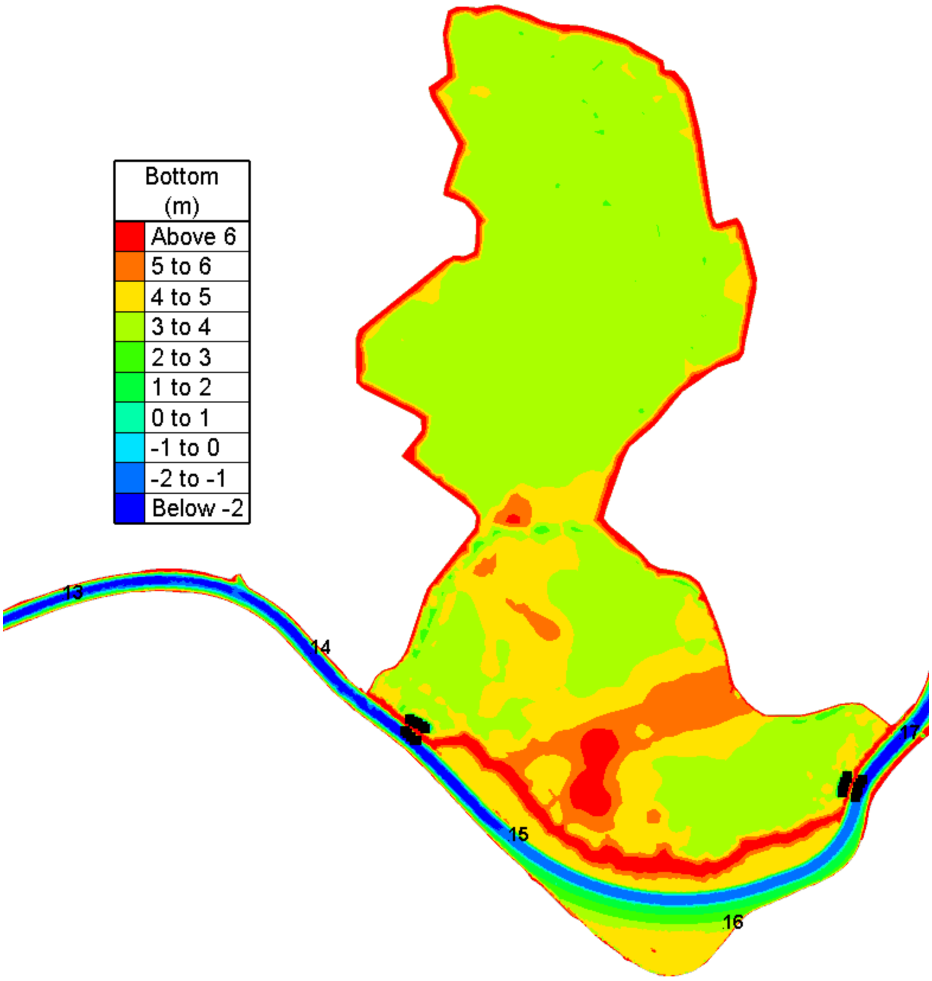
In the 2050REF_B, the FCA Wijmeers has 12 outlet culverts with bottom elevation at 2.75 mTAW implemented, 6 on the west side and 6 on the east side. The same configuration of the culverts are kept in the 2050REF_C.

C1 alternative

No new measure defined in the C1 alternative. The same configuration of the culverts in 2050REF_C is used in C1.

C2 alternative

Figure 54 – The location of the culver nodes in FCA Wijmeers in the C2 alternative
(black square: outlet culverts)

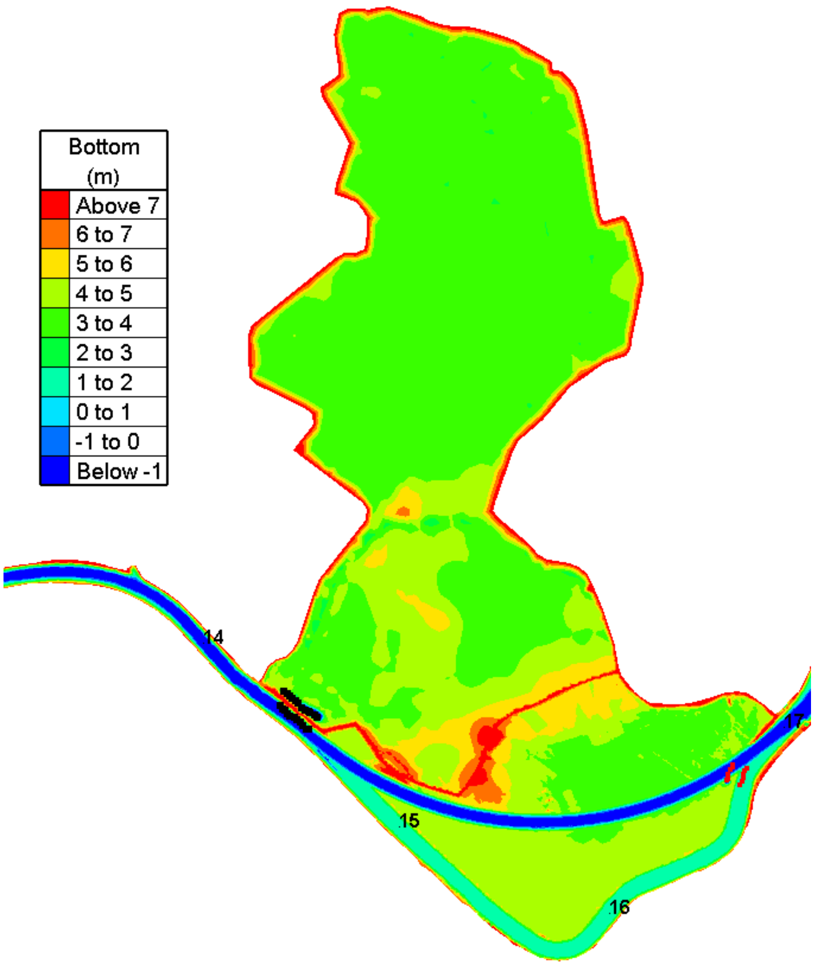


In the 2050REF_C and 2050_C1 grids, the outlet structure is defined with 12 culverts at 2.75 mTAW. The same culverts applied in C1 alternative will be implemented in the C2 alternatives. Note this is different from the implementation in the 1D model, in which 8 outlet culverts are implemented. It is not expected that this will influence the results

C3 alternative

In the C3 alternative, the existing dyke in the FCA Wijmeers is lowered to the surrounding ground level because of the new channel cutting through the FCA Wijmeers and depoldered area. Due to this new measure, the culverts on the east side will be relocated to the west, placed together with the existed culverts there.

Figure 55 – The location of the culver nodes in FCA Wijmeers in the C3 alternative
(black square: new location of the outlet culverts, red square: original location of the outlet culverts)



The parameters of the culverts will remain the same but the culvert node numbers will be changed, as shown in Table 17

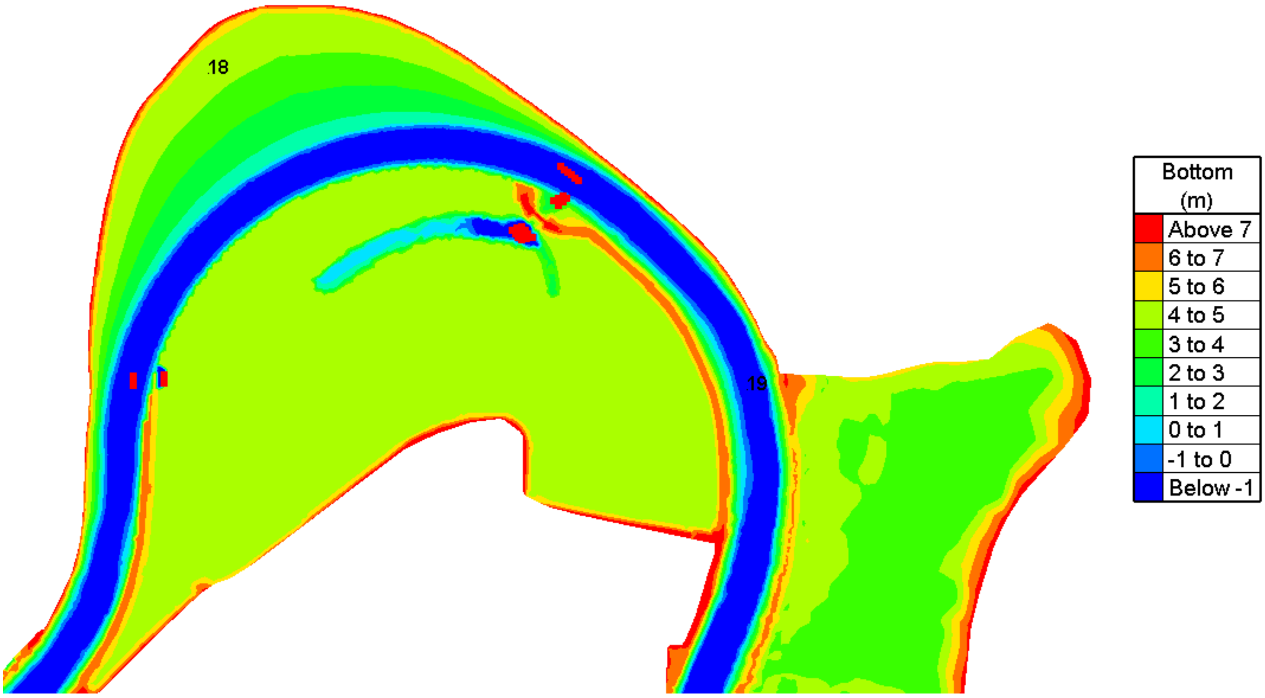
Km 15-17: Channel cut off at Hoogland – Uitbergen - Paardenweide

C1 alternatives

In C1 alternative, the Uitbergen bend will be further smoothened by a new channel in the Bergenmeersen FCA-CRT area (south of the old meander). The existing channel will remain, but filled to 0.5 m below MLW. The FCA-CRT will be completely depoldered (40 ha). Safety against flooding function is compensated through the new FCA in Kalkense Meersen (Km 13) (175 ha).

Because of this new measure, the culverts in this areas will be removed, converting it into the depoldering area.

Figure 56 – The location of the removed culver nodes in Bergenmeersen in C1 alternative
(red square: culvert nodes in the 2050REF_C grid, all of them are removed in the C alternatives)



The removed culvert node numbers are listed in Table 18.

C2 alternatives

The new measures are the same as in the C1 alternative.

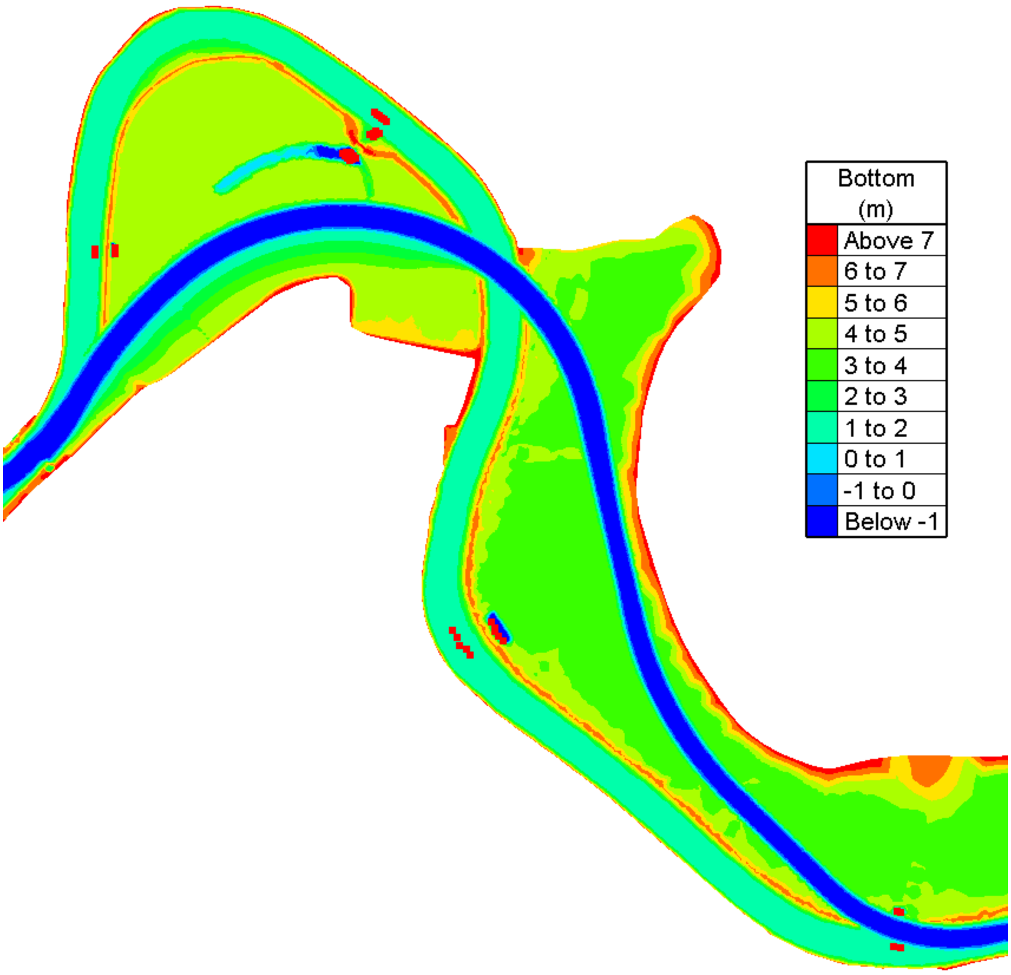
C3 alternative

In the C3 alternative, the Uitbergen bend will be further smoothened by a new channel in the Bergenmeersen FCA-CRT area (south of the old meander). The existing channel will remain, but filled to 0.5 m below MLW. The FCA-CRT will be completely depoldered (40 ha). Safety against flooding function is compensated through the new FCA in Kalkense Meersen (175 ha). The principles for designing C alternatives are followed (tidal flat development at inner bend, tidal marsh at outer bend).

An new navigation channel will be created at Paardeweide. The existing channel will remain, but filled up to 0.5 m below MLW. The Sigma FCA surrounding this measure is depoldered. Safety is compensated by the extension of the Wijmeers FCA into the Kalkense Meersen (see earlier).

Therefore, in addition to the removed culverts in the C2 alternative, the culverts in the further downstream in Paardeweide are also removed (Table 19).

Figure 57 – The location of the removed culver nodes in Bergenmeersen and Paardeweide in the C3 alternative
(red square: culvert nodes in the 2050REF_C grid, all of them are removed in the C alternatives)



Km 27: FCA-CRT Scheldebroek

C1 alternative

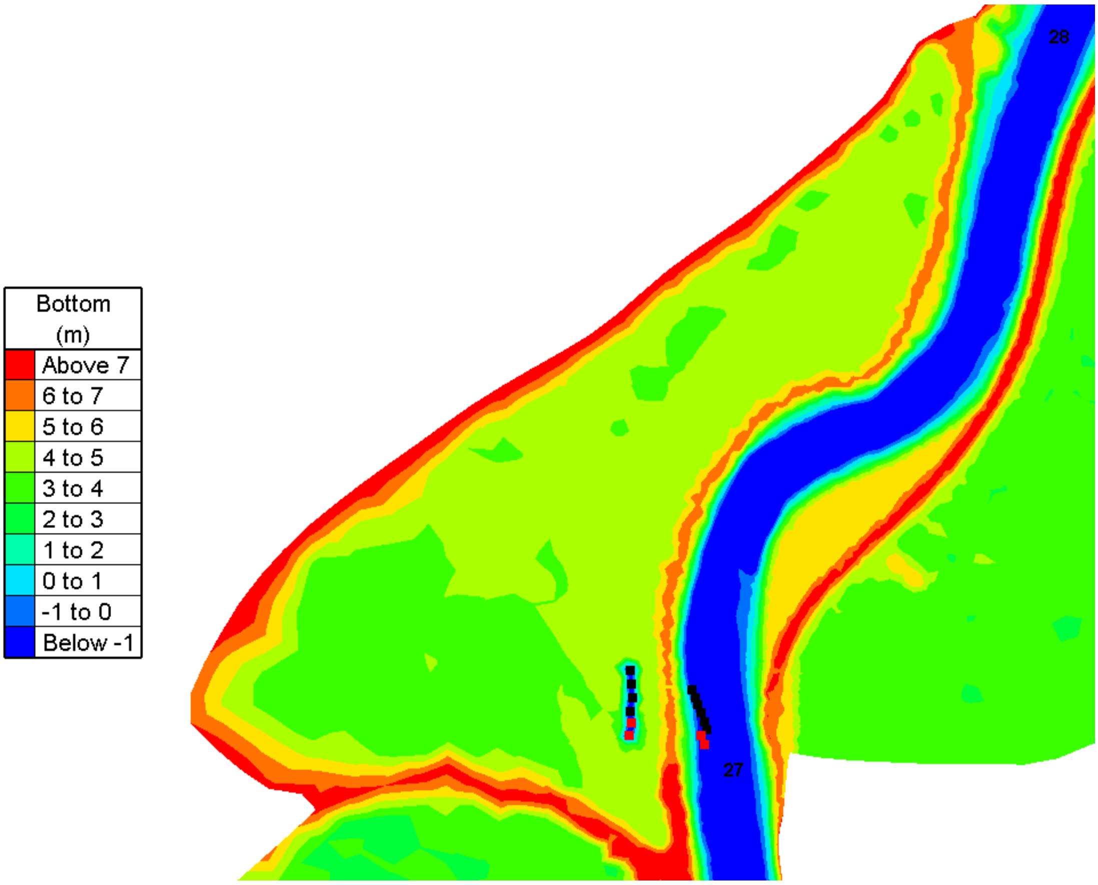
In the C1 alternative, the FCA Scheldebroek is converted into FCA with CRT, as a next stepping stone for nature. The outlet culverts remain the same as defined in the 2050REF_C grid. In addition, there are 4 inlet culverts (with bottom level 4.4 mTAW, length 20 m, 3.0 m wide, 2.2 m high) added next to the existed 2 outlet culverts for introducing the CRT function. The proposed definition of new culverts is given in Table 6.

Table 6 – Definition of the new inlet culverts in Scheldebroek (C1 alternative)

Type of culvert	Number of culvert	Ground level (mTAW)	Length (m)	Width (m)	Height (m)
Inlet	4	4.4	20	3	2.2

The location of the new inlet culverts is shown in Figure 58.

Figure 58 – The location of the culver nodes in FCA-CRT Scheldebroek in the C alternatives
(red square: existed outlet culverts, black square: newly added inlet culverts in the C alternatives)



C2 alternative

The same measure from the C1 alternative is implemented. The same new inlet structures are implemented.

C3 alternative

The same measure from the C1 alternative is implemented. The same new inlet structures are implemented.

Km 40: Kramp

Two variants of the bend straightening at km 40 (Kramp) are defined.

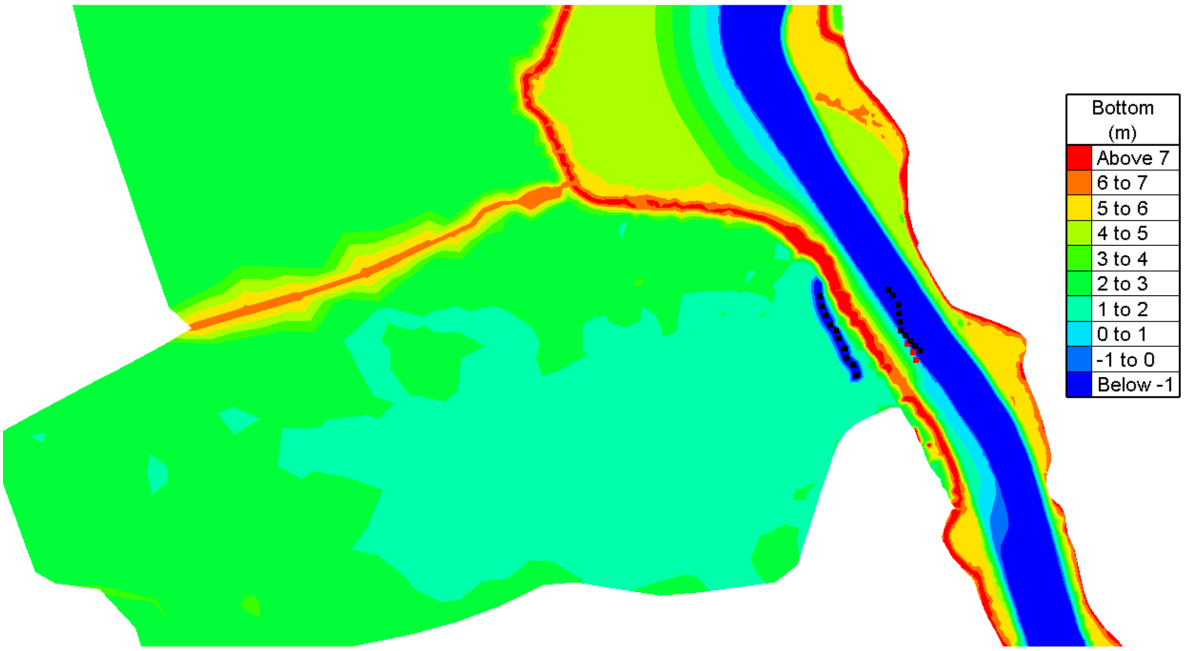
C1 alternative

In the C1 alternative a milder straightening is applied to the navigation channel when compared to the variant in the C2-C3 alternative. This measure does not affect the existing culvert nodes.

C2 alternative

In the C2 alternative, the locations of culvert nodes in the FCA Vlassenbroek Zuid are modified due to the straightening of the main channel, while they are not affected in the C1 alternative. To be more specific, the configuration of the culverts are not changed, only the last three nodes to the south are moved to the deeper area.

Figure 59 – The location of the culver nodes in FCA Vlassenbroek Zuid in the C2 and C3 alternatives (red square: original culverts, black square: new locations of the culverts in the C alternatives)



C3 alternative

The same measure from C2 alternative is implemented. The same changes of the culvert node locations are applied.

Km 48 : Blankaart-Akkershoofd

C1 alternative

In the C1 alternative, the FCA will be extended. The FCA Wal-Zwijn will be converted into FCA-CRT and Blankaart will be converted into FCA and combined with the FCA-CRT Wal-Zwijn. There is no dike between FCA Wal-Zwijn and FCA Blankaart. The FCA Blankaart will be connected with the main channel with an overflow dyke with crest level at 6.7 mTAW.

The new measures in the C1 alternative requires additional culvert structures. To be more specific, there are 3 new inlet culverts added in Wal alongside the existing 6 outlet culverts (Table 7), 4 new inlet culverts added in Zwijn alongside the existing 6 outlet culverts (Table 8), and 3 new outlet culverts added in the FCA Blankaart (Table 9). The locations of the new culverts are shown in Figure 60.

Table 7 – Definition of the new inlet culverts in Wal in C1 alternative

Type of culvert	Number of culvert	Ground level (mTAW)	Length (m)	Width (m)	Height (m)
Inlet	1	4.3	20	3	1.8
Inlet	1	4.5	20	3	1.5
Inlet	1	4.6	20	3	1.4

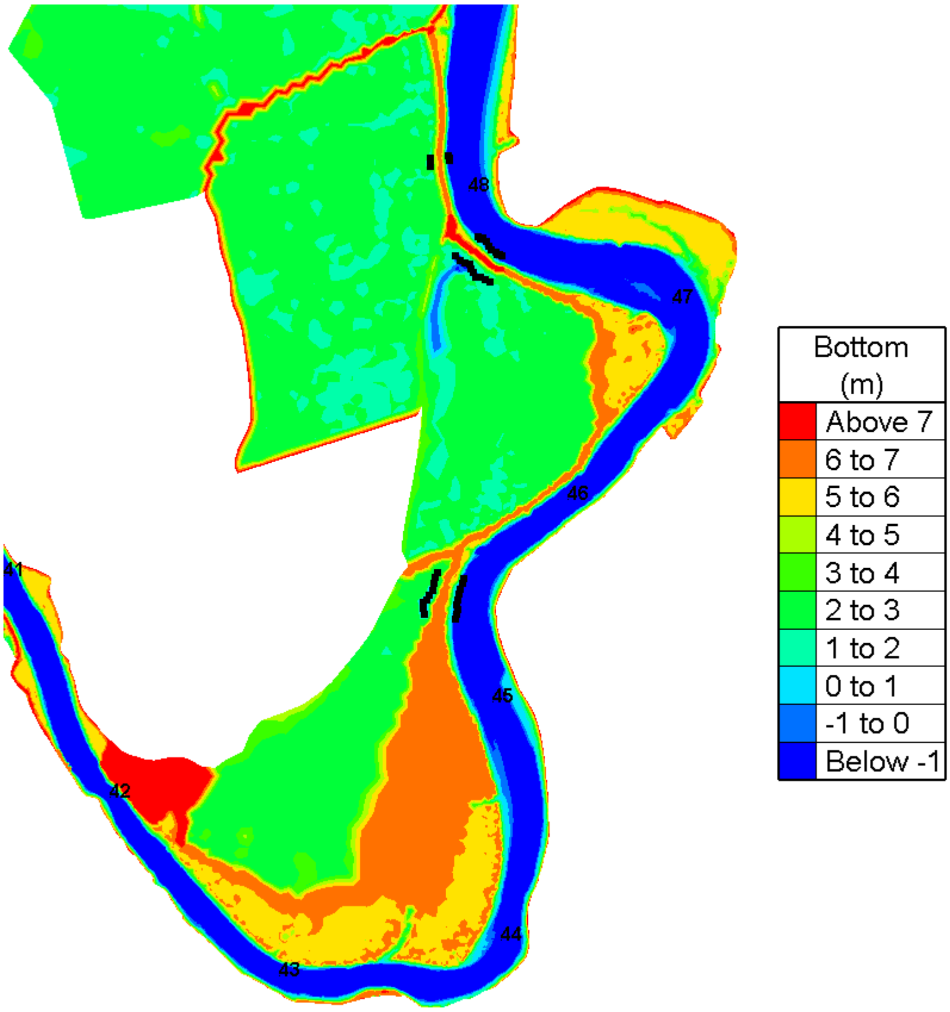
Table 8 – Definition of the new inlet culverts in Zwijn in C1 alternative

Type of culvert	Number of culvert	Ground level (mTAW)	Length (m)	Width (m)	Height (m)
Inlet	4	4.3	20	3	1.8

Table 9 – Definition of the new outlet culverts in Blankaart in C1 alternative

Type of culvert	Number of culvert	Ground level (mTAW)	Length (m)	Width (m)	Height (m)
Outlet	3	1.5	20	3	2.2

Figure 60 – The location of the culver nodes in the FCA Wal-Zwijn and FCA Blankaart in the C1 alternative (black square: inlet and outlet culverts)



The parameters of the new culverts used in the Telemac-3D model are listed in Table 22.

C2 alternative

The FCA Wal-Zwijn in the C2 alternative will be converted into FCA-CRT. The Blankaart will be a depoldering area, and this area will be separated from the FCA-CRT Wal-Zwijn with a dike at 8 mTAW. For adapting to the new measures in the C2 alternatives, there are 3 new inlet culverts added in Wal alongside the existing 6 outlet culverts (Table 10) and 4 new inlet culverts added in Zwijn alongside the existing 6 outlet culverts (Table 11). Although the number of the new culverts are the same as in the C1 alternative, but they have slightly different configurations. The locations of the new culverts are shown in Figure 61.

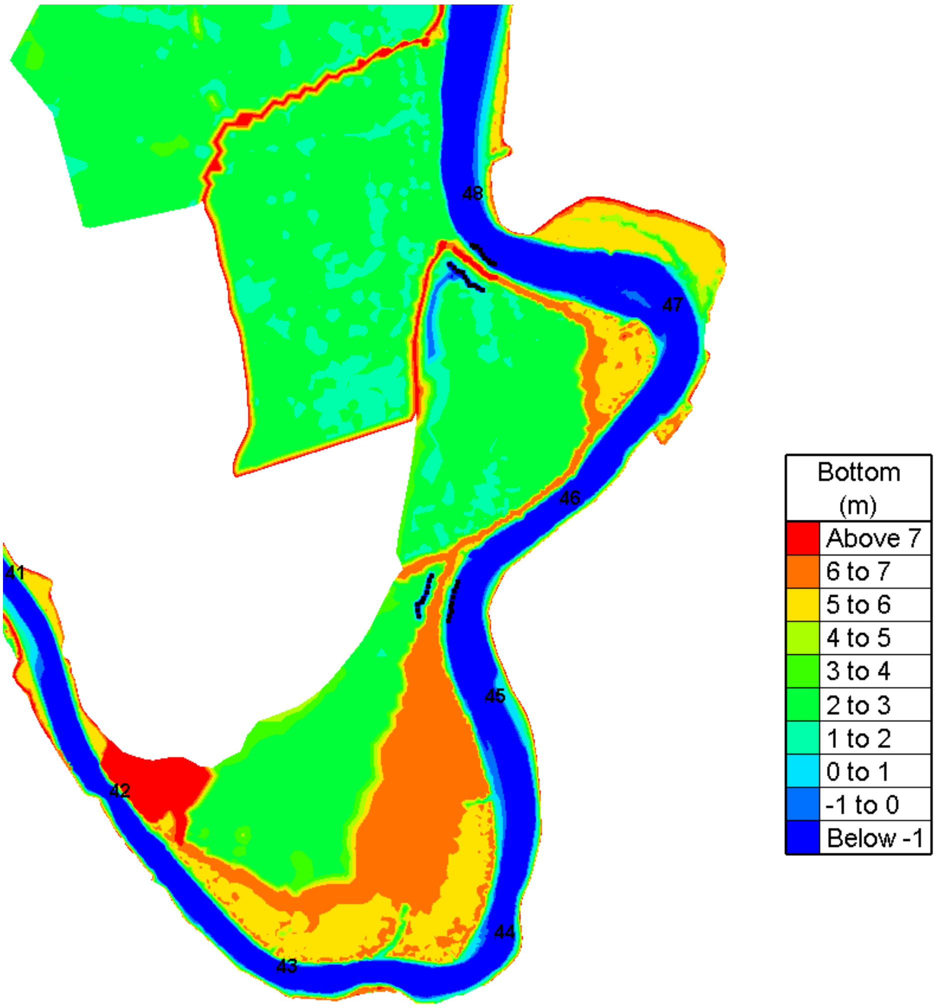
Table 10 – Definition of the new inlet culverts in Wal in C2 alternative

Type of culvert	Number of culvert	Ground level (mTAW)	Length (m)	Width (m)	Height (m)
Inlet	1	4.3	20	3	1.8
Inlet	1	4.5	20	3	1.5
Inlet	1	4.6	20	3	1.4

Table 11 – Definition of the new inlet culverts in Zwijn in C2 alternative

Type of culvert	Number of culvert	Ground level (mTAW)	Length (m)	Width (m)	Height (m)
Inlet	1	4.3	20	3	1.8
Inlet	2	4.6	20	3	1.4
Inlet	1	4.8	20	3	1.2

Figure 61 – The location of the culver nodes in the FCA Wal-Zwijn and FCA Blankaart in the C2 alternative (black square: inlet outlet culverts)

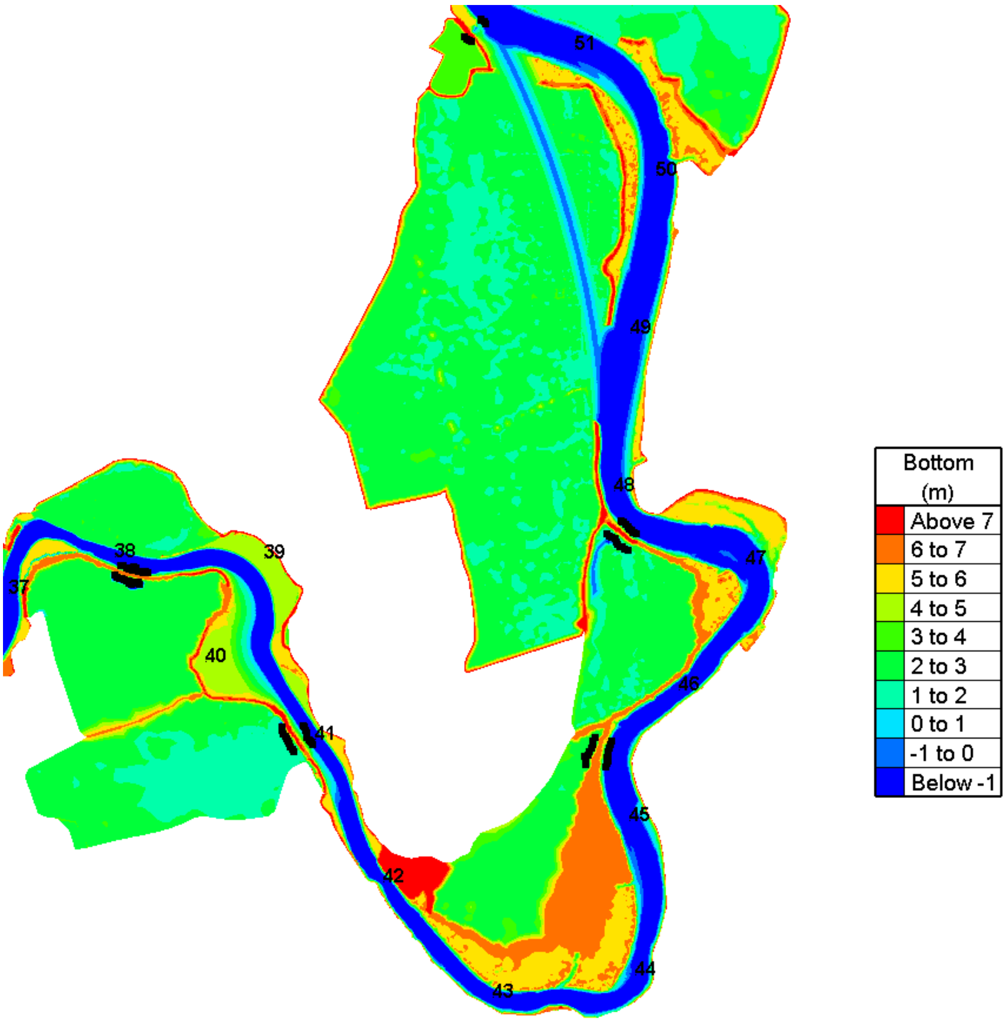


The parameters of the new culverts are defined in Table 23.

C3 alternative

In the C3 alternative, the FCA Wal-Zwijn will be converted into FCA-CRT. Blankaart and Akkershoofd will be combined and become a larger depoldering area, in which a new side channel will be constructed.

Figure 62 – The location of the culver nodes in the FCA Wal-Zwijn and FCA Blankaart in the C3 alternative
(black square: inlet outlet culverts)



Although the new measures in the C3 alternative includes extending the depoldering area, it does not require further adaptions of the culverts. The same new culverts proposed in the C2 alternative will also be implemented here.

Km 53: New connection with Durme

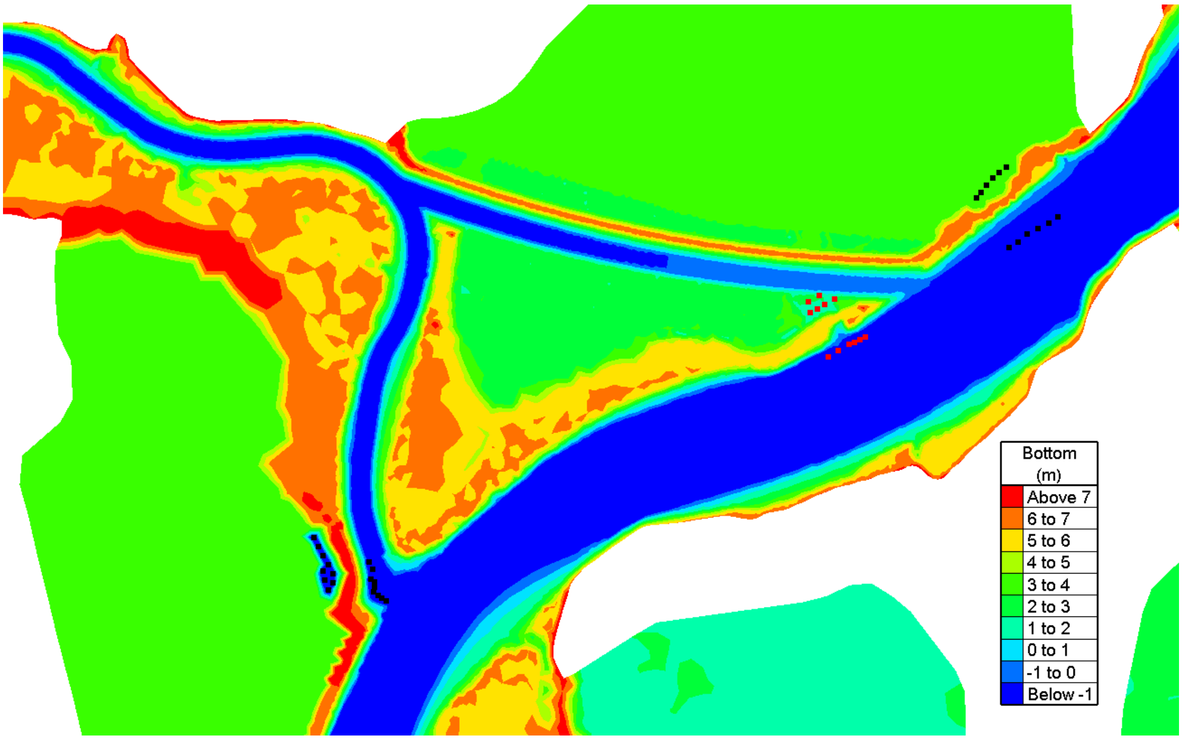
C1 alternative

In the C1 alternative, a secondary branch to Durme in combination with depoldering southern section of FCA-CRT area Tielrode broek is created. The loss in safety will be compensated by the measures in Blankaart at km 48.

With this operation ca 6 ha of the original FCA-CRT area is converted into the side channel. Ca 15 ha of the FCA-CRT is converted to depoldered area (south of the new side channel). The total depoldered area is 27 ha. The part north of the side channel of this area keeps the original function as FCA-CRT. An overflow dyke (6.6 m TAW) is foreseen in the design of the new side channel.

Due to the new measures in the C1 alternative, the existing culverts defined in the 2050REF_C grid are moved to new location but their configurations are kept the same (Table 24). The new locations of the culverts are moved northeast of the previous locations as indicated in Figure 63.

Figure 63 – The location of the culvert nodes in FCA-CRT Tielrodebroek
(red square: culvert locations in the 2050REF_C grid, black square: new culvert locations in the C1 alternative)



C2 alternative

The same measures from the C1 alternative are implemented. The existing culverts are moved to the same locations as in the C1 alternative.

C3 alternative

The same measures from the C1 alternative are implemented. The existing culverts are moved to the same locations as in the C1 alternative.

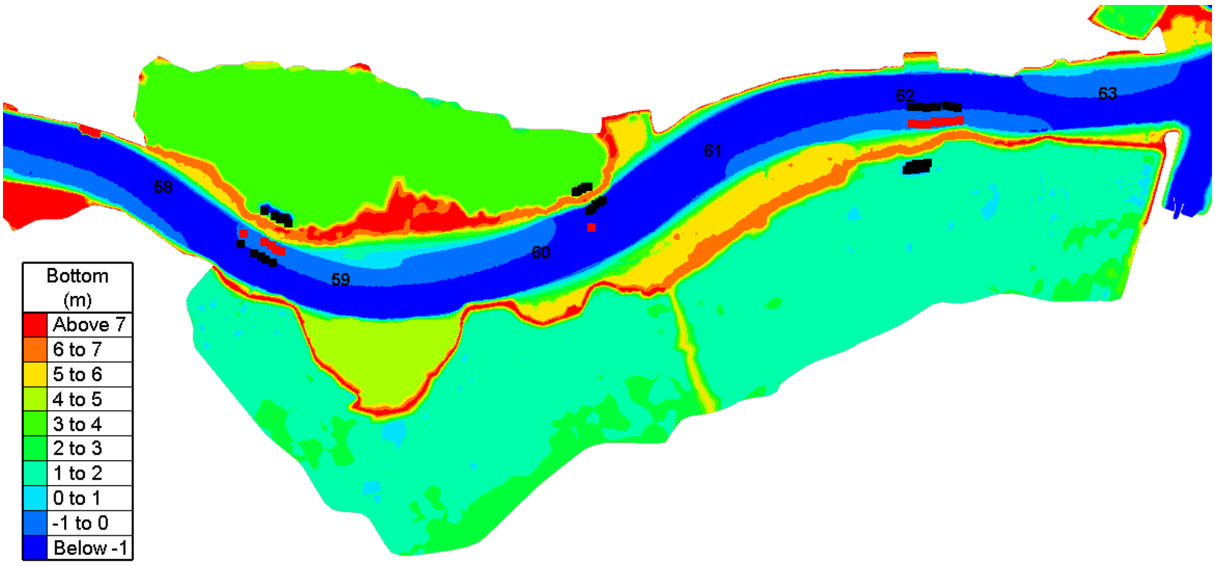
Km 57-64: Bornem

Since the bend straightening is already included in the C1 alternative, a measure between Temse and the mouth of the Rupel is already defined in the C1 alternative. Extended measures are implemented for the C2 (side channel) and C3 alternative (side channel + additional undeepening) since the bend straightening at km 40 (Kramp) in these alternatives is expected to result in a larger increase in tidal amplitude.

C1 alternative

Local undeepening (cfr Baasrode pilot) at 5 locations between km 56 and 65 to a level not higher than 0.5 m below MLW, in order to preserve the valuable tidal flats of this area. Due to undeepening in the main channel, the locations of the culvert nodes in the riverside have to be changed. They are shifted towards relatively deeper area (Figure 64). The new node numbers are given in Table 25.

Figure 64 – The location of the culvert nodes in Schouselbroek-Schellandpolder in the C1 alternative
(red square: riverside culvert nodes in the 2050REF_C grid, black square: shifted riverside culvert nodes in 2050_C1)



C2 alternative

In addition to the C1 alternative, two new side channels: one through Schouselbroek and one through Schelland/Oudbroekpolder are defined. To compensate for the loss of Sigma areas with safety function, the reserve areas Spierbroekpolder and Hingene Broekpolder are activated as a FCA with CRT, in order to maximise the surface of estuarine nature. Schellandpolder, Oudbroekpolder and Schouselbroek converted into depoldered area.

The original culverts in this area are removed in the C2 alternative, and the following configurations of the new culverts is proposed:

Table 12 – Definition of the new inlet culverts in Hingenebroekpolder in C2 alternative

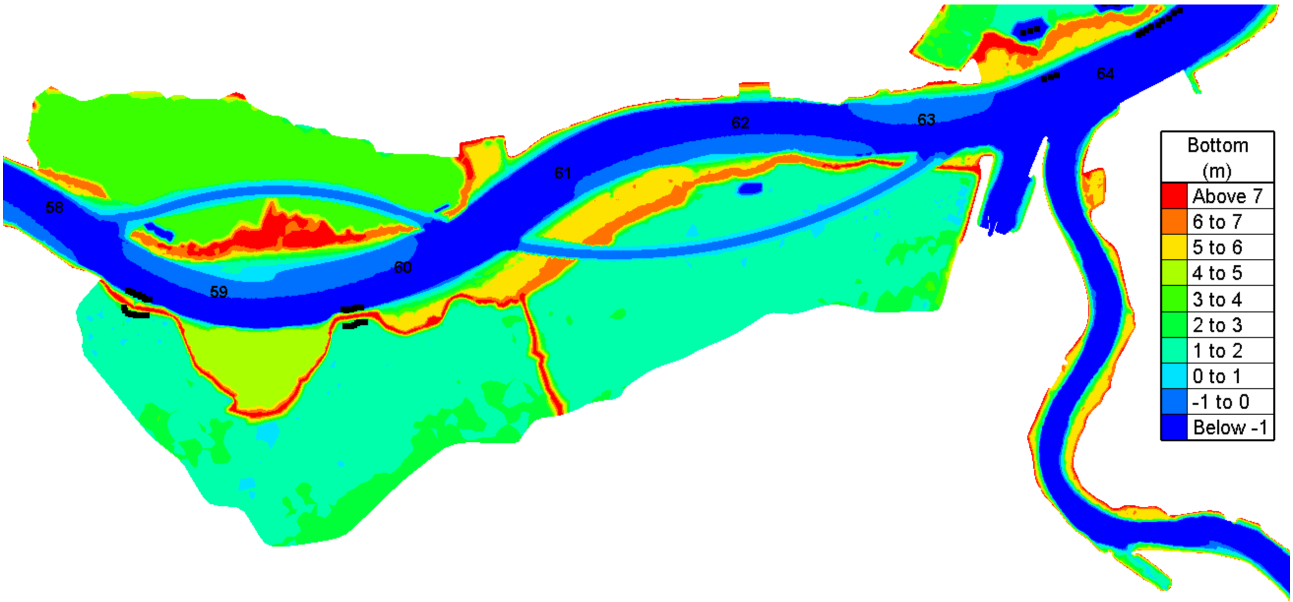
Type of culvert	Number of culvert	Ground level (mTAW)	Length (m)	Width (m)	Height (m)
Inlet	1	4.45	20	3	2.2
Inlet	3	4.6	20	3	2.2
Outlet	4	0.5	20	3	2.2

Table 13 – Definition of the new inlet culverts in Spierbroekpolder in C2 alternative

Type of culvert	Number of culvert	Ground level (mTAW)	Length (m)	Width (m)	Height (m)
Inlet	1	4.45	20	3	2.2
Inlet	4	4.6	20	3	2.2
Outlet	5	0.5	20	3	2.2

The parameters of the new culverts are defined in Table 26 and Table 27. The location of the new culverts is shown in Figure 65.

Figure 65 – The location of the culvert nodes in Schouselbroek-Schellandpolder in the C2 alternative (black square: The new culvert nodes in 2050_C2)



C3 alternative

Same as C2, but with an extra undeepening to a level of -5.3 m TAW in the main channel. Reserve areas Spierbroekpolder and Hingene Broekpolder are activated as a FCA with CRT. Schellandpolder, Oudbroekpolder and Schouselbroek converted into depoldered area, and the original culverts are removed. The same new culverts for the Spierbroekpolder and Hingene Broekpolder are implemented in the C3 alternative.

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Appendix I.
Explanation of the culvert parameters

The following parameters are used to simulate culverts in the Telemac-3D. The name of the parameter and its meaning is given in Table 14.

Table 14 – The definition of the culvert parameters

I1	The node number of culvert on the riverside
I2	The node number of culvert on the floodplain side
CE1	Inlet head loss coefficient. just called C1 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 C3 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)
LRGbus	The width of the culvert.
Haut1	Height of the culvert at the river side.
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).
LBUS	Linear head loss coeffcient used only when OPTBUSE = 1 (the simplified equations); If OPTBUSE = 2 (new set of equations distinguishing between five flow types), LBUS is calculated.
Z1	Culvert bottom elevation on river side.
Z2	Culvert bottom elevation on floodplain side.
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 Cv=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 C1 (present in CE1 and CE2) and to CV 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)
Ctrash	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).
Haut2	Height of the culvert at the floodplain side
Fric	Manning Strickler's coefficient for the structure (usually taken 0.015 for smooth concrete according to Smolders et al., 2016)
Length	Length of the culvert
Circ	This indicates whether the culvert is rectangular (=0) or circular (=1); in case of a circular culvert the height is taken to calculate the wet section.

Appendix II. Parameters of the new culverts

1. Km 5: Extra depoldering Melleham

Table 15 – The parameters for the inlet culvert in CRT Melleham in C1 alternative

Area	Melleham
I1	434279
I2	434317
CE1	0.5
CE2	0.5
CS1	1
CS2	1
LRGbus	2.6
Haut1	2.2
CLP	0
LBUS	0.2
Z1	4.4
Z2	4.4
CV	1
C56	10
CV5	0
C5	6
Ctrash	1
Haut2	2.2
Fric	0.015
Length	20
Circ	0

Table 16 – The parameters defined for the new culverts in Melleham in C2 alternative

Area	**Melleham**			
I1	434279	434295	434310	434328
I2	434317	434336	434359	434384
CE1	0.5	0.5	0.5	0.5
CE2	0.5	0.5	0.5	0.5
CS1	1	1	1	1
CS2	1	1	1	1
LRGbus	2.6	2.6	2.6	2.6
Haut1	2.2	2.2	2.2	2.2
CLP	0	0	2	2
LBUS	0.2	0.2	0.2	0.2
Z1	4.4	4.4	2.5	2.5
Z2	4.4	4.4	2.5	2.5
CV	1	1	1	1
C56	10	10	10	10
CV5	0	0	1.5	1.5
C5	6	6	6	6
Ctrash	1	1	1	1
Haut2	2.2	2.2	2.2	2.2
Fric	0.015	0.015	0.015	0.015
Length	20	20	20	20
Circ	0	0	0	0

2. Km 13: FCA Wijmeers

Table 17 – The change of culvert node numbers of FCA Wijmeers in C3 alternative

Area	I1 (old)	I2 (old)	I1 (New)	I2 (New)
FCA Wijmeers	223350	457845	176288	442032
	223399	457862	176276	441982
	223433	457884	176265	441944
	223425	457921	176255	441923
	223459	457978	176238	441891
	223488	457962	176227	441837

3. Km 15-17: Channel cut off at Hoogland – Uitbergen - Paardenweide

Table 18 – The removed culvert nodes in Uitbergen in the C1 and C2 alternatives

Area	I1 (Removed)	I2 (Removed)
Bergenmeersen	212625	211473
	212566	211511
	212503	211563
	212439	211620
	212376	211726
	212309	211842
	212302	211642
	212195	211703
	212277	211769
	212369	211542
	212350	211593
	212435	211657
	202970	203763
	202966	203761
	202969	203759

Table 19 – The removed culvert nodes in Uitbergen and Paardeweide in the C3 alternative

Area	I1 (Removed)	I2 (Removed)
Paardeweide	224811	459112
	224735	458998
	224621	458944
	224547	458939
	224439	458870
	227339	468301
	227310	468257
Bergenmeersen	212625	211473
	212566	211511
	212503	211563
	212439	211620
	212376	211726
	212309	211842
	212302	211642
	212195	211703
	212277	211769
	212369	211542
	212350	211593
	212435	211657
	202970	203763
	202966	203761
	202969	203759

4. Km 27: FCA-CRT Scheldebroek

Table 20 – The parameters defined for the 4 inlet culverts in FCA-CRT Scheldebroek in C1-C2-C3 alternatives

Area	FCA-CRT Scheldebroek			
I1	487281	487152	487045	486931
I2	485433	485491	485462	485457
CE1	0.5	0.5	0.5	0.5
CE2	0.5	0.5	0.5	0.5
CS1	1	1	1	1
CS2	1	1	1	1
LRGbus	2	2	2	2
Haut1	2.2	2.2	2.2	2.2
CLP	0	0	0	0
LBUS	0.2	0.2	0.2	0.2
Z1	4.4	4.4	4.4	4.4
Z2	4.4	4.4	4.4	4.4
CV	1	1	1	1
C56	10	10	10	10
CV5	0	0	0	0
C5	6	6	6	6
Ctrash	1	1	1	1
Haut2	2.2	2.2	2.2	2.2
Fric	0.015	0.015	0.015	0.015
Length	20	20	20	20
Circ	0	0	0	0

5. Km 40: Kramp

Table 21 – The change of culvert node numbers of Vlassenbroek Zuid in C2 and C3 alternatives

Area	I1 (Old)	I2 (Old)	I1 (New)	I2 (New)
FCA Vlassenbroek Zuid	246326	245795	246393	245795
	246302	245774	246318	245774
	246220	245754	246245	245754

6. Km 48: Blankaart-Akkershoofd

Table 22 – The parameters defined for the new culverts in Wal-Zwijn and Blankaart in C1 alternative

Area	Zwijn (North)				Wal (South)			Blankaart		
I1	275285	274825	274332	274106	267657	267894	268076	266252	266313	266360
I2	272850	272029	271325	270403	265206	265248	265369	522444	522381	522406
CE1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CE2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CS1	1	1	1	1	1	1	1	1	1	1
CS2	1	1	1	1	1	1	1	1	1	1
LRGbus	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Haut1	1.8	1.8	1.8	1.8	1.8	1.5	1.4	2.2	2.2	2.2
CLP	0	0	0	0	0	0	0	2	2	2
LBUS	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Z1	4.3	4.6	4.6	4.8	4.3	4.5	4.6	1.5	1.5	1.5
Z2	4.3	4.6	4.6	4.8	4.3	4.5	4.6	1.5	1.5	1.5
CV	1	1	1	1	1	1	1	1	1	1
C56	10	10	10	10	10	10	10	10	10	10
CV5	0	0	0	0	0	0	0	1.5	1.5	1.5
C5	6	6	6	6	6	6	6	6	6	6
Ctrash	1	1	1	1	1	1	1	1	1	1
Haut2	1.8	1.8	1.8	1.8	1.8	1.5	1.4	2.2	2.2	2.2
Fric	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Length	20	20	20	20	20	20	20	20	20	20
Circ	0	0	0	0	0	0	0	0	0	0

Table 23 – The parameters defined for the new culverts in Wal-Zwijn in C2-C3 alternatives

Area	Zwijn (North)				Wal (South)		
I1	275285	274825	274332	274106	267657	267894	268076
I2	272850	272029	271325	270403	265206	265248	265369
CE1	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CE2	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CS1	1	1	1	1	1	1	1
CS2	1	1	1	1	1	1	1
LRGbus	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Haut1	1.8	1.4	1.4	1.2	1.8	1.5	1.4
CLP	0	0	0	0	0	0	0
LBUS	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Z1	4.3	4.6	4.6	4.8	4.3	4.5	4.6
Z2	4.3	4.6	4.6	4.8	4.3	4.5	4.6
CV	1	1	1	1	1	1	1
C56	10	10	10	10	10	10	10
CV5	0	0	0	0	0	0	0
C5	6	6	6	6	6	6	6
Ctrash	1	1	1	1	1	1	1
Haut2	1.8	1.4	1.4	1.2	1.8	1.5	1.4
Fric	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Length	20	20	20	20	20	20	20
Circ	0	0	0	0	0	0	0

7. Km 53: New connection with Durme

Table 24 – The change of culvert node numbers in FCA-CRT Tielrodebroek in C1-C2-C3 alternatives

Area	I1 (Old)	I2 (Old)	I1 (New)	I2 (New)
FCA-CRT Tielrode Broek	277077	532235	284726	533056
FCA-CRT Tielrode Broek	277925	532130	284966	533061
FCA-CRT Tielrode Broek	277491	532063	285227	284385
FCA-CRT Tielrode Broek	278365	531989	285469	284524
FCA-CRT Tielrode Broek	275049	532087	285757	284641
FCA-CRT Tielrode Broek	276136	531979	285995	284793

8. Km 57-64: Bornem

Table 25 – The change of culvert node numbers in Bornem in C1 alternative

Area	I1 (Old)	I2 (Old)	I1 (New)	I2 (New)
Schellandpolder	308469	548566	308465	548566
	308377	548458	308348	548458
	308253	548288	308239	548288
	308101	548128	308104	548128
	308526	548029	308506	548029
	308611	548276	308628	548276
	308698	548404	308692	548404
	308773	548559	308759	548559
Schouselbroek	303310	540704	303310	540704
	303243	540674	303243	540674
	303163	540662	303149	540662
	298994	534840	298920	534840
	298951	534752	298839	534752
	298904	534646	298787	534646
	298829	534543	298702	534543
	303194	540719	303194	540719
	303358	540743	303358	540743
	298562	534342	298534	534342

Table 26 – The parameters defined for the new culverts in FCA-CRT Hingene Broekpolder in C2-C3 alternatives

Area	**Hingene Broekpolder**							
I1	301375	301421	301452	301493	301517	301547	301576	301607
I2	541756	541773	541794	541809	541832	541849	541862	541877
CE1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CE2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CS1	1	1	1	1	1	1	1	1
CS2	1	1	1	1	1	1	1	1
LRGbus	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Haut1	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
CLP	2	2	2	2	0	0	0	0
LBUS	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Z1	0.5	0.5	0.5	0.5	4.45	4.6	4.6	4.6
Z2	0.5	0.5	0.5	0.5	4.45	4.6	4.6	4.6
CV	1	1	1	1	1	1	1	1
C56	10	10	10	10	10	10	10	10
CV5	1.5	1.5	1.5	1.5	0	0	0	0
C5	6	6	6	6	6	6	6	6
Ctrash	1	1	1	1	1	1	1	1
Haut2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Fric	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Length	18	18	18	18	18	18	18	18
Circ	0	0	0	0	0	0	0	0

Table 27 – The parameters defined for the new culverts in FCA-CRT Spierbroekpolder in C2-C3 alternatives

Area	**Spierbroekpolder**									
I1	298539	298585	298611	298658	298708	298726	298763	298790	298813	298850
I2	541012	541019	541028	541041	541052	541070	541083	541095	541114	541126
CE1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CE2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CS1	1	1	1	1	1	1	1	1	1	1
CS2	1	1	1	1	1	1	1	1	1	1
LRGbus	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Haut1	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
CLP	2	2	2	2	2	0	0	0	0	0
LBUS	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Z1	0.5	0.5	0.5	0.5	0.5	4.45	4.6	4.6	4.6	4.6
Z2	0.5	0.5	0.5	0.5	0.5	4.45	4.6	4.6	4.6	4.6
CV	1	1	1	1	1	1	1	1	1	1
C56	10	10	10	10	10	10	10	10	10	10
CV5	1.5	1.5	1.5	1.5	1.5	0	0	0	0	0
C5	6	6	6	6	6	6	6	6	6	6
Ctrash	1	1	1	1	1	1	1	1	1	1
Haut2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Fric	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Length	18	18	18	18	18	18	18	18	18	18
Circ	0	0	0	0	0	0	0	0	0	0

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