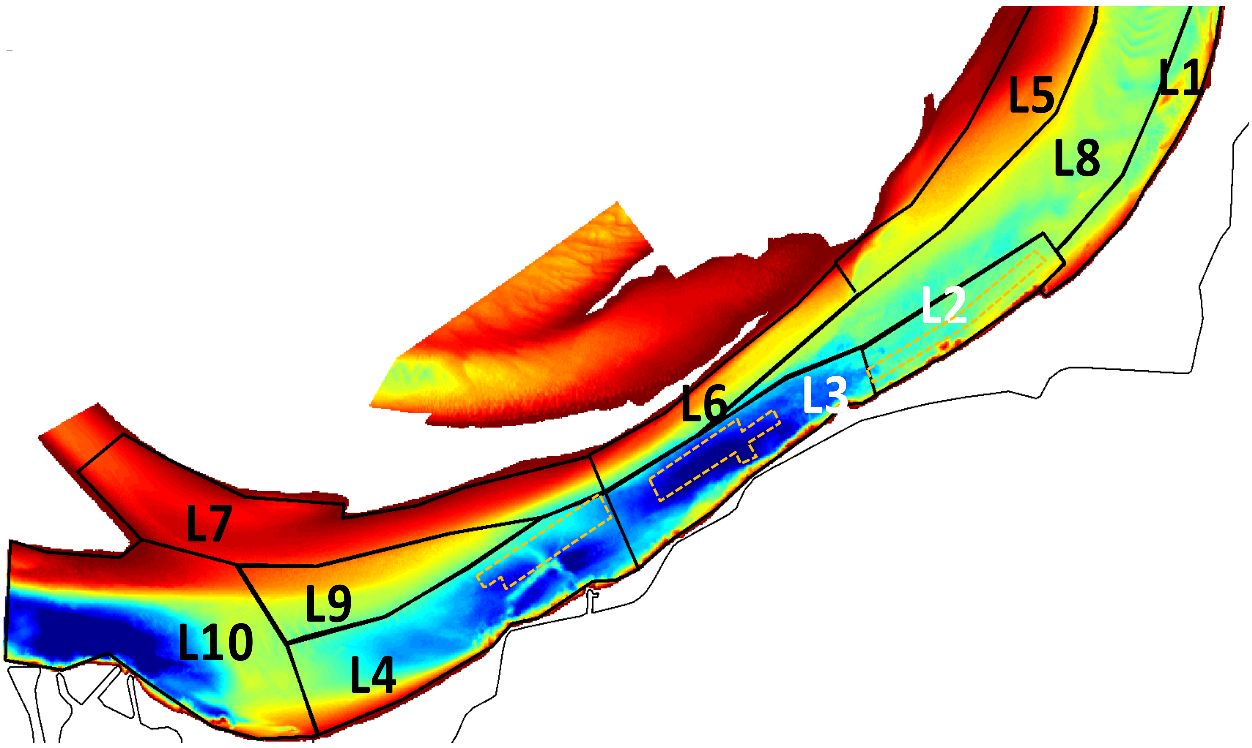
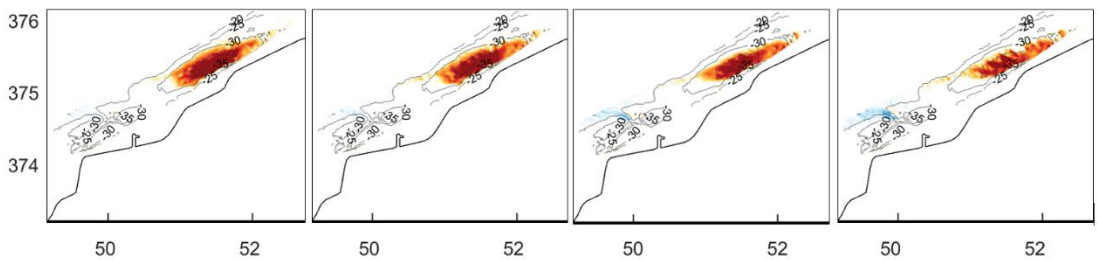
Deltares

Mesoscale morphology of the Inloop van Ossenisse

Influence of pilot disposals in relation to autonomous trends





Mesoscale morphology of the Inloop van Ossenisse
Influence of pilot disposals in relation to autonomous trends

Author(s)
Jose Antolinez
Bas Huisman
Ymkje Huismans

Deltares

Mesoscale morphology of the Inloop van Ossenisse
Influence of pilot disposals in relation to autonomous trends

Client	Vlaams-Nederlandse Scheldecommissie
Contact	Frederik Roose (aMT)
Reference	
Keywords	Western Scheldt, Morphology, Inloop van Ossenisse, Dredge-Disposal strategy

Document control	
Version	1.0
Date	14-01-2021
Project nr.	1210301-015
Document ID	1210301-015-ZKS-0013
Pages	39
Status	final

Author(s)		
	Jose Antolinez	
	Bas Huisman	
	Ymkje Huismans	

Doc. Version	**Author**	**Reviewer**	**Approver**	**Publish**
1.0	Jose Antolinez	Zheng Bin Wang	Toon Segeren	
	Bas Huisman			
	Ymkje Huismans			

Samenvatting

De vaargeul van de Westerschelde heeft regelmatig onderhoud nodig om het voor grote schepen mogelijk te maken de haven van Antwerpen te bereiken. Het gebaggerde sediment dient terug geplaatst te worden in het estuarium om een netto verlies van sediment te voorkomen. Verschillende locaties binnen de Westerschelde worden gebruikt om sediment terug te plaatsen, van deze locaties worden met name de diepe putten in de hoofdgeul in toenemende mate gebruikt. In dit rapport wordt het gedrag onderzocht van proefstortingen van baggerspecie in de diepe put van de Inloop van Ossenisse in opdracht van de Vlaams Nederlandse Scheldecommissie (VNSC) en de afdeling Maritieme Toegang van het Vlaamse Ministerie van Openbare Werken. Het doel van deze studie is om de herverdeling en opslag van gebaggerde specie op de bodem van de diepe put van de Inloop van Ossenisse te onderzoeken én tevens beter te leren begrijpen wat de invloed hiervan is op het regionale morfologische systeem (i.e. van Drempel van Hansweert tot aan de Overloop van Hansweert, en aan de noordwest zijde het Straatje van Willem). Het in deze studie opgebouwde conceptuele overzicht van de verspreiding van sediment vanuit de Inloop van Ossenisse draagt bij aan de kennisbasis voor de stortstrategie van de Westerschelde.

Drie proefstortingen hebben plaats gevonden in de Inloop van Ossenisse in 2016, 2017 en 2019, waardoor een goed beeld is verkregen van de lokale verspreiding op de stortlocatie. Het sediment erodeert geleidelijk vanaf de bodem van de diepe put met een snelheid van 1100 tot 1400 m^3 per dag (over de beschouwde periode), wat duidelijk minder is dan voor de andere dichtbij gelegen stortlocaties in diepe putten zoals het Gat van Ossenisse, de Overloop van Hansweert (SH41) en de Put van Hansweert waar de erosie zeker twee tot drie keer sneller gaat. Dit betekent dat er enige opvulling kan ontstaan van de diepe put van de Inloop van Ossenisse wanneer er grote volumes baggerspecie worden geplaatst over een lange periode. Het oppervlak en het bergend volume van de Inloop van Ossenisse zijn echter vrij groot. Het kan daarom nog steeds heel nuttig zijn om de Inloop van Ossenisse te gebruiken voor het storten van baggerspecie, vooral om de hoeveelheid gestort sediment te beperken op dichtbij gelegen stortlocaties zoals SH41 en de Put van Hansweert.

In algemene zin zijn de effecten van de proefstortingen in de Inloop van Ossenisse zeer beperkt in vergelijking met de autonome morfologische ontwikkelingen in de regio, én kleiner dan de invloed van de andere dichtbij gelegen stortlocaties waar overigens veel grotere volumes zijn gestort. Een enigszins grotere aanzanding wordt verwacht bij de Drempel van Terneuzen als gevolg van het netto eb-transport van sediment in de Inloop van Ossenisse. Dit zorgt op de lange-termijn mogelijk ook voor extra aanzanding van de Zuid-Everingen. Mogelijk zal er ook sediment worden getransporteerd naar de Drempel van Baarland, maar dit kon niet worden vastgesteld tijdens de proefstortingen.

Ondanks de relatief beperkte impact op de omgeving/regio, is het sterk aan te raden om met bodemhoogtemetingen te verifiëren in hoeverre de toekomstige effecten overeenkomen met de bevindingen tijdens de proefstortingen. De huidige kennis is namelijk voor een groot deel gebaseerd op expert interpretatie van een relatief kortdurende meetreeks. Het verzamelen van aanvullende meetgegevens over een meerjarige periode van proefstortingen (in de gehele hier beschouwde regio) zal de kennis van de effecten op de omgeving aanzienlijk vergroten, wat essentieel is voor een goed onderbouwde keuze van een stortstrategie.

Summary

The navigation channel of the Western Scheldt needs regular dredging to allow large vessels to reach the port of Antwerp. This dredged-material needs to be placed back in the estuary to prevent a net loss of sediment. Various locations within the Western Scheldt are used to dispose the sediment, of these locations especially the deeper pits of the main channel are increasingly used. In this report the pilot disposal of dredged sediment in the deep pit of the Inloop van Ossenisse is investigated for the Vlaams Nederlandse Scheldecommissie (VNSC) and the department of Maritieme Toegang of the Flemish Ministry of Public Works. The aim of this pilot is to obtain information on the redistribution and retention of the disposed sediment at the bed within the deep pits and the impact on the surrounding morphological systems (i.e. from Drempel van Hansweert to the Overloop van Hansweert, and on the northwestern side the Straatje van Willem). The obtained conceptual framework for the spreading of sand from the disposal site of the Inloop van Ossenisse, as presented in this study, contributes to the knowledge basis for the disposal strategy of the Western Scheldt.

Three pilot disposals were placed in the Inloop van Ossenisse in 2016, 2017 and 2019. Data from these pilots provide a clear overview of the local spreading of the sediment at the disposal site. The sediment disposed at the bed of these deep pits gradually erodes at a rate of about 1100 to 1400 m^3/day, which is less than other nearby disposal sites at the Gat van Ossenisse, Overloop van Hansweert (SH41) and Put van Hansweert where the erosion rates were two to three times higher. This means that some infill of the deep pit of the Inloop van Ossenisse may take place when large volumes of sediment are placed over a long period of time. The area and storage volume of the Inloop van Ossenisse are very large. It may therefore still be useful to dispose dredged sediment in the Inloop van Ossenisse to reduce the amount that is needed to be disposed at neighbouring disposal sites (e.g. SH41 and Put van Hansweert).

In general, the regional effects of the disposals at the Inloop van Ossenisse were rather limited compared to the autonomous morphological development of the region, and smaller than the impact of other nearby disposal sites where much larger volumes of sand were disposed. Some additional accretion is expected at the Drempel van Terneuzen as a result of the net eb-directed sediment transport in the Inloop van Ossenisse. On the long-term this may also lead to additional accretion at the Zuid-Everingen. Possibly some sediment will be transported to the Drempel van Baarland, but this could not be verified during the pilot disposals.

Despite the relatively small observed impacts on the region, it is strongly recommended to use monitoring of the disposal site and regional morphology to verify whether future measures have similar impacts as found during the pilot disposals. Such a verification is needed, since the current knowledge is based largely on expert interpretation of a relatively short measurement period. Gathering additional field data over a multi-year period (for the whole considered region in this study) will improve the knowledge of the effects of the sediment disposals at the Inloop van Ossenisse on the regional morphology considerably, which is essential for a well-founded future disposal strategy.

Contents

1 Introduction

1.1 Background

The Inloop van Ossenisse is part of the main navigation channel of the Western Scheldt providing access to the Harbour of Antwerp. A considerable dredging effort is needed at the shallow sections of the navigation channel, of which the dredged material is disposed back into the estuary to maintain its sediment budget and minimize effects on the estuarine processes. Deltares was requested by the 'Vlaams Nederlandse Schelde Commissie' (VNSC) to study the effect of placement of dredged sediment in the deep channels of the Western Scheldt on the morphology of the surrounding area. In this study the bathymetric data are analysed at the Inloop van Ossenisse where a considerable amount of sediment was successfully placed in recent years, with the aim to further understand the morphological effects on the surrounding regions and proportion of sand remaining in the channel.

1.2 Study area

The Inloop van Ossenisse is located in the middle section of the Westerschelde (Western Scheldt) Estuary (Figure 1.1). In total the Scheldt system is 350 km long and extends through the Netherlands, Belgium and France. The water motion in the estuary is forced by a semi-diurnal (progressive) tide from the North Sea. The tidal wave is amplified and distorted as it travels up the estuary; the mean tidal range increases from 3.8 m at Vlissingen to 5.2 m at Antwerp, 78 km upstream. Peak tidal velocities range between 1 and 1.5 m/s.

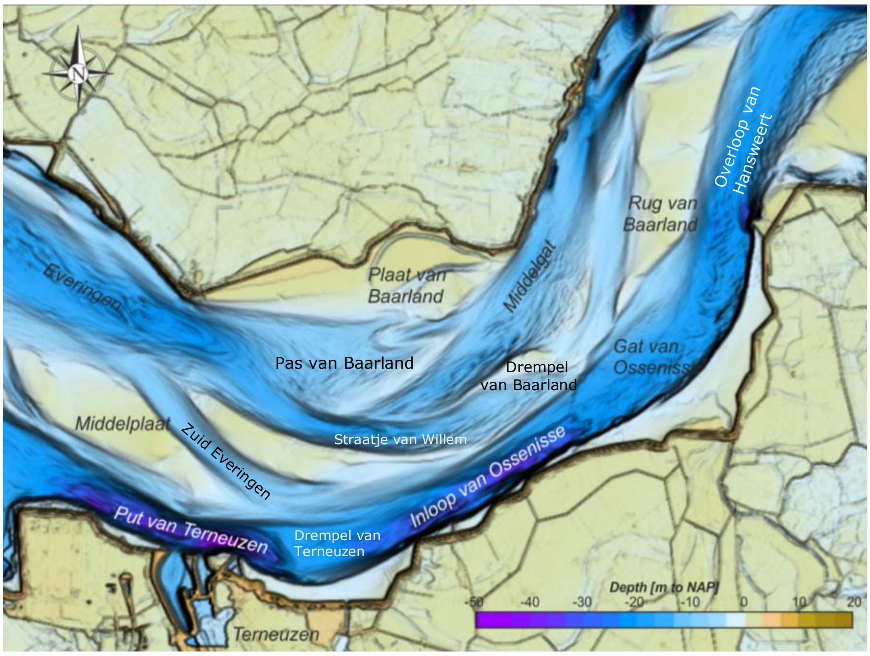


Figure 1.1 Overview of the study location

The Westerschelde estuary is characterised by two channels, separated by shoal complexes. The largest of the channels is typically the ebb-channel, while the parallel subordinate channels are flood channels. The ebb- and flood channels tend to join in subtidal shoal areas. The general channel (and shoal) patterns has been described by Winterwerp (2001) as a series of six macro cells. The Inloop van Ossenisse is located in macro cell 3 with a maximum depth of ~30 m (Figure 1.1). It connects to the Drempel van Terneuzen in the West and the Gat van Ossenisse in the North-East.

On the northern side a narrow intertidal shoal complex is present with the relatively shallow flood-channels of the Everingen on both sides (Straatje van Willem and Zuid Everingen) and the Drempel van Baarland. Further North we find the ebb-channel of the Middelgat, Rug van Baarland and flood-channel of the Overloop van Hansweert.

Dredging takes place at a number of shallow sections of the navigation channel of the Western Scheldt (for an overview of dredge locations see Huisman et al., 2018). This sediment is then placed back in nearby disposal sites to maintain the sediment budget of the estuary. Specific regions are carefully selected to place the sediment back into the system with the aim of preserving the navigation, safety and nature functions. Some of the sediment is, for example, placed at shallow regions in the Western Scheldt to increase the area of the intertidal flats (e.g. Plaat van Walsoorden and Hooge Plaaten), while sediment is also placed in eroding sections of the main channel (e.g. Gat van Ossenisse and Zuidergat) to avoid a too strong sideways migration of the main channel. Sediment has also been disposed in secondary channels (e.g. Everingen and Schaar van Waarde) which had a large amount of accommodation space and relatively small degree recycling of sediment back to the sills of the navigation channel. However, the volumes placed in the secondary channels were reduced over time to avoid too strong accumulation in the secondary channels, since it is preferred to maintain a natural two-channel configuration of the Western Scheldt. In recent years the focus therefore has shifted more and more towards placement of sediment in the deeper sections of the main channel of the Western Scheldt.

1.3 Research questions

This research aims at understanding the morphological impact of placement of dredged sediment in the Inloop van Ossenisse. The main research questions in this study are

- What is the autonomous morphological change of the Inloop van Ossenisse and surroundings?
- How quickly will sediment erode from the disposal location in the Inloop van Ossenisse and what fraction of the sediment will remain in place?
- To what extent do sediment disposals in the Inloop van Ossenisse affect the regional morphology?

Following from this research it is expected that we have a better insight in the morphological functioning of the Inloop van Ossenisse and the relation it has with the surrounding region. The region considered in this study is the main navigation channel from the Put van Terneuzen to the southern end of the Overloop van Hansweert, including also the Drempel van Baarland and Straatje van Willem on the northwestern side. Effects of future disposals can be understood better with the aim to minimize eventual negative effects.

1.4 Readers guide

In addition to this introduction, this report consists of 3 chapters. Chapter 2 provides a brief description of the methodology. Chapter 3 provides the results and analysis of the bathymetrical data and interpretation of the morphological system of the Inloop van Ossenisse. The final Chapter presents the conclusions and recommendations.

2 Methodology & Data

2.1 Introduction

This chapter presents the applied methodology and available data for the assessment of the impact of the pilot disposals at the Inloop van Ossenisse. This requires also some investigation of nearby disposal sites such as the Gat van Ossenisse and Overloop van Hansweert (SH41) as the effects of these disposal sites may interfere with the pilot disposal site of the Inloop van Ossenisse. Section 2.2 describes the general approach. Then the sections 2.3 and 2.4 describe the information on the sediment disposal, the available bathymetric data and method for analysis.

2.2 Approach

This study aims at quantifying the erosion rate of the sediment at the bed of the disposal site in the Inloop van Ossenisse, as well as the identification of possible regional morphological impacts and relevant morphological processes in the Inloop van Ossenisse. For this purpose, data of bathymetric surveys in the Inloop van Ossenisse and adjacent regions are used in this study. The aim is to research the morphological changes over time and where possible identify which changes relate to the pilot sediment disposal at the Inloop van Ossenisse. The methodology to analyse the bathymetric data splits into the following parts:

A) Create an overview of the locations, timing and volumes of the disposals at each disposal location in the area (Inloop van Ossenisse, Gat van Ossenisse, SH41) throughout the considered period. Note that the pilot disposal site on which this study focuses is the Inloop van Ossenisse, but as the regular disposal sites Gat van Ossenisse and SH41 are in its close vicinity, these should be considered as well in the analysis (Section 2.3).
B) Assess the availability of bathymetric data and their coverage and timing (Section 2.4), with the variability in the bed level can be assessed. Furthermore, sub-regions can be defined with similar morphological behaviour. It is noted that the exact shape of these regions was later substantiated (iteratively) based on findings of the qualitative analysis of the bathymetric changes (i.e. step C and D). It is the intention to obtain regions which internally have rather similar morphological changes.
C) Qualitatively assess the autonomous changes of the morphology of the Inloop van Ossenisse and surrounding regions with sufficient data coverage (i.e. from Put van Terneuzen to southern end of the Overloop van Hansweert) for the period 2005 to 2016 (Section 3.2.1).
D) Qualitatively assess the regional scale morphological changes (i.e. for surveys with a larger coverage than the disposal site) after the pilot disposals at the Inloop van Ossenisse from 2016 to 2019 (Section 3.2.2). Here the most relevant dynamics of the morphological features and potential impacts can be identified.
E) Quantify the volumetric changes in the regional scale analysis for the identified sub-regions. The trends in time can be computed for each sub-region (Section 3.2.2).
F) The local changes in the morphology at the disposal site of the Inloop van Ossenisse are analysed. This analysis consists of I) a quantification of the part of the disposed sediment that can be found back at the bed, II) the rate of erosion of the sediment at the disposal site and III) the local spatial patterns in the erosion (Section 3.3). A comparison is made to the regular disposal sites at the Gat van Ossenisse and SH41.
G) An interpretation is made of the relevant morphological processes in the Inloop van Ossenisse (Section 3.4). This expert-interpretation is assisted by available results from morphological models, which can indicate flood or ebb dominant transport patterns. The conceptual overview can provide a basis for the judgment on the future sediment disposals (i.e. location, volumes and possible effects).

2.3 Dredging and disposal data

This study is about the effects of sediment disposal in the Inloop van Ossenisse where sediment is disposed in the main navigation channel. For this study it is relevant to consider the whole of the middle section of the Western Scheldt (Macrocel 3) which is located between the Put van Terneuzen and the Overloop van Hansweert, as the effects of other disposal sites in this region (the Gat van Ossenisse and the Overloop van Hansweert / SH41) interfere with the effects of the disposal site at the Inloop van Ossenisse. It is noted that many million cubic meters of sand have been placed in the last decade in the Gat van Ossenisse and Overloop van Hansweert (SH41). The extent of the disposal sites is shown in Figure 2.1. The Inloop van Ossenisse (deeper part of the channel) has been recently added as disposal site and over the past years three pilot disposals have been carried out and monitored. It should be noted that the disposed sediment is not placed uniformly over these areas, but concentrated in specific regions within the contour, which will be shown later. Basically, in locations where it is practical to place the sediment or where it is considered useful to reduce the erosion of the channel.

There are also other disposal sites in the region, but most of them are not used much or are located further away from the area of interest. For example, the Rug van Baarland, Middelgat and Schaar van Waarde were hardly used, because these are accretive areas where any further heightening of the bed is considered undesirable. The Everingen is used as a sediment disposal site only occasionally. The Put van Hansweert is also a pilot location in which 3 million m^3 has been disposed in the period from 2016 to 2020 (Huismans et al., 2021). As most of this sediment is believed to spread to the inner bend and upstream, it will have minor or no impact on the Inloop van Ossenisse area.

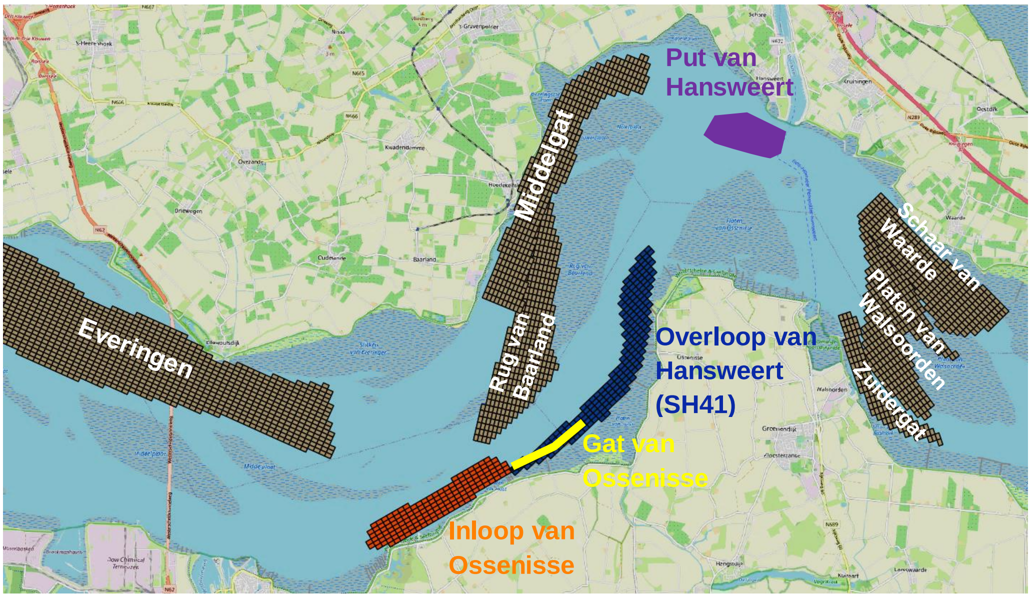


Figure 2.1 Main disposal areas in the study area. Inloop Van Ossenisse (INOS) in green, Gat Van Ossenisse in orange, and SH41 in blue. The grey areas are not explored in this analysis. The small cells in the colored areas represent the small disposal polygons where sediments are placed in time.

Data of the disposal of the sediment was provided by the afdeling Maritieme Toegang of the ministry of Openbare Werken of Vlaanderen for the period 2012-2020. The data provided contains information regarding the specific coordinates of the disposal area, the date of disposal, and the volume of sand supplied.

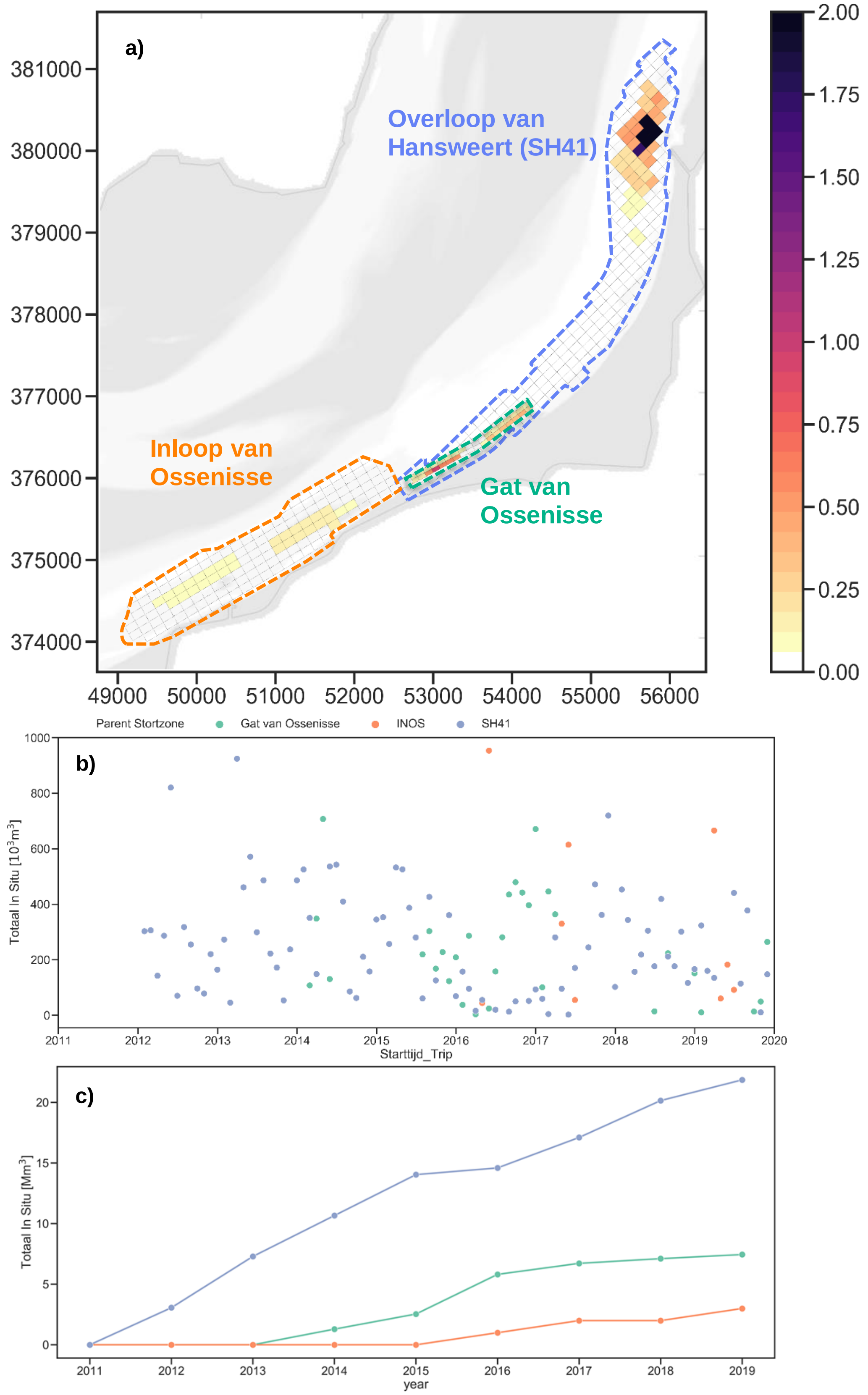


Figure 2.2 Overview of the locations and volume of sediment that was disposed at the Gat van Ossenisse, Inloop van Ossenisse and Overloop van Hansweert (SH41). Panel A : overview map of the polygons of the considered disposal regions with the intensity of the disposed material within these regions; Panel B : The monthly volumes for each of the disposal per location; Panel C : The cumulative volume of disposed sediment per disposal location.

An average of 4 million cubic meter per year of dredged sediments are disposed in the study area. Figure 2.2 shows how this sediment was distributed over the disposal regions of the Inloop van Ossenisse (INOS), Gat van Ossenisse (GvO) and Overloop van Hansweert (SH41), as well as the monthly volumes of the disposal operations over time at these sites.

Three pilot disposals were placed at the Inloop van Ossenisse of about 1 million m^3 each, which were placed in May 2016, May 2017 and March 2019. The sediment disposals in 2016 and 2017 at the Inloop van Ossenisse were placed in a relatively small area at a few ridges inside the eastern of the two deep pits of the Inloop van Ossenisse (see Figure 2.3), whereas the sediment disposal in 2019 was made in a section of the western pit of the Inloop van Ossenisse. This illustrates the large storage capacity of the deep pits. More frequent bathymetric surveys started in the year 2016, when more of the dredged sediment was placed in the Gat van Ossenisse and the Inloop van Ossenisse, which are intended for obtaining understanding of their effects.

The effects of the disposal at the Inloop van Ossenisse are, however, not easy to trace as large volumes of sediment were also placed in the nearby Gat van Ossenisse and Overloop van Hansweert (SH41), and also prior to the sediment disposal at the Inloop van Ossenisse. In the period 2012 to 2014 most of the disposed sediment in this region (an average of 3.5 million m^3) was placed in SH41. In the years 2014 to 2015 the disposed sediment was also placed in the Gat van Ossenisse (about 1 million m^3 per year) besides the disposals at SH41. The volume applied at SH41 then decreased to about 0.5 million m^3 in 2016, while a large amount was placed that year in the Gat van Ossenisse (3.25 million m^3). From 2017 to 2019 the sediment disposal is distributed between the Inloop van Ossenisse, Gat van Ossenisse and SH41, but with most sediment still being placed in SH41. Within the deposition regions the sediment was not distributed uniformly (i.e. within the permitted disposal area of INOS, GvO and SH41). Over the period from 2012 till 2019 the sediment was placed rather concentrated in particular sections (Figure 2.2). This holds especially for SH41 where the sediment was placed in the northern part of the polygon (West of Knuitershoek), which effectively is the southeast side of the Overloop van Hansweert.

The placement of the sediment also differed per year. A similar volume of about 3 million m^3/yr was placed in SH41 in the years 2012, 2014, 2015 and 2018, but their spatial distribution is very different. In 2012 the disposed sediments are placed along the eastern side of the Overloop van Hansweert as a long alongshore elongated disposal within the permit area, while sediment was placed in a larger part of the permit area in the years 2013 to 2015. From 2017 onwards the sediments at SH41 are concentrated in a small area West of Knuitershoek, which is a much smaller part of the permit area. It is expected that these more concentrated disposals were chosen for practical reasons (i.e. operation of the sediment disposal).

Due to the small coverage of the Gat van Ossenisse area, disposals are not only more uniformly spread but also more consistent in time there.

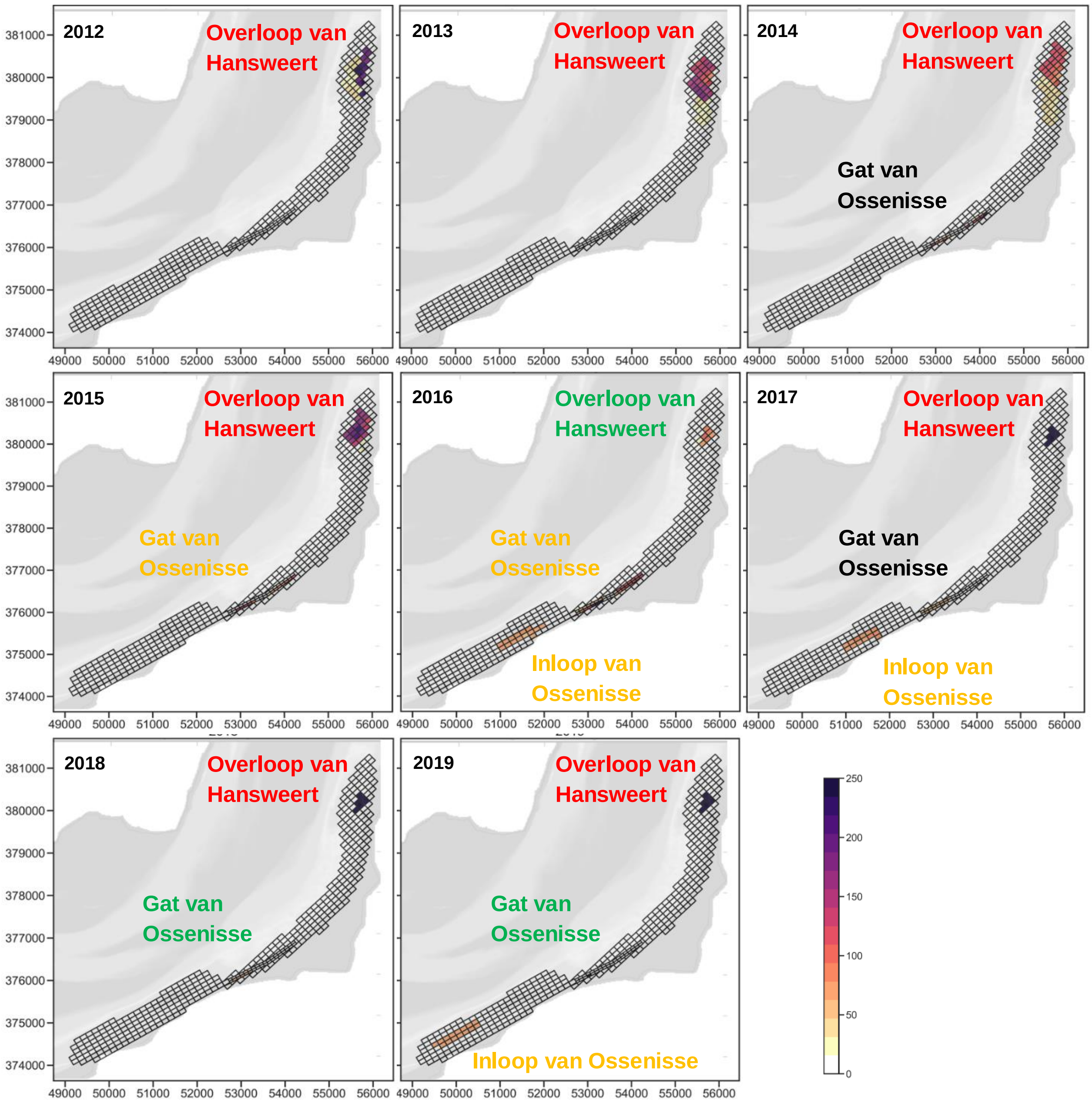


Figure 2.3 Overview of the location of the sediment that was disposed in the Inloop van Ossenisse, Gat van Ossenisse, and Overloop van Hansweert (SH41) from 2012 to 2019. The colours show the yearly disposed volume per cell in 1000 m³.

2.4 Bathymetries

2.4.1 Bathymetric surveys

This study uses the Vaklodingen data (Rijkswaterstaat, 2020) and detailed multibeam measurements of the bathymetry of the Inloop van Ossenisse, Gat van Ossenisse and Overloop van Hansweert, which were provided by the afdeling Maritieme Toegang (aMT) of the ministry of Openbare Werken of Vlaanderen. The areas covered by the different surveys differ substantially (Figure 2.4). A large regional survey, a local scale survey at the Inloop van Ossenisse disposal site and a medium survey at the Overloop van Hansweert can be discerned.

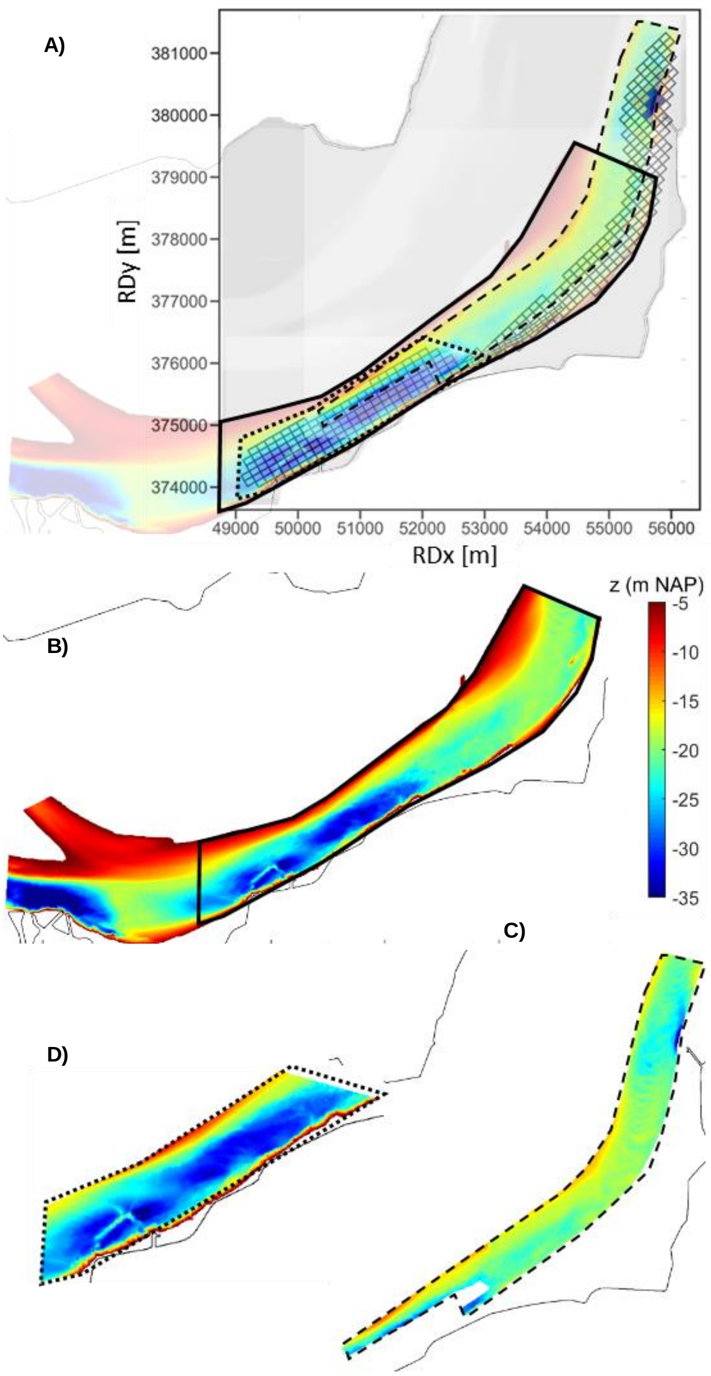


Figure 2.4 Overview of bathymetric data sets. Panel A : overlapping of surveys on disposal areas; Panel B : Large Survey bathymetric data obtained the 11th of June of 2019; Panel C : Medium Survey bathymetric data obtained the 13th of February of 2017; Panel D : Small Survey bathymetric data obtained the 28th of May of 2018.

The largest surveys cover the region around the Inloop van Ossenisse from the Put van Terneuzen to the southern end of the Overloop van Hansweert, which is referred to as the 'large survey'. The Large Survey dataset covers an area of 30 to 50 km^2 (Figure 2.4) and has data at moments closely before and after the pilot sediment disposal in the Inloop van Ossenisse in May 2016. Later surveys are available in 2017, 2018 and 2 surveys in 2019, so a total of 6 surveys. Table A.1 provides a descriptive summary of the extent and dates of the bathymetric data included under the Large Survey dataset.

Other surveys cover only a small area around the pilot disposal sites at the Inloop van Ossenisse (referred to as the ‘small survey’). Here it is noted that the ‘large’ surveys also provide coverage of the ‘small area’. To calculate the local changes in the small area the 2016 ’large survey’ can therefore be used as initial bathymetry. The small survey area was updated on a monthly basis (Figure 2.5; Table A.3).

Besides surveys at the Inloop van Ossenisse also an intermediate size survey was available at the Overloop van Hansweert which covers also a small part of the Gat van Ossenisse (referred to as ‘medium survey’). The Medium Survey Dataset was surveyed monthly (Figure 2.5; Table A.2) but covers just the North-East depositional zone in the SH41. In the analysis of the bathymetric changes in time, we complement the small and medium survey data with the large survey data.

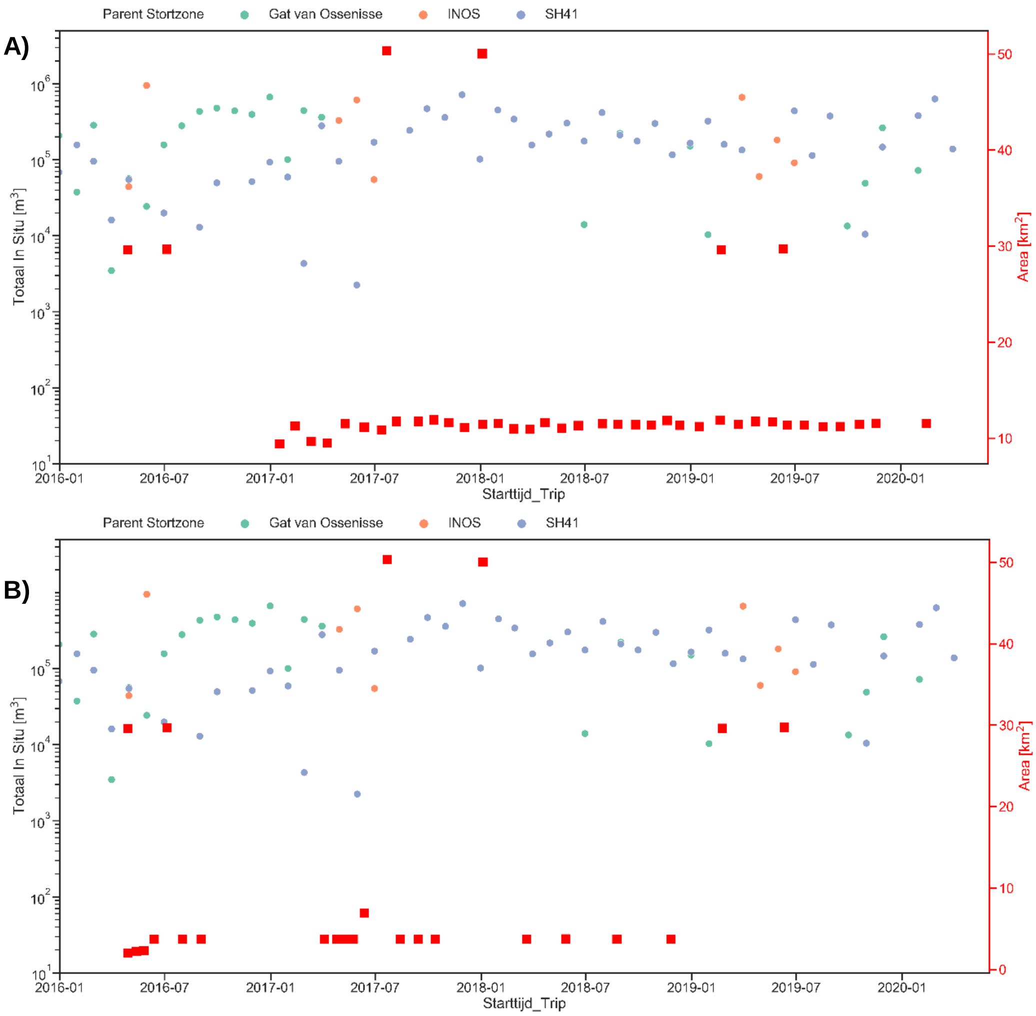


Figure 2.5 A) Surveys available for the Large and Medium extent datasets, and B) Surveys available for the Large and Small extent datasets. The left y-axis shows the sediment supply at each disposal area and the right y-axis the spatial extent of the survey.

In order to extend the analysis of the bathymetric changes further back in time and understand the response of the system to this sediment supply, we also make use of the available Vaklodingen bathymetries (Rijkswaterstaat, 2020) for the area. The available data in the region covers the years 2005, 2008, 2011, 2012, 2013, and 2014. These data are used to assess the autonomous bathymetric changes prior to the pilot sediment disposal at the Inloop van Ossenisse (i.e. for the period 2005 to 2016). The survey for the year 2014 (Figure 2.6) is taken as the reference for the medium survey datasets.

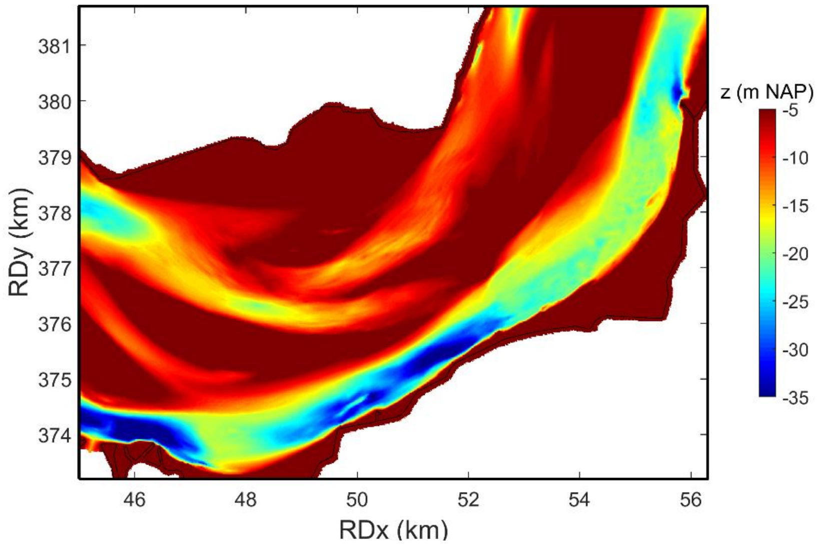


Figure 2.6 Vaklodingen bathymetric data for the year 2014. This survey is used as reference bathymetry for several analysis.

The coefficient of variation (shown in Figure 2.7) was computed for this bathymetric dataset (i.e. standard deviation per cell divided by the mean depth), which is an indicator of the relative variance of the bathymetric changes. This shows a high value in regions with large relative changes in the morphology (i.e. the most active features). Here the large changes at the Drempel van Baarland, Straatje van Willem and at both the western and eastern side of the Gat van Ossenisse can be seen. Furthermore, the bathymetric changes in the survey data also show the sediment supply at the sediment disposal sites (i.e. Inloop van Ossenisse, Gat van Ossenisse and SH41).

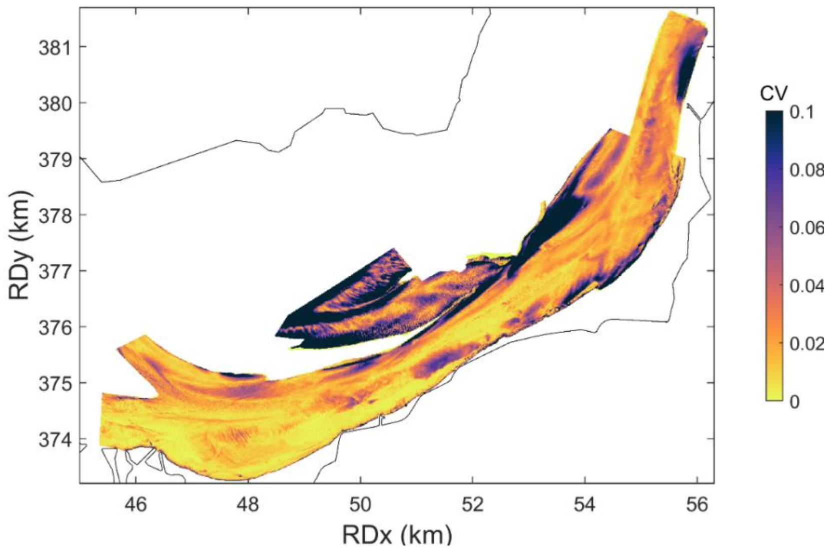


Figure 2.7 Coefficient of variation (std/abs[mean]) of the measured depth in the combined Large, Medium, and Small Datasets over the period 28 April 2016 (T01) to 14 February 2020 (T99).

2.4.2 Identified sub-regions

A partitioning of the domain was made for each of the surveys, which basically clusters regions with similar morphological changes and properties (e.g. depth). These regions should be sufficiently small to capture the spatial differences in erosion and accretion, but also large enough to obtain a steady change in the volumes. An overview of the polygons is shown in Figure 2.8.

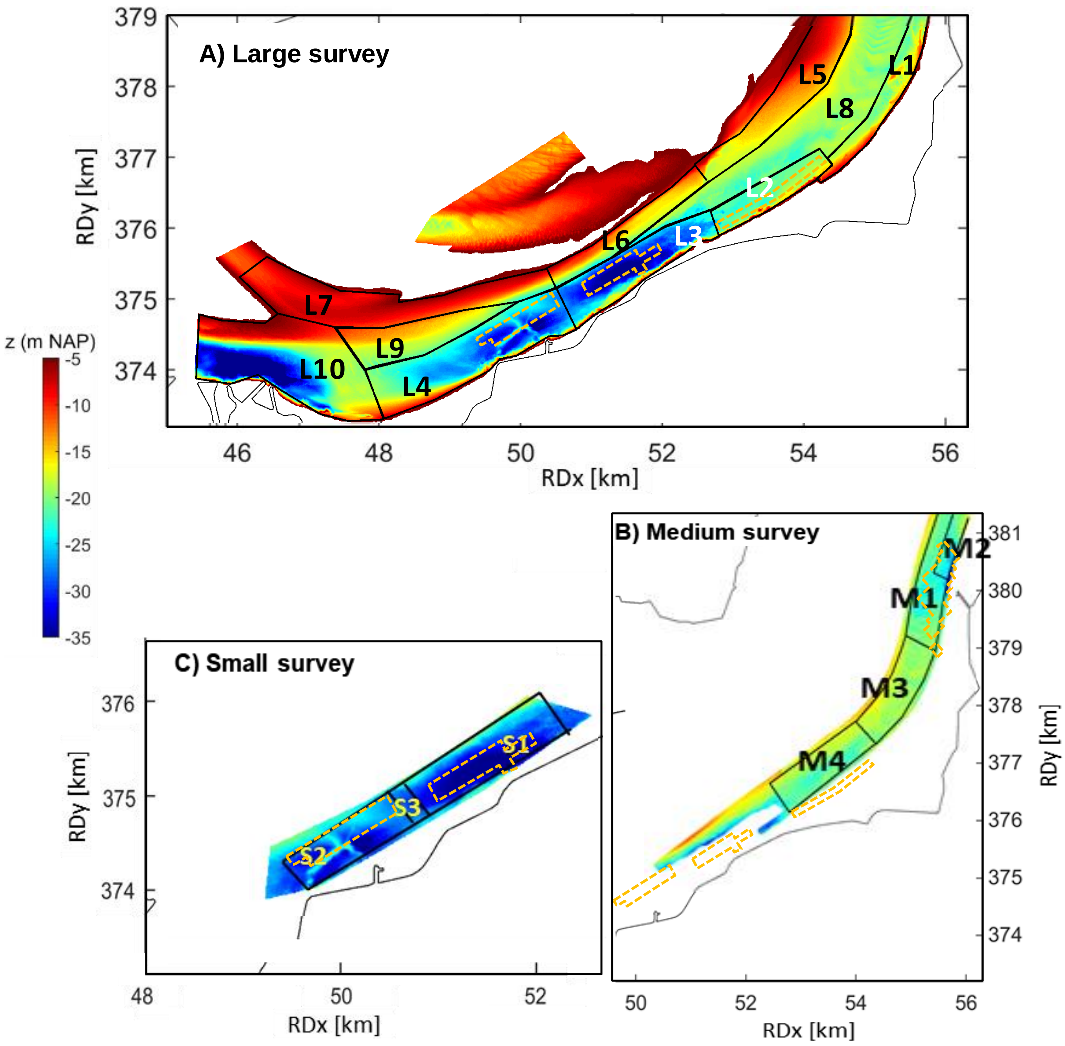


Figure 2.8 Overview of the partitioning of the surveys in smaller regions with similar morphological response with disposal sites in orange dashed lines. Panel A: Large survey of the Inloop van Ossenisse and surroundings; Panel B: Medium survey with Gat van Ossenisse and Overloop van Hansweert; Panel C: Detailed survey of the Inloop van Ossenisse.

Sub-regions were made for the large-scale survey in both along-channel and cross-channel direction. In along-channel direction the sub-regions start at the Put van Terneuzen (#L10 in Figure 2.8.), then go via the Drempel van Terneuzen (#L4 and #L9) to the Inloop van Ossenisse (#L3) and to the Gat van Ossenisse (#L2 and #L8), which extents up to the southern end of the Overloop van Hansweert. Cross-channel there are separate sub-regions for the channel sidewalls (or shoal margins) in the large survey. These were defined to capture accretion or erosion due to a shift in the channel position over time, such as at the eastern and western sides of the Gat van Ossenisse (#L1 and #L5). Also the dominant transport may be directed differently at the shoal margins than in the main channel, or an influence may be presented of connecting channels with the Everingen (e.g. for #L6 and #L7).

The small and medium survey were partitioned mainly in along-channel sub-regions. These are referred to as #M1 to #M4 for the medium survey and #S1 to #S3 for the small survey. The small survey did not have cross-channel partitioning, while the medium survey has one extra cross-channel sub-region at the disposal site of SH41 (within #M2). Disposal areas are located in separate sub-regions.

The Gat van Ossenisse disposal site is in sub-regions #L1 and #L2, while the eastern and western pits of the Inloop van Ossenisse are located in #L3 and #L4 respectively for the large survey. Similarly, also in the medium survey a separation is made for the Inloop van Ossenisse (#M4), Gat van Ossenisse (#M3) and SH41 (#M2).

2.4.3 Hydrodynamics and transports

The literature on the Western Scheldt (e.g. Cleveringa, 2013) clearly shows the eb dominance of most of the main navigation channels of the Western Scheldt (also Inloop van Ossenisse), and flood-dominance of the secondary channels. An exception, however, is the Overloop van Hansweert, which is a section of the main channel that is partially flood and ebb-dominant, with flood dominating the sediment transport at the eastern embankment and ebb at the western side. The main channel of the Overloop van Hansweert is, however, slightly dominated by flood transport. As a result, a divergence is present at the Gat van Ossenisse, with net flood-transport on the northern side and southeast directed eb-transport in the south.

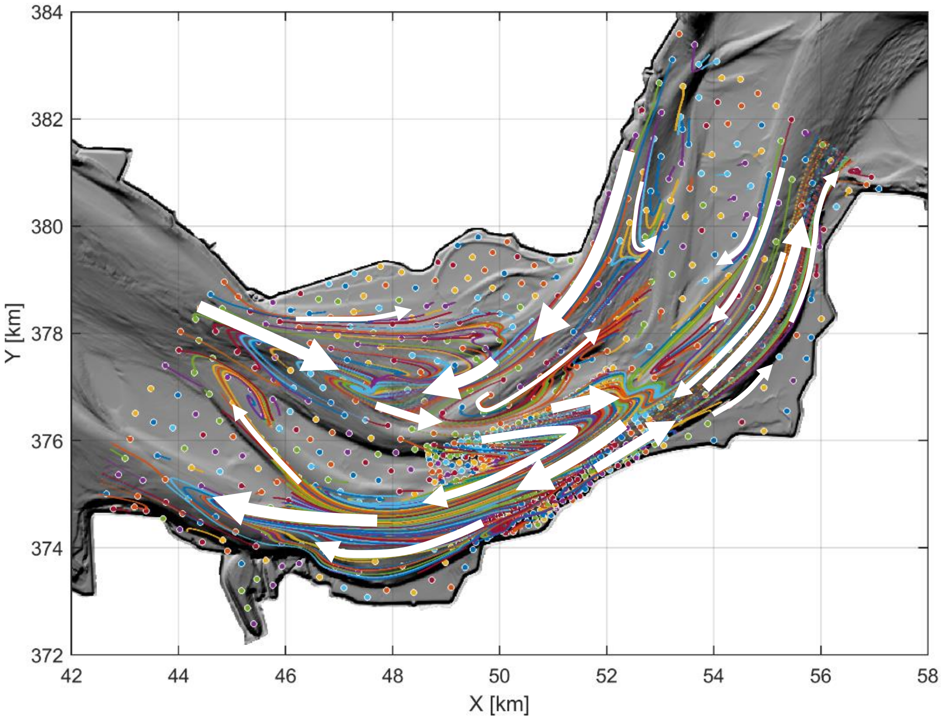


Figure 2.9 SedTRAILS visualization of the net sediment transport pathways in the Gat van Ossenisse and surrounding region. The dots indicate the start point of the sediments, and the lines the pathways that the sediments are expected to follow. An interpretation of the transport directions is given by the white arrows. The bathymetry is shown with a gray scale.

This is confirmed with available information on transport pathways from numerical models of sediment transport for the Gat van Ossenisse and surrounding area (Figure 2.9). Reference is made to the report of Elias et al. (2021) for a description of the methodology for deriving the sediment transport pathways using *SedTRAILS*, which was focused in that report on for the Put van Hansweert. An interpretation of the transport directions is given by the white arrows in the figure, which also shows the net transport from the Everingen (and Middelgat) to the Drempel van Baarland. It is noted that these model results should only be considered qualitatively for a general understanding of the morphological system, as the bathymetry was not updated and no verification of the model performance in this area was made. Many more things can be said about the transport patterns, but are outside the scope. A follow-up study may use the computed transport patterns to improve the understanding of the morphological system.

3 Analysis

3.1 Introduction

The analysis of the morphological changes around the pilot disposal site of the Inloop van Ossenisse is discussed in this chapter. First the regional scale bathymetric changes are analysed to obtain information on the morphological impact of the disposals in relation to autonomous morphological changes. This is followed by an analysis of the local morphological changes at the disposal site, which provides insight into the initial losses during the disposal processes, rate of erosion of the disposal sites and possible accretion of material in the deep pit of the Inloop van Ossenisse. A comparison is made to the erosion rates at nearby disposal sites at the Gat van Ossenisse and Overloop van Hansweert (SH41).

3.2 Regional scale bathymetric changes

Here the observed changes in the morphology of the Inloop van Ossenisse and surrounding regions, such as the Gat van Ossenisse, Put van Terneuzen, and Rug van Baarland are discussed. The autonomous changes can be reviewed over the period 2005 to 2015, while developments after the sediment placement at the Inloop van Ossenisse are discussed further for the period 2016 to 2020.

3.2.1 Autonomous changes (2005 - 2016)

Sedimentation erosion maps of the region for the period 2005 to 2016 are shown in Figure 3.1 tot Figure 3.4, indicating the regions where sedimentation has taken place in red and erosion in blue. The period considered here ranges from 2005 to 2016. Considerable autonomous changes have occurred before the first pilot sediment disposal at the Inloop van Ossenisse in May 2016. The changes over the considered four year periods are in the order of +/- 1 to 3 meter per year. The actual rate of changes is rather similar for these periods, but the patterns shift over time. The large-survey measurements for the Inloop van Ossenisse over the period 2014 to 2016 show a very similar trend as for the previous years.

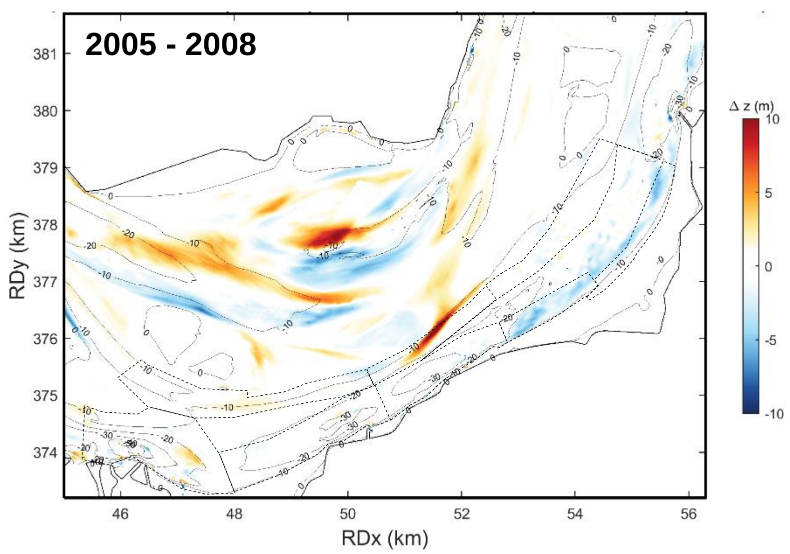


Figure 3.1 Sedimentation and erosion maps of the Inloop van Ossenisse and surrounding regions for the period 2005 to 2008.

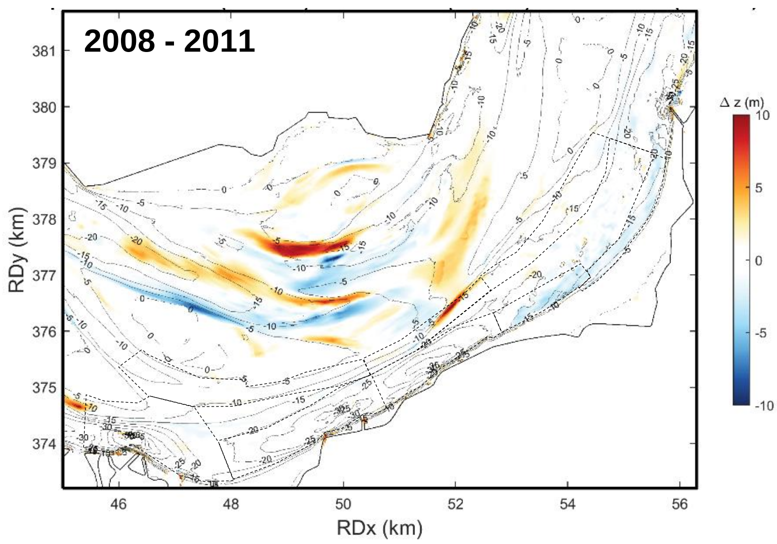


Figure 3.2 Sedimentation and erosion maps of the Inloop van Ossenisse and surroundings for 2008 to 2011.

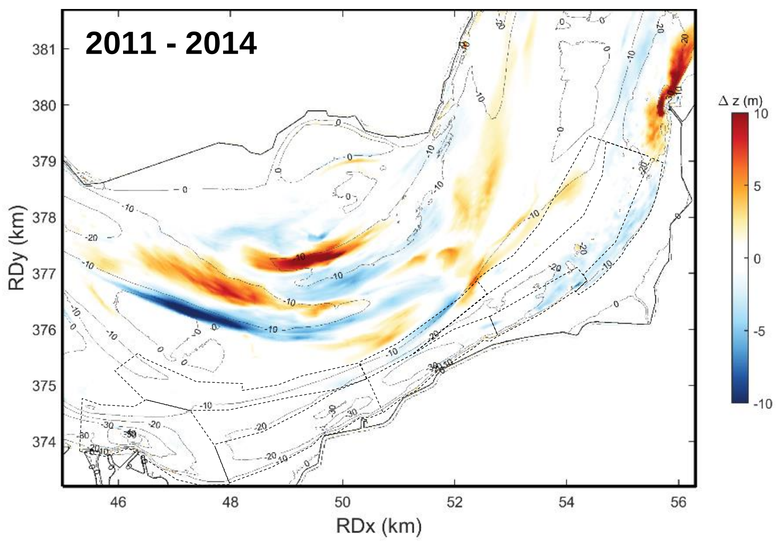


Figure 3.3 Sedimentation and erosion maps of the Inloop van Ossenisse and surroundings for 2011 to 2014.

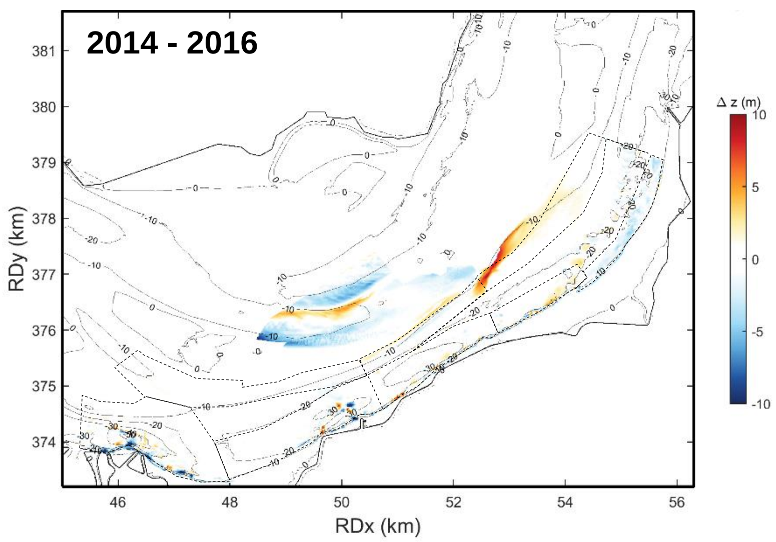


Figure 3.4 Sedimentation and erosion maps of the Inloop van Ossenisse and surroundings for 2014 to 2016

Important is that various dredging and disposal operations have taken place over time, of which some dredged-sediment disposals at the Rug van Baarland and in the Everingen, which may have contributed to the changes. Also, a large amount of sediment was placed in the SH41 region which is East of the Gat van Ossenisse, just outside the considered region. Dredging was performed at the Drempel van Terneuzen at the western side of the Inloop van Ossenisse.

A summary of the autonomous changes for the considered region is shown in Figure 3.5 based on the sedimentation erosion maps. This shows that the section of the Inloop van Ossenisse (I) has remained rather stable. Here the hard layers seem to prevent further erosion (Van der Vegt et al., 2019). Further to the northeast, however, a strong accretion can be observed over the period 2005 to 2011 at the northwestern side of the Gat van Ossenisse (II). This accretive region prograded towards the northeast over time, thus narrowing the main channel on this side. At the same time a strong erosion can be observed at the southeastern side of the Gat van Ossenisse (III). The erosion here reduced after 2014, which is expected to be due to the sediment disposals here.

Erosion is seen at the western side of the Overloop van Hansweert (IV) jointly with strong accretion at the eastern side (also IV) over the period 2011 to 2014. It is very likely that the strong accretion at the eastern side of the Overloop van Hansweert is caused by the sediment disposal at SH41, which is located here. The erosion at the western side of the channel (IV) may be a response to this neighbouring sedimentation.

A strong accretive region is found at the southern end of the Middelgat (V), which is expected to be due to a combination of the ongoing shift of the tidal flow from the Middelgat to the Overloop van Hansweert, local disposal of dredged sediment (in the past) and the natural dynamics of the ‘drempels’. A shift in patterns towards the South can be observed in the main channel of the Everingen (VI). The sediment disposals in the Everingen (e.g. De Vet et al., 2020) are expected to be of relevance for the changes here at the Pas van Baarland. In-between the Everingen and the Inloop van Ossenisse an accretive area is prograding eastward (VII), while erosion is taking place just northeast of this accretive area (VIII) which also shifts to the northeast over time.

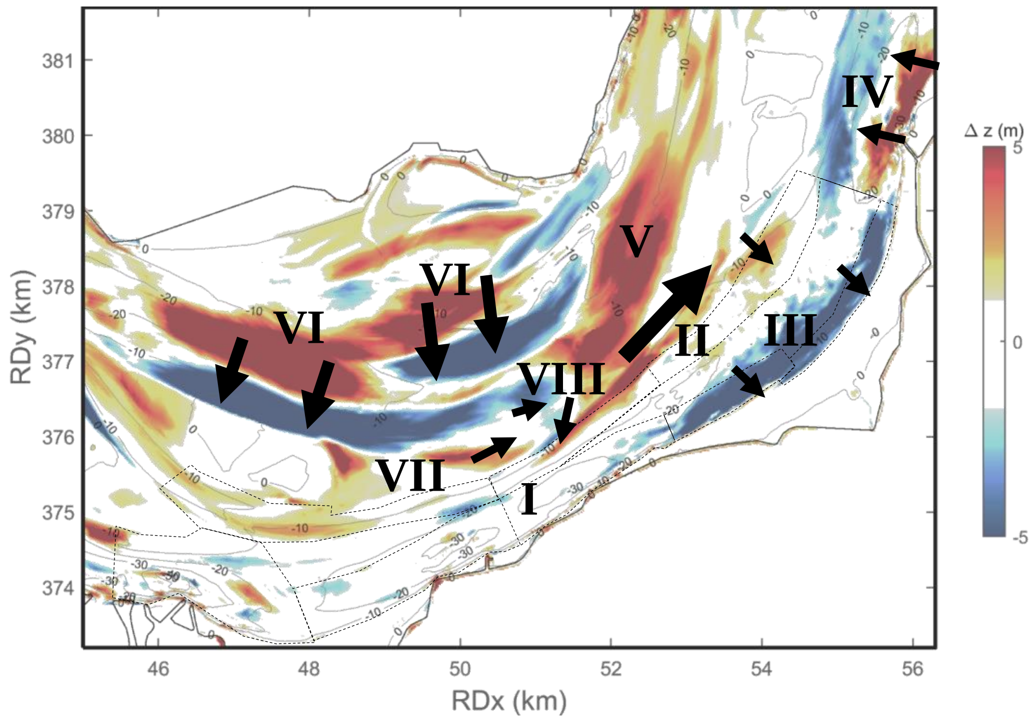


Figure 3.5 Schematic overview of autonomous changes (2005 to 2014)

It is noted that the current study focuses on the impact of the pilot disposals in the Inloop van Ossenisse rather than the autonomous developments, which should be studied in further detail to discern the causes for the morphological changes.

3.2.2 Changes after placement of dredged sediment in the Inloop van Ossenisse (2016 – 2020)

In order to analyse the impact of the three sediment disposals in the Inloop van Ossenisse, it is evaluated whether patterns can be discerned which differ from the above described autonomous behaviour, or relevant changes in the trends that were found. As such changes can provide information on the spreading of sediment from the disposal site at the Inloop van Ossenisse and from the other disposal sites in the Gat van Ossenisse and at SH41. Here the bathymetric changes in the large survey are investigated starting from April 2016 till June 2019 (Figure 3.6 to Figure 3.10). The first survey starts just before the first pilot disposal at the Inloop van Ossenisse in May 2016, which is included in the second survey. Later another pilot disposal was made in May 2017, which is included in the third survey. The latest pilot disposal is present in the June 2019 survey.

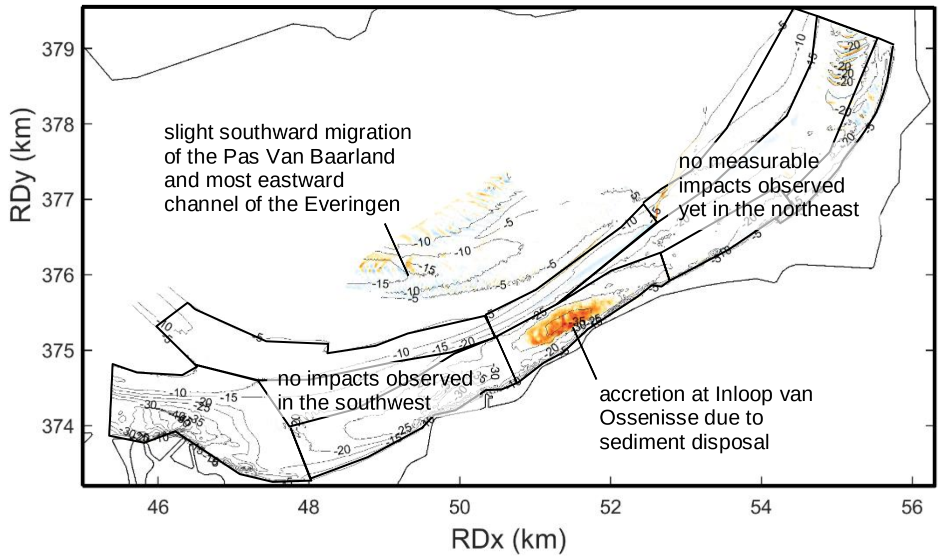


Figure 3.6 Bathymetric change of the Inloop van Ossenisse (April to July 2016)

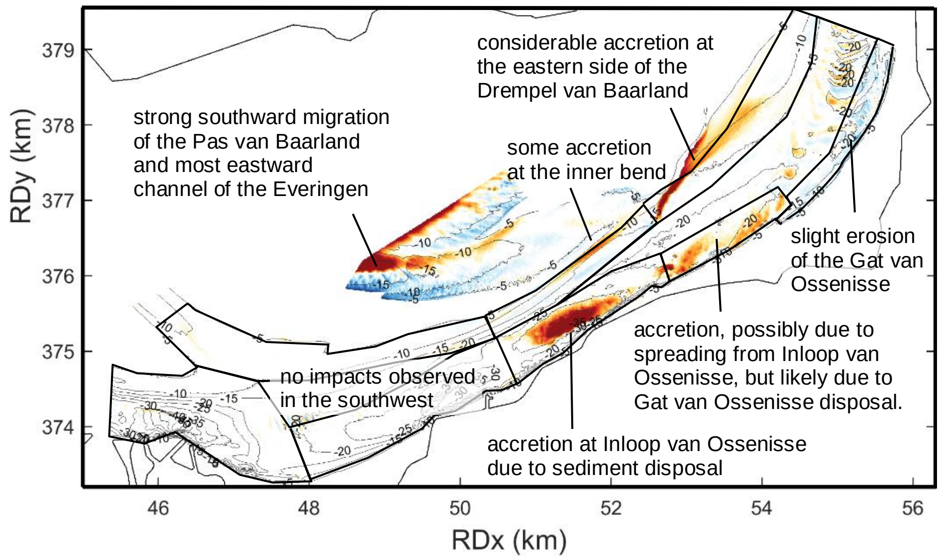


Figure 3.7 Bathymetric change of the Inloop van Ossenisse (July 2016 to July 2017)

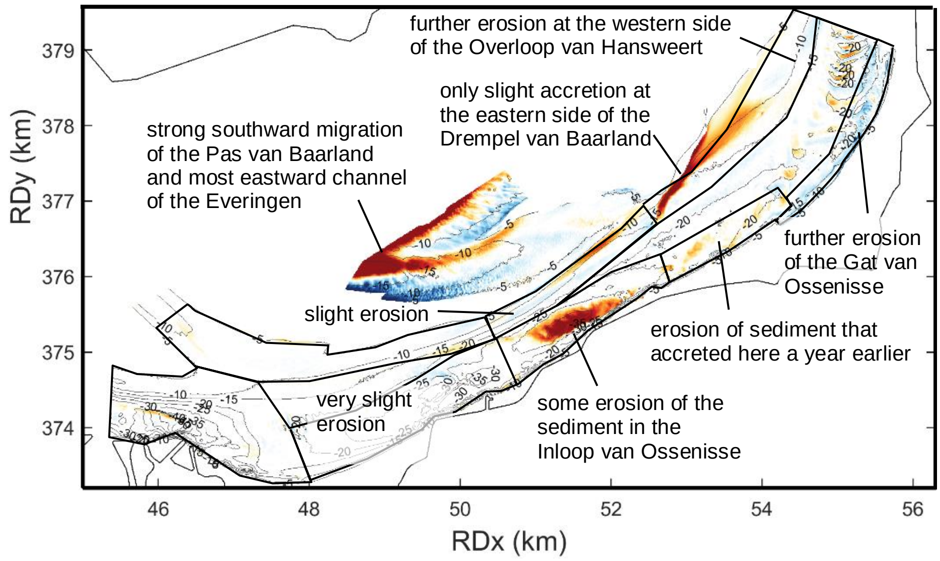


Figure 3.8 Bathymetric change of the Inloop van Ossenisse (July 2017 to January 2018)

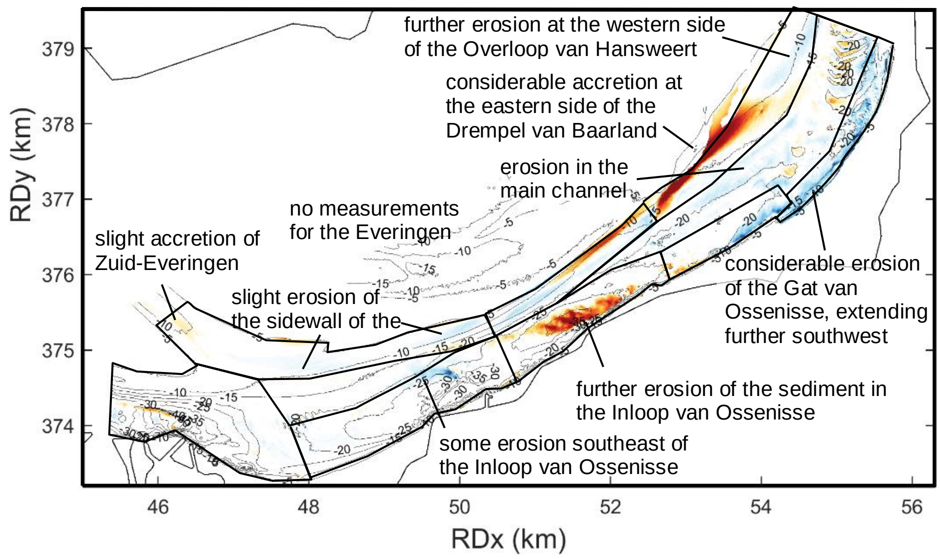


Figure 3.9 Bathymetric change of the Inloop van Ossenisse (January 2018 to February 2019)

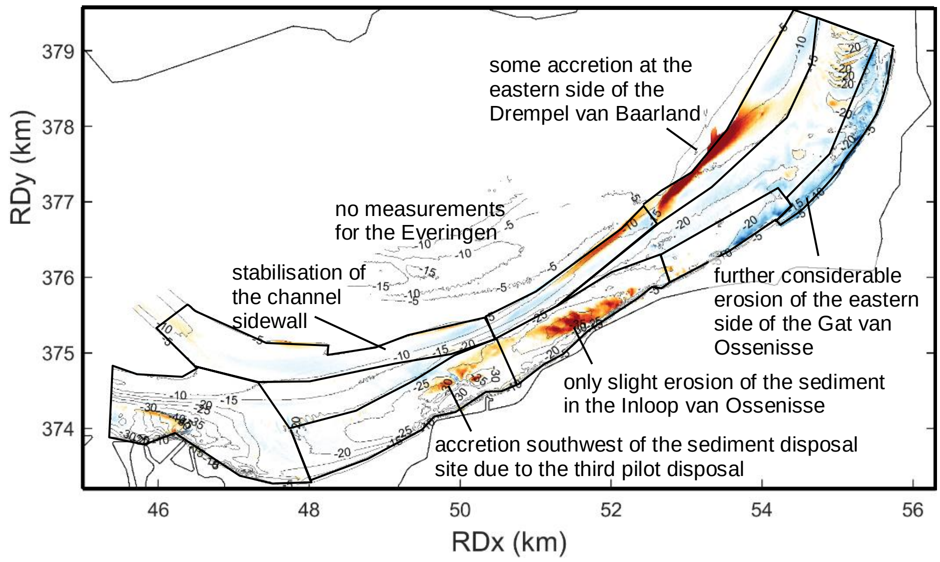


Figure 3.10 Bathymetric change of the Inloop van Ossenisse (February to June 2019)

In addition, also the volumetric changes have been quantified for each of the regions around the Inloop van Ossenisse, which are demarcated with numbers (#L1 to #L10) in Figure 3.11.

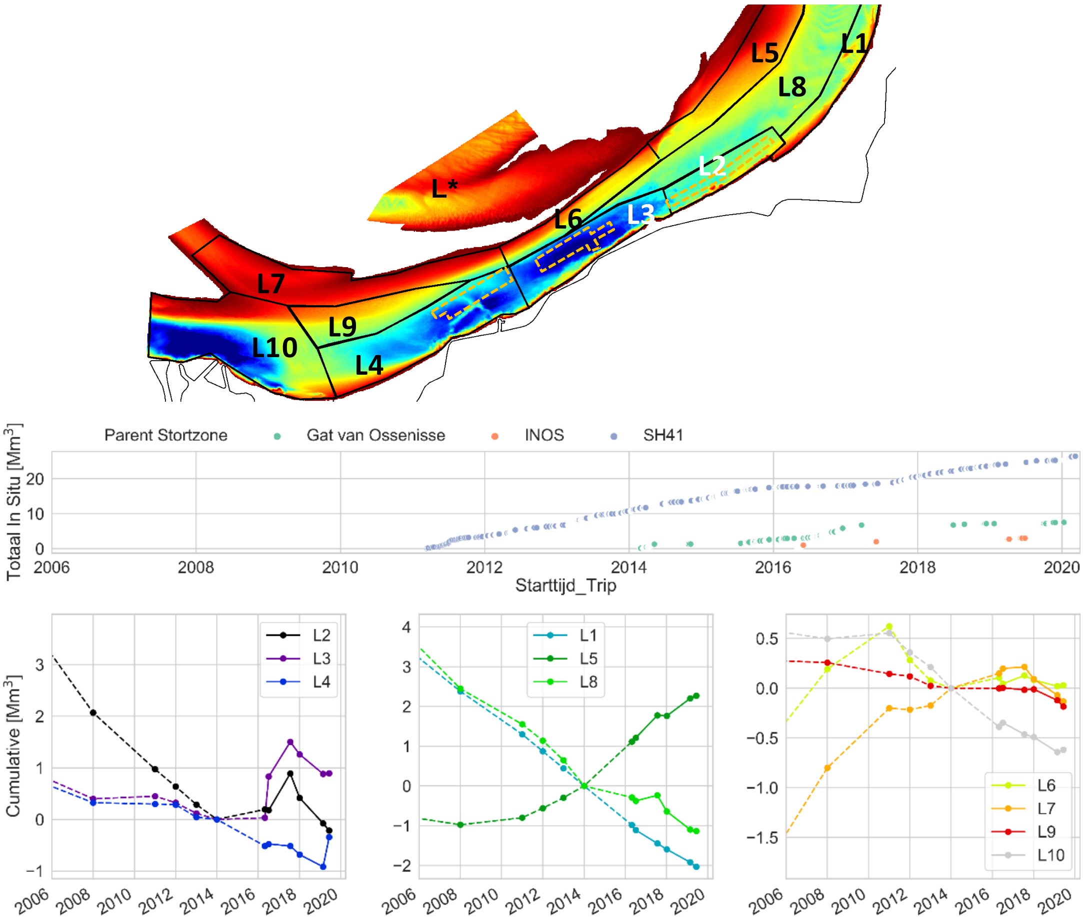


Figure 3.11 Large survey bathymetric evolution showing the sub-regions with disposal sites in orange dashed lines (upper panel), the cumulative volume of disposed sediment at the disposal sites (middle panel) and the volumetric changes of these sub-regions over time with respect to the 2014 Vaklodingen (lower panels). The reference period before the May 2016 disposal is shown with a dashed line.

The observed bathymetric changes after the two pilot disposals (over the period from April 2016 till June 2019) are discussed for the following sections of the large survey:

I) Main channel of the Inloop van Ossenisse and adjacent southern section of the Gat van Ossenisse (regions #L2, #L3 and #L4 in Figure 3.11), which accreted due to the pilot disposals.
II) Northeastern sidewall of the Inloop van Ossenisse (#L6) with accretion and erosion areas, while also the entrance to the Everingen-Zuid channel (#L7) is quite stable.
III) The Gat van Ossenisse (southern section of #L5, #L8 and #L1) which shows a continuation of the autonomous migration. This concerns an eastward migration due to accretion at the Drempel van Baarland (#L5) and erosion at the eastward side of the Gat van Ossenisse (#L1) and in the main channel (#L8).
IV) Overloop van Hansweert, which shows a slight westward migration (northern part of #L5).
V) Western regions with the Drempel van Terneuzen (western side of #L4 and #L9) and Put van Terneuzen (#L10) show gradual erosion.
VI) Straat van Willem (eastern channel of the Everingen; L* in Figure 3.11) shows a strong southward shift.

I: Main channel around the pilot disposal site
A clear accretion can be observed in the Inloop van Ossenisse (#L3) as a result of the pilot sediment disposals in the first survey periods up till July 2017 (Figure 3.6 and Figure 3.7). A total of about ~1.6 million m^3 of sediment was found at the bed for the May 2016 and May 2017 sediment disposals at the Inloop van Ossenisse (#L3 in Figure 3.11). Over time this sediment gradually eroded from this area (Figure 3.8 to Figure 3.10). These local changes are discussed in more detail in Section 3.3.

Accretion was also observed northeast of the Inloop van Ossenisse (#L2) after the pilot disposals in the second year (July 2016-2017). This accretion at the Gat van Ossenisse had a volume of about 700,000 m^3 (Figure 3.11). The explanation for the increase in the sediment budget in #L2 is that sediment was disposed at the Gat van Ossenisse in this period (between September 2016 and March 2017; see Figure 2.3) which is located within #L2. In addition, some of the accretion may have originated from the sediment disposal site of the Inloop van Ossenisse. However, the eb-dominant (westward dominated) transport in the main channel (based on computations of Elias et al., 2021) would rather suggest that the sediment from the Inloop van Ossenisse is mainly transported to the West. Noticeable is that the accretion in #L2 is followed by continuous erosion in subsequent years without pilot sediment disposals in this area, suggesting that the accretion was not the result of autonomous morphological changes.

A minor impact was observed in the western deep pit of the Inloop van Ossenisse (#L4) from 2016 till July 2017, but later on erosion of about 500,000 m^3 was observed until February 2019 (Figure 3.11). A local erosion hot spot was also visible, which was possibly due to the local erosion of a hard layer. It is noted that a similar erosion rate was already observed before 2016 in the western section of the Inloop van Ossenisse (#L4), which indicates that this erosion is likely due to ongoing natural morphological processes. The next survey in June 2019 did, however, show regions of accretion in this area (#L4). The previously found erosion spot was also largely filled up. This accretion is most likely due to the pilot disposal in March 2019.

II: Northeastern sidewall of the Inloop van Ossenisse and Zuid-Everingen
The second survey period with a sediment disposal (from July 2016 to July 2017) shows accretion at the north-eastern sidewall of the Inloop van Ossenisse (or ‘inner bend’; #L6) where the Straatje van Willem connects to the main channel. This accretion area then remains in place in later years after the disposal of sediment stopped in 2017, but is compensated by slight erosion further southwest along the shoal margin from 2018 onwards. Effectively the net sediment volume in this sub-region remains the same (Figure 3.11). It is uncertain whether this accretion and erosion are related to the pilot disposal at the Inloop van Ossenisse, as the most likely cause is a net transport from the Straatje van Willem (Everingen). The appearance of the accretion area during the period when the sediment was disposed is, however, an indication that some interaction between this area and the disposed sediment in the Inloop van Ossenisse may be present. The other connection channel to the Everingen (#L7) shows very small net changes in volume.

III : Gat van Ossenisse and Overloop van Hansweert
A clear erosional trend is observed at the eastern side of the Gat van Ossenisse (#L1) over the full considered period, as well as some deepening of the main channel of the Gat van Ossenisse (#L8). This erosion is considered for a large part the result of the persistent accretion at the northwestern side of the Gat van Ossenisse (or eastern side of the Drempel van Baarland; #L5), which forces the tide eastward. This migration process was already taking place before the pilot disposals (i.e. in the preceding period from 2005 till 2016). The volume change of the accretion at the eastern margin of the Drempel van Baarland was about 1.2 million m^3 since 2016, while the erosion at the eastern side of the Gat van Ossenisse was about 1 million m^3 (Figure 3.11), which means that both are of similar magnitude. The rate of erosion of the main channel (#L8) was about 800,000 m^3 since 2016.

IV: Overloop van Hansweert
The Overloop van Hansweert (i.e. at the northern section of the large survey) shows a westward migration, which is opposite to the eastward shift of the Gat van Ossenisse (Figure 3.10). A similar migration was observed over the period 2005 to 2014 for the Overloop van Hansweert (Figure 3.5). This erosion at the western side of the Inloop van Ossenisse is also observed further North (Huismans et al., 2021). The westward shift at the Overloop van Hansweert is most likely an effect of the sediment placement at SH41, which accretes the eastern side of the Overloop van Hansweert.

V : Put van Terneuzen and adjacent Drempel van Terneuzen
Weak erosion took place in the south-western regions, such as the Put van Terneuzen (#L10) and adjacent section of the Drempel van Terneuzen (#L9) since 2016 (respectively 300,000 and 200,000 m^3), but this was distributed over the whole area which makes it difficult to distinguish in the sedimentation-erosion plots. An impact of the sediment disposal at these locations is not visible, even though ebb transport is considered dominant for this section of the main channel.

VI : Straatje van Willem (East-Everingen)
A continuation of the southward migration is observed at the Straatje van Willem (#L* in Figure 3.11), which is the most eastward channel section of the Everingen (northeast of the Inloop van Ossenisse). These changes are very similar to the autonomous development (2005 till 2016). It is very unlikely that these changes are the result of the sediment disposals at the Inloop van Ossenisse, because the rate of changes is very large and net transport is towards the East.

3.3 Local erosion of the disposal sites

The local development of the erosion at the Inloop van Ossenisse is discussed here in relation to the changes that were observed at the Gat van Ossenisse and SH41. First, the amount of sediment that can be traced back initially is discussed. Then an overview of the observed morphological changes (e.g. migration) is provided and the subsequent rate of erosion of the local disposed sediment at the bed is quantified.

A quantitative analysis, based on the combined small and large scale surveys, shows that the volume that could be found at the bed shortly after the disposal at the disposal sites of the Inloop van Ossenisse (in May 2016 and 2017) was about 800,000 m^3 (Figure 3.12). This sediment then slowly eroded in the following year until a new sediment disposal was made in May 2017, of which also 800,000 m^3 could be found at the bed in the survey directly after the May 2016 and May 2017 sediment disposals. The volume found at the bed is about 80% of the total volume that was disposed here, which was 1 million m^3 in both years (Figure 2.2). This aligns well with the findings on the measurements of the Inloop van Ossenisse in IMDC (2019). It is expected that the initial losses during the disposal are the result of stripping of the finer sediments from the plume (~10% based on expert judgment), while another part (~10%) is lost due to the turbulence and resuspension created when the plume hits the bed (see also Huisman et al., 2021; IMDC, 2020). Plancke et al. (2019a) shows that the sediment at the bed is considerably coarser than the sediment that was dredged suggesting a winnowing of the material during the disposal process. The initial losses of sediment during the disposal are, however, considerably smaller than what has been found at the Put van Hansweert, where up to 50% of the sediment could not be traced back even in the first survey (Huisman et al., 2018; IMDC, 2019; Huismans et al., 2021).

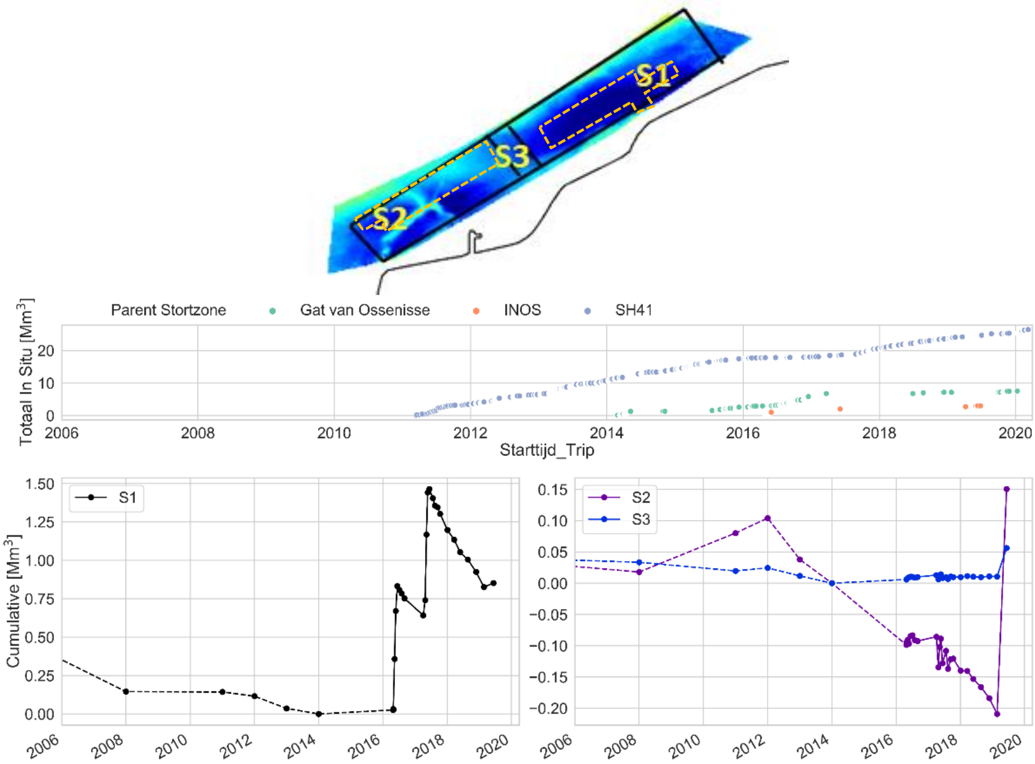


Figure 3.12 Small survey bathymetry with sub-regions #S1 to #S3 with disposal sites in orange dashed lines (upper panel), the cumulative volume of the sediment disposals in SH41, Inloop van Ossenisse and Gat van Ossenisse (middle panel) the volumetric changes of these sub-regions over time with respect to the 2014 Vaklodingen (lower panel). The reference period before the May 2016 disposal is shown with a dashed line.

The bathymetric measurements for the small regions show the sediment that is disposed in the deep pit of the Inloop van Ossenisse for the May 2016 (Figure 3.13) and May 2017 (Figure 3.14) disposals. The volumetric change of the eastern and western pit of the Inloop van Ossenisse are presented in Figure 3.12. Over time the sediment at the bed erodes slowly, especially at the south-eastern side of the deposition region, which means that the deposition zone with sediment became narrower in cross-channel direction over time. Furthermore, the sediment at the southern side of the pit seems to migrate towards the North-East (i.e. in flood direction). This may indicate some flood dominant transport for the southern side of the deep pit. The local erosion rate at the Inloop van Ossenisse disposal area was about 1100 m^3/day for the May 2016 disposal and 1400 m^3/day after the second disposal in May 2017 (Figure 3.12). This means that it will take almost 2 years to erode the 800,000 m^3 of the pilot disposal from sub-region #S1 assuming a linear erosion in time. In addition to the erosion also a regular pattern of large bed forms develops at the disposal site, which is especially the case for the November 2018 situation (Figure 3.14). Noticeable is also that the lack of erosion visible close to the disposal site. Some erosion is only observed at a kilometre distance towards the southwest, which may not even be related to the sediment disposal.

A small migration to the northeast took place, which is expected to be due to flood dominant transport at the southern side of the pit. However, selective erosion in the southwest in combination with local redistribution may as well be an explanation. It is noted that sediment is likely to redistribute quickly within the deep parts of the Inloop van Ossenisse directly after the sediment disposal as the sediment spreads out over the bed. The observation period is too short to distinguish the precise reasons for the slight elongation of the region with sediment, which will require also some additional information on currents.

So, the sediment is expected to redistribute quickly after the disposal over the deep pit, followed by a gradual erosion with only a small migration of the sediment at the southern side of the deep pit. The eroded sediment will be deposited at some distance from the disposal site, as it cannot be traced back in the measurements.

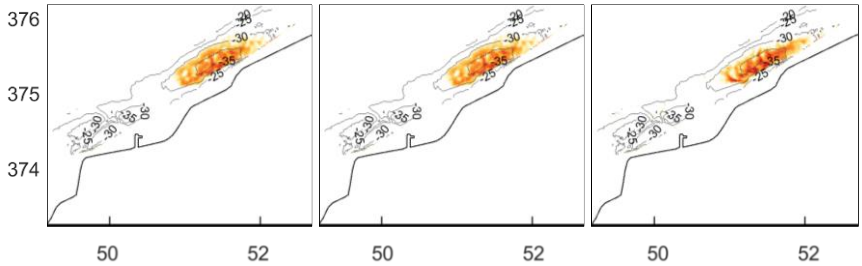


Figure 3.13 Morphological changes after the May 2016 pilot disposal at the Inloop van Ossenisse (with respect to the April 2016 survey). Panel A : June 2016 bathymetry (T004); Panel B : September 2016 bathymetry (T007); Panel C : April 2017 bathymetry (T013).

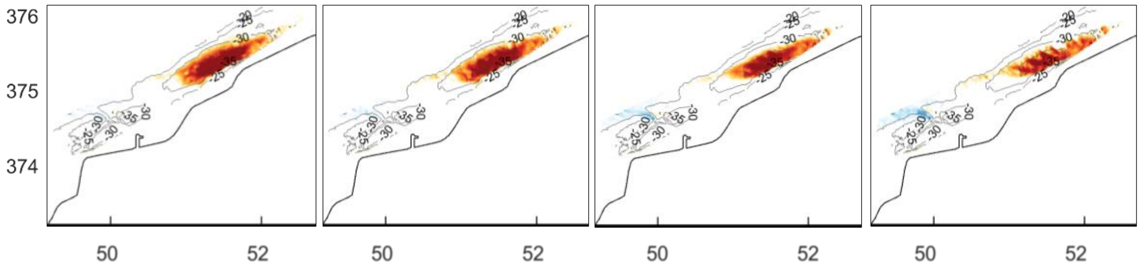


Figure 3.14 Morphological changes after the May 2017 pilot disposal at the Inloop van Ossenisse (with respect to the April 2017 survey). Panel A : June 2017 bathymetry (T021); Panel B : October 2017 bathymetry (T033); Panel C : May 2018 bathymetry (T048); Panel D : November 2018 bathymetry (T060).

The adjacent region #S2 showed some erosion from 2016 to 2019 (i.e. during the period with the pilot disposals and later) with a rate of about 100 m^3/day (or ~30,000 per year), which is the same as the erosion in #S1 for the period preceding the sediment disposal. This suggests that the area is already eroding mildly without the pilot disposals. A sudden increase in volume can be seen in the last measurement for #S2 due to the third pilot disposal in 2019 (Figure 3.12). The erosion rates after the pilot disposal in 2019 could not be determined, as measurement data were not yet available for this analysis.

It will be difficult to know in advance what the erosion rate will be after a more prolonged period of sediment disposals at the Inloop van Ossenisse. The rate of erosion may somewhat increase when more sediment is present, as the coverage of the area with disposed sediment will increase and the depth will become somewhat smaller (i.e. on-average rather decimetres than meters). On the other hand, it may also be the case that small erosion takes place at other sections of the Inloop van Ossenisse, which may reduce the forces on the sediment in the deep pit of the Inloop van Ossenisse and thus (partly) balance out any strengthening of the erosion in the deep pits with sediment.

When making the comparison to other regions, it is clear that the Inloop van Ossenisse is less erosive than the Gat van Ossenisse and SH41. For example, the volume change in the Gat van Ossenisse was about 700,000 m^3 in the ‘Large measurements’ (in #L2) for the years 2016 and 2017 (Figure 3.15), while a volume of more than 4 million m^3 was placed here according to dredging and disposal specifications (Figure 2.2). This suggests an erosion rate of about 4500 m^3/day over this period for the Gat van Ossenisse.

Even the initial disposals at Gat van Ossenisse quickly eroded compared to the Inloop van Ossenisse, which is expected to be related to the large autonomous erosion at the Gat van Ossenisse (also prior to the sediment disposals). Also at SH41 only a small part of the sediment remained in the disposal area. Only 1 million m^3 could be found in the measurements (combined #M1 and #M2 in Figure 3.15) of the ~7 million m^3 that was disposed from 2016 to 2019. Erosion rates of pilot disposals at the Put van Hansweert (Huismans et al., 2021) show an average erosion rate of 1100 to 3300 m^3/day, with a maximum rate of 6600 m^3/day, which is larger than for the Inloop van Ossenisse. The volumes of the pilot disposal at the Put van Hansweert were the same (3x ~1million m^3) as for the Inloop van Ossenisse, which makes it relevant to compare to the Put van Hansweert.

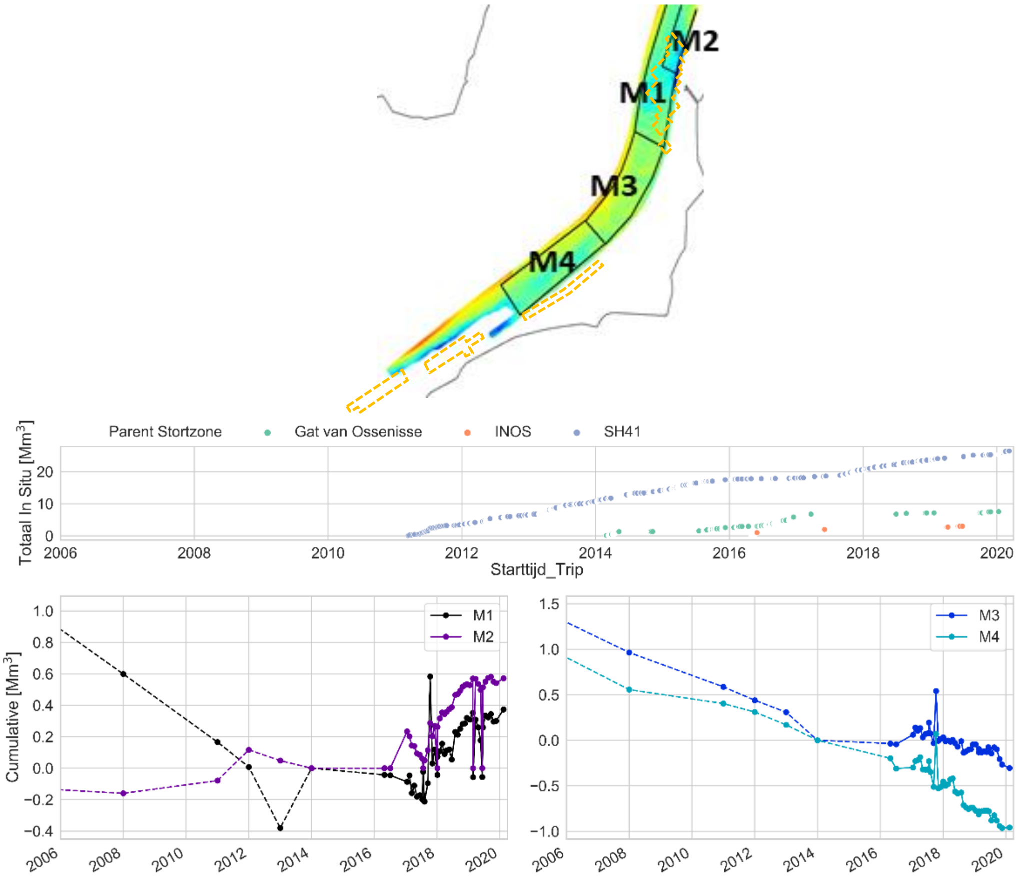


Figure 3.15 Medium survey bathymetric evolution showing the division in sub-regions with disposal sites in orange dashed lines (upper panel), the cumulative volume of disposed sediment at the disposal sites (middle panel) and the volumetric changes of these sub-regions over time with respect to the 2014 Vaklodingen (lower panels). The reference period before the May 2016 disposal is shown with a dashed line.

3.4 Interpretation of the morphological system

The morphological system of the Inloop van Ossenisse and the impact of the pilot sediment disposal is characterised on the basis of the findings of the morphological analyses (Sections 3.2 and 3.3) which is aided by the information from numerical models on the pathways of sediment at the Inloop van Ossenisse (Section 2.4.3). It must be noted that quite some uncertainty is present in the conceptual model, as only a limited number of regional surveys was available for the Inloop van Ossenisse.

In addition, the understanding of the physical system is complicated, as the effects of the studied pilot disposals at the Inloop van Ossenisse are quite small compared to the disposed volumes in nearby regular disposal sites (Gat van Ossenisse and Overloop van Hansweert) and to the autonomous morphological changes in this region. The conceptual overview is therefore considered the provisional understanding of the system based on the current knowledge. This interpretation is shown in Figure 3.16, which shows the following features:

I. Local storage in the deep pit of the Inloop van Ossenisse
The capacity of the western and eastern deep pit of the Inloop van Ossenisse is smaller than for the Gat van Ossenisse, SH41 and Put van Hansweert, which have erosion capacities that are two to three times larger. This means that part of the disposed sediment may remain stored in the deep pit when sediment disposal volumes exceed the local erosion capacity (which was 1100 and 1400 m^3/day). In principal the storage volume of the deep pit is large, as it has a very large area and over-depth. The local storage can also be considered beneficial depending on the aims of the strategy.

II. Redistribution of sediment in the main channel.
Sediment will be redistributed in the main channel due to tidal currents. The transport in most of the Inloop van Ossenisse is in the ebb-direction (towards the southwest; see Figure 2.9). Most of the sediment will then end up at the Drempel van Terneuzen. The southern side of the Inloop van Ossenisse is, however, flood dominated, which means that another part of the sediment in the eastern pit (mainly what is placed on the southern side) will be transported towards the Gat van Ossenisse. This aligns with the small eastward migration of the sediment that was observed at the southern side of the eastern deep pit.

III. Morphological changes at the side walls of the main channel
Some accretion was observed North of the pilot sediment disposal in July 2017 and some erosion directly adjacent further southwest from this accretive area. The numerical modelling suggests that the morphological change here is the result of supply from the Straatje van Willem. Moreover, rather similar accretion took place prior to 2016 (before the pilot disposals), suggesting it is not related to the pilot disposal. Still it may be possible that the pilot disposal has some effect in this region, especially on the erosion. So, these effects could not be traced to the pilot sediment disposal, but this region should be kept in mind in any verification monitoring of the disposal strategy.

IV. Transport towards the connection channel of the Zuid-Everingen
The Zuid-Everingen is expected to have eb-dominant transport pathways (see Figure 2.9), which can transport sediment towards the Everingen. On the long-term it is expected that sediment from the Inloop van Ossenisse contributes to the sediment budget of the Zuid-Everingen and southwestern margin of the Middelplaat.

V. Indirect transport to the Drempel van Baarland
Numerical computations suggest that the ebb current can transport sand towards the Drempel van Baarland from the northern side of the Gat van Ossenisse (see Figure 2.9). This means that an indirect route from the Inloop van Ossenisse to the Drempel van Baarland may be present, as sediment from the pilot disposal site is partially transported towards the Gat van Ossenisse during flood conditions in the main channel. A noticeable effect of the pilot disposal at the Inloop van Ossenisse on the Drempel van Baarland is not expected, as the autonomous development already shows strong accretion at the Drempel van Baarland. There are also many contributors to the local morphological changes here (e.g. supply from the Everingen and sediment disposal sites at the Gat van Ossenisse and SH41).

VI. Flood transport at the shoal margins

Some of the finer sand may end up at the margins of the intertidal flats, where it can be transported with the flood current until it reaches a location where it can settle (e.g. at the Platen van Hulst). It is not expected that large volumes of sediment will be transported in this way. It is noted that the southeast side of the Gat van Ossenisse is very erosive, which means that an impact of the Inloop van Ossenisse on the eastern flats and side walls of the Gat van Ossenisse is likely to be much smaller than the autonomous changes.

VII. Middelplaat

A direct transport to the Middelplaat is not expected, but long-term accretion in adjacent channels may result in a growth of the intertidal areas over time (in analogy with De Vet, 2020). Although a strategy which places the sediment directly on shoals does, of course, have a much larger impact on the inter-tidal areas.

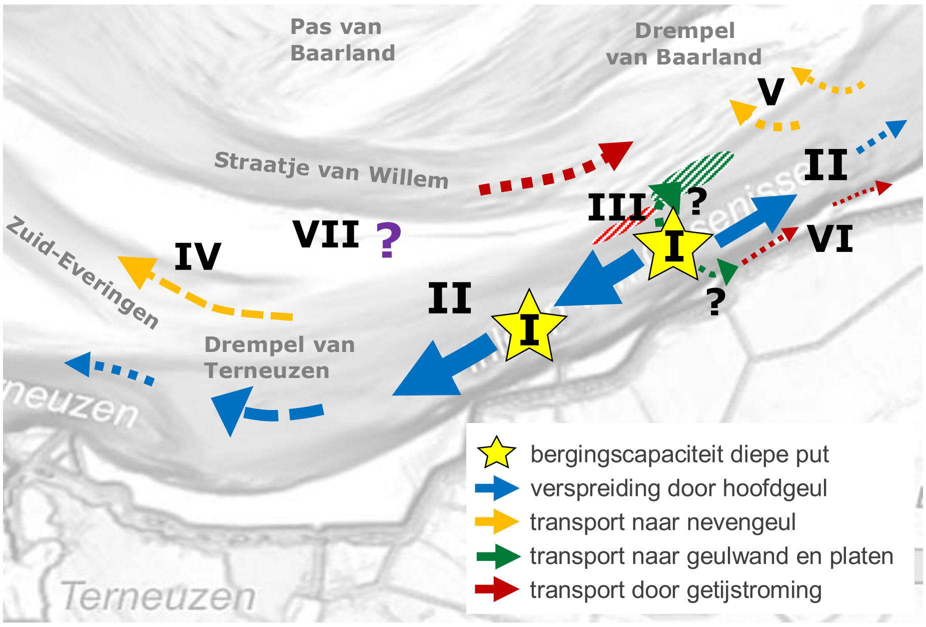


Figure 3.16 Conceptual overview of the morphology of the Inloop van Ossenisse on the basis of expert interpretation. The stars show the eastern and western pits of the Inloop van Ossenisse. Roman numbers correspond to the process description in the text above. The arrows indicate net sand transport, with the size representative for the transport capacity. Uncertain transports are shown as dashed arrows and question marks used to indicate uncertain relations. The shaded areas indicate either expected erosion (red) or accretion (green).

The most relevant effects for the dredge-disposal strategy of the Western Scheldt are 1) the possible gradual filling up of the deep pits Inloop van Ossenisse over time if the erosion capacity is exceeded substantially and 2) the along-channel transport of sediment from the disposal site at the Inloop van Ossenisse mainly to the southwest, and to a lesser extent also to the northeast. The erosion capacity of the Inloop van Ossenisse is considerably smaller than for the Gat van Ossenisse, SH41 and Put van Hansweert.

It is noted that the conceptual framework was made on the basis of a relatively short series of measurements at the Inloop van Ossenisse (~ 3 years from the first disposal in May 2016) which results in a relatively small signal and inherent uncertainty in the interpretation. The interpretation in this study was therefore aided by expert-interpretation. In the future it will be relevant to further improve the conceptual framework of the morphology of the Inloop van Ossenisse on the basis of additional data and with a broader group of experts.

4 Conclusions and Recommendations

4.1 Conclusions

This study uses an analysis of bathymetric survey data to assess the regional and local scale impacts of two pilot sediment disposal sites at the Inloop van Ossenisse. The results are used by the Vlaams Nederlandse Scheldecommissie to further optimize the disposal strategies for this area with least impact on the morphology. Questions were answered with respect to the autonomous changes of the morphology, local erosion of sediment at the bed of the disposal location and regional effects on the morphology.

What is the autonomous morphological change of the Inloop van Ossenisse and surroundings?

- Large autonomous changes in morphology have taken place in the considered region (see Figure 3.5). These bathymetric changes were much larger than the pilot sediment disposals at the Inloop van Ossenisse.
- Noticeable was that the Inloop van Ossenisse and Drempel van Terneuzen were relatively stable compared to the surrounding regions.
- Within the Everingen a strong southward migration of the shoals and channels of the Straatje van Willem and Pas van Baarland is observed.
- The Gat van Ossenisse migrates eastward with strong erosion along the Platen van Hulst (eastern side) and accretion at the Drempel van Baarland (west of the Gat van Ossenisse).
- The Overloop van Hansweert migrates in westward direction instead of eastward as seen for the Gat van Ossenisse. At the Overloop van Hansweert (SH41) the sediment disposals seem to have changed the erosive behaviour, as the channel now migrates westward.

How quickly will sediment erode from the disposal location in the Inloop van Ossenisse and what fraction of the sediment will remain in place?

- Part of the sediment that is disposed in the Inloop van Ossenisse (~20%) is lost during and shortly after the disposal, which is expected to be the finer sand fraction that is stripped from the plume or winnowed out from the bed quickly after the sediment disposal. This initial loss is considerably smaller than for the pilot disposals at the Put van Hansweert where up to 50% of the sediment could not be traced within a few weeks after disposal (Huismans et al., 2021).
- Over time the sediment disposed at the deep pits will gradually erode (with an observed 1100 to 1400 m^3/day over the two-year period of the pilot disposals). The erosion rate of the Inloop van Ossenisse is considerably smaller than those of the Gat van Ossenisse, SH41 and Put van Hansweert, where the erosion rate is two to three times larger. A gradual filling of the deep pits of the Inloop van Ossenisse may be possible when the erosion capacity of ~500,000 m^3/yr is exceeded substantially, although this should not necessarily be a problem. It may also be useful to store sediment at the deep pits. Still the amount of accretion should not be excessive such that negative impacts will take place in adjacent regions (e.g. erosion at the channel sidewalls).

To what extent do sediment disposals in the Inloop van Ossenisse affect the regional morphology?

- Sediment from the Inloop van Ossenisse is assumed to be transported mainly to the southwest to the Drempel van Terneuzen by the ebb-dominant flow in the Inloop van Ossenisse, and to a lesser extent also to the northeast due to flood currents.
  The flood currents seem to affect especially the southern side of the eastern pit of the Inloop van Ossenisse. The along-channel transport of sediment from the disposal site is expected to be the most dominant process. Possibly, a placement further to the east will reduce the maintenance at the Drempel van Terneuzen.
- It is expected that a part of the sediment from the Inloop van Ossenisse will be transported to the Zuid-Everingen due to the eb-dominant transport (see Figure 2.9), which is based on the computations of sediment transport. On the long-term this contributes to the sediment budget of the Zuid-Everingen and southwestern margin of the Middelplaat. It is uncertain to what extent this affects the morphology of the Zuid-everingen.
- Some accretion and erosion zones were observed North of the pilot sediment disposal region in the Inloop van Ossenisse in July 2017. These changes are most-likely the effect of sediment from the Straatje van Willem. Still it is possible that some erosion or accretion may take place here if large volumes of sediment are disposed in the Inloop van Ossenisse over a long period.

4.2 Recommendations

This study provides a conceptual framework of the morphology of the disposal site of the Inloop van Ossenisse and the regional impacts, which is based on the findings of the morphological analyses (Sections 3.2 and 3.3) and aided by the information from numerical models on the pathways of sediment at the Inloop van Ossenisse (Section 2.4.3). It must be noted that quite some uncertainty is present in the conceptual model, as only a limited number of regional surveys was available for the Inloop van Ossenisse. In addition, the understanding of the physical system is complicated, as the effects of the studied pilot disposals at the Inloop van Ossenisse are quite small compared to the disposed volumes in nearby regular disposal sites (Gat van Ossenisse and Overloop van Hansweert) and to the autonomous morphological changes in this region. The conceptual overview is the provisional understanding of the system based on the current knowledge, but it is relevant to verify the local and regional morphological changes to better learn what the exact effects are locally at the Inloop van Ossenisse and the spreading of the material to the surrounding regions. The main thing is to be able to discern whether the disposed sediment will just redistribute over a larger area or whether the morphology may change. This knowledge is essential for optimization of the disposal strategy. For this reason, the following recommendations are made:

- Sediment disposal at the Inloop van Ossenisse should be build up mildly over time (i.e. in the initial year not more than 1 million m^3) to allow for some reflection on the longer-term sediment redistribution in the Inloop van Ossenisse and effects on the surrounding regions. An evaluation of the actual infilling of the deep pit can be made after a few years, on the basis of which the disposal volumes can be fine-tuned. A judgment by Flexibel Storten is recommended if a higher volume is placed in the Inloop van Ossenisse.
  Depending on the preferred effects of the disposal strategy, it will be possible to dispose sediment at the Inloop van Ossenisse, where part of the sediment may be stored (within limits of storage capacity below the dredging depth) and thus comes with relatively small effects on the surrounding regions. Or alternatively, to place the sediment at other disposal sites (e.g. SH41) which transport sediment quickly away from the disposal site, but with a larger impact on the regional morphology (e.g. for SH41 on the erosion of western side of the Overloop van Hansweert and influx of sediment at the inner bend of the Put van Hansweert; Huisman et al., 2021).

- It is important to continue with the monitoring of the rate of erosion inside the deep pit of the Inloop van Ossenisse at regular time intervals (e.g. 3 monthly) as this will greatly help in understanding the local dynamics within the pit of the Inloop van Ossenisse. It could then also be checked what the actual accretion in the deep pit is, which is especially useful to check the scalability of the disposal location when large volumes are placed (i.e. much more than the transport capacity of 500,000 m^3/yr).
- Monitoring is recommended to determine the regional impact on the Zuid-Everingen, southern margin of the Middelplaat (North of the Inloop van Ossenisse), Drempel van Baarland, Drempel van Terneuzen and Gat van Ossenisse. These regional scale bathymetric measurements can substantially improve the understanding of the physical system and regional impacts of the dredge-disposal strategy at the Inloop van Ossenisse.
- It is recommended to analyse the development of the dredging volumes at the Drempel van Terneuzen to assess the possible influence of sediment disposals at the Inloop van Ossenisse.
- It is recommended to perform a follow-up study using the computed transport patterns (e.g. SedTRAILS and hydrodynamic computations) to improve the understanding of the morphological system and conceptual framework of the Inloop van Ossenisse, which is to be discussed with a broad group of experts in relation to the literature. The numerical simulations of the hydrodynamics and sediment transport of the Inloop van Ossenisse can show the eventual direction of the transport (e.g. towards the Drempel van Terneuzen). As a result, the knowledge base will be made much stronger, thus making it easier to effectively choose disposal sites and identify the influence on the morphology.
- The autonomous development of the region around the Inloop van Ossenisse was not the main aim of this study, but rather a necessity to understand the impacts of the disposals at the Inloop van Ossenisse. The long-term development of the Western Scheldt can, however, be understood much better when the autonomous changes are further investigated in relation to the impacts of disposal sites. This holds especially for very active morphological areas such as the Everingen, Pas van Baarland, Drempel van Baarland, Middelgat, Gat van Ossenisse and Overloop van Hansweert.

References

Cleveringa, J. (2013). Ontwikkeling mesoschaal Westerschelde (factsheets). Basisrapport kleinschalige ontwikkeling K-16. Project LTV veiligheid en toegankelijkheid; LTV V&T-rapport K-16. 30 augustus 2013. *Rapport A2666*. I/RA/11387/13.083/GVH.

De Vet, P.L.M., van Prooijen, B.C., Colosimo, I., Ysebaert, T., Herman, P.M.J., & Wang, Z.B. (2020). Sediment disposals in estuarine channels alter the ecomorphology of intertidal flats. *Journal of Geophysical Research: Earth Surface*, Vol. 125.

Elias, E., Roelvink, F., Pearson, S., & Huisman, B.J.A. (2021). Investigation of Sediment Pathways in the Put Van Hansweert. Morphological effects of dumping in a deep pit of the Western Scheldt. *Deltares Report 1210301-001-ZKS-0010*.

Huisman, B.J.A., Schrijvershof, R., Lanckriet, T., & Van der Werf, J. (2018). Baggerdepositie in Diepe Geulen. Strategie Voor Het Plaatsen van Sediment in de Diepere Getijdegeulen van de Westerschelde. *Deltares rapport 1210301-000-ZKS-0027*. In opdracht van de Vlaams Nederlandse Schelde Commissie (VNSC).

Huisman, B.J.A., Huismans, Y., Vroom, J., (2021). Effecten van storten in diepe putten van de Westerschelde. Synthese van proefstortingen en modelanalyses. *Deltares rapport 1210301-015-ZKS-0012*. In opdracht van de Vlaams Nederlandse Schelde Commissie (VNSC).

Huismans, Y., Van der Vegt, H., Huisman, B.J.A., & Alonso, A.C. (2021). Westerschelde: storten in diepe putten Technische rapportage: mesoschaal morfologische ontwikkelingen rond de Put van Hansweert. *Deltares rapport 1210301-015-ZKS-0006*. In opdracht van de Vlaams Nederlandse Schelde Commissie (VNSC).

IMDC. (2019). Vaarwegbeheer 2016-2021 Bestelopdracht 6: Flexibel Storten 2018-2019 - Maandrapport oktober-november 2019. 34 pp.

IMDC (2020). Report on CFD calculations disposal plumes. IMDC report for VNSC I/RA/12161/20.005/BDC/FKY. Auteurs: Foteini Kyrousi & Boudewijn Decrop.

Plancke, Y., Bastiaensen, E., & Mostaert, F. (2019a). Proefstortingen Westerschelde: Deelrapport 2 – Analyse beun- en boxcorerstalen bij de uitvoering van de stortproef 2019 in de diepe put van Hansweert. Versie 0.1. WL Rapporten, 19_079_2. Waterbouwkundig Laboratorium: Antwerpen.

Plancke, Y., Meire, D., & Mostaert, F. (2019b). Agenda voor de Toekomst - Sedimentstrategie Westerschelde: Syntheserapport. Versie 0.1. *WL Rapporten, 13_122_1*. Waterbouwkundig Laboratorium: Antwerpen.

Rijkswaterstaat (2020). Vaklodingen bathymetric surveys of the Dutch sea bed and lakes. Rijkswaterstaat Data-ICT-Dienst (RWS DID). https://waterinfo-extra.rws.nl/monitoring/morfologie/#h53b817e6-e5cd-49d1-873c-9a0f85d8e416

Van der Wegen, M., Schrijvershof, R., Alonso, A.C., Broekema, Y., Kranenburg, W., & Huisman, B.J.A. (2021). Hydrodynamics in the Pits of Borssele and Hansweert - Data-Analysis and Delft3D-FM Modeling. *Deltares report 1210301–015*.

Winterwerp, J.C., Z.B. Wang, M.J.F. Stive, A. Arends, C. Jeuken, C. Kuijper, & P.M.C. Thoolen (2001). A new morphological schematization of the Western Scheldt Estuary, The Netherlands, River, Coastal and Estuarine Morphodynamics Conference RCEM2001 (IAHR), Japan.

A Bathymetric datasets

Table A.1. Overview of regional scale survey data of the Inloop van Ossenisse and adjacent regions (large survey Data). Other regions in the data set are the Put van Terneuzen, Drempel van Terneuzen, Everingen-Zuid, Straatje van Willem, Gat van Ossenisse and Drempel van Baarland. Coordinates are in Amersfoort RD, EPSG:28992.

DATE	N. OF POINTS	AREA [M²]	XMIN	XMAX	YMIN	YMAX	FILENAME
2016-04-28 00:00:00	19768592	29612708	45351.26	55781.02	373253.5	379536.4	20160428_IOS_Z_MB_300_1x1RD.txt
2016-07-05 00:00:00	19824198	29665473	45351.26	55780.26	373252.9	379534.9	ios_z_t6_XYZ.txt
2017-07-22 00:00:00	19863532	50368827	45248.23	55778.23	373255.9	379949.9	ios_z_t14_xyz.txt
2018-01-04 00:00:00	19966125	50038745	45351.26	55784.75	373255.9	379946	IOS_Z_t18_XYZ.txt
2019-02-23 00:00:00	15890346	29614325	45352.26	55781.84	373257.6	379528.8	stiossg_t24_xyz.txt
2019-06-11 00:00:00	15918121	29732412	45352.26	55783.26	373254.5	379533.5	stiossg_t34_xyz.txt

Table A.2. Overview of survey data of the Gat van Ossenisse and Overloop van Hansweert (medium survey Data). Coordinates are in Amersfoort RD, EPSG:28992.

DATE	N. OF POINTS	AREA	XMIN	XMAX	YMIN	YMAX	FILENAME
2016-04-28 00:00:00	19768592	29612708	45351.26	55781.02	373253.5	379536.4	20160428_IOS_Z_MB_300_1x1RD.txt
2016-07-05 00:00:00	19824198	29665473	45351.26	55780.26	373252.9	379534.9	ios_z_t6_XYZ.txt
2017-01-17 00:00:00	4852460	9403186	51278.69	56105.69	375595.3	381544.3	170117_GAT_OSS_MB_300_Rd_NAP.txt
2017-02-13 00:00:00	5344869	11260623	50288.73	56071.73	375057.6	381493.6	170213_GAT_OSS_MB_Rd_NAP.txt
2017-03-13 00:00:00	4987600	9693389	51297.44	56188.44	375714.7	381598.7	170313_GAT_OSS_MB_Rd_NAP.txt
2017-04-10 00:00:00	4889422	9489476	51289.07	56163.07	375634.3	381494.3	170410_GAT_OSS_MB_Rd_NAP.txt
2017-05-11 00:00:00	5443794	11505655	50268.41	56129.41	375022.1	381582.1	170511_GAT_OSS_MB_300_Rd_NAP.txt
2017-06-13 00:00:00	5131144	11154012	50327.96	56153.96	374977.2	381588.2	170613_GAT_OSS_MB_Rd_NAP.txt
2017-07-13 00:00:00	4820300	10842131	50327.06	56135.06	375041.6	381509.6	170713_GAT_OSS_MB_Rd_NAP.txt
2017-07-22 00:00:00	19863532	50368827	45248.23	55778.23	373255.9	379949.9	ios_z_t14_xyz.txt
2017-08-08 00:00:00	5559678	11754412	50282.78	56137.78	375039.3	381598.3	170808_GAT_OSS_MB_Rd_NAP.txt
2017-09-15 00:00:00	5504423	11750619	50255.13	56147.13	374985.9	381631.9	170915_GAT_OSS_MB_300_Rd_NAP.txt
2017-10-12 00:00:00	5628195	11918729	50286.45	56133.45	375113.1	381626.1	171012_GAT_OSS_MB_300_Rd_NAP.txt
2017-11-07 00:00:00	5737588	11620851	50278.78	56105.78	375037	381516	171107_GAT_OSS_MB_Rd_NAP.txt
2017-12-04 00:00:00	5059974	11129015	50294.55	56062.55	375046.6	381520.6	171204_GAT_OSS_MB_Rd_NAP.txt
2018-01-04 00:00:00	19966125	50038745	45351.26	55784.75	373255.9	379946	IOS_Z_t18_XYZ.txt
2018-01-05 00:00:00	5236884	11428001	50306.37	56087.37	375005.5	381495.5	180105_GAT_OSS_MB_Rd_NAP.txt
2018-02-01 00:00:00	5124282	11530524	50324.58	56189.58	375088.5	381596.5	180201_GAT_OSS_MB_Rd_NAP.txt

2018-02-28 00:00:00	5002204	10976736	50329.45	56108.45	375021.8	381565.8	180228_GAT_OSS_MB_Rd_NAP.txt
2018-03-28 00:00:00	5102994	10920242	50389.71	56126.71	375107.7	381531.7	180328_GAT_OSS_MB_Rd_NAP.txt
2018-04-23 00:00:00	5506092	11644811	50297.24	56125.24	375095.2	381583.2	180423_GAT_OSS_MB_Rd_NAP.txt
2018-05-22 00:00:00	5055849	11062822	50331.02	56128.02	375103.6	381503.6	180522_GAT_OSS_MB_Rd_NAP.txt
2018-06-20 00:00:00	5148072	11327018	50332.98	56099.98	375082.2	381592.2	180620_GAT_OSS_MB_Rd_NAP.txt
2018-08-01 00:00:00	5375791	11505487	50329.43	56201.43	375070.9	381611.9	180801_GAT_OSS_MB_Rd_NAP.txt
2018-08-28 00:00:00	5443196	11440806	50295.4	56096.4	375042.9	381511.9	180828_GAT_OSS_MB_Rd_NAP.txt
2018-09-27 00:00:00	5360414	11408907	50272.59	56053.59	375030.5	381493.5	180927_GAT_OSS_MB_Rd_NAP.txt
2018-10-25 00:00:00	5328194	11383414	50336.92	56089.92	375117.4	381532.4	181025_GAT_OSS_MB_Rd_NAP.txt
2018-11-21 00:00:00	5632123	11845479	50302.91	56154.91	375048.9	381586.9	181121_GAT_OSS_MB_Rd_NAP.txt
2018-12-13 00:00:00	4973014	11338651	50383.29	56063.29	375114	381504	181213_GAT_OSS_MB_Rd_NAP.txt
2019-01-16 00:00:00	5218762	11234010	50455.4	56065.4	375122.5	381518.5	190116_5746_OSS_MB_Rd_NAP.txt
2019-02-21 00:00:00	5616130	11902123	50311.2	56186.2	375048.5	381580.5	190221_5829_OSS_MB_Rd_NAP.txt
2019-02-23 00:00:00	15890346	29614325	45352.26	55781.84	373257.6	379528.8	stiossg_t24_xyz.txt
2019-03-25 00:00:00	5213783	11434782	50420.68	56085.68	375058.8	381545.8	190325_5881_OSS_MB_Rd_NAP.txt
2019-04-24 00:00:00	5227422	11755671	50331.48	56114.48	375105.5	381639.5	190424_5985_OSS_MB_Rd_NAP.txt
2019-05-23 00:00:00	5315249	11686775	50314.96	56115.96	375050.6	381546.6	190523_6083_OSS_MB_Rd_NAP.txt
2019-06-11 00:00:00	15918121	29732412	45352.26	55783.26	373254.5	379533.5	stiossg_t34_xyz.txt
2019-06-18 00:00:00	5186433	11364670	50322.35	56043.35	375054.7	381537.7	190618_6135_OSS_MB_Rd_NAP.txt
2019-07-17 00:00:00	5012494	11360832	50375.29	56086.29	375139.7	381651.7	190717_6211_OSS_MB_Rd_NAP.txt
2019-08-19 00:00:00	4927492	11197626	50364.26	56041.26	375077	381532	190819_6303_OSS_MB_Rd_NAP.txt
2019-09-18 00:00:00	4808059	11229427	50343.56	56057.56	375093.3	381543.3	190918_6369_OSS_MB_Rd_NAP.txt
2019-10-21 00:00:00	5090483	11428766	50337.45	56090.45	375020.3	381617.3	191021_6454_OSS_MB_Rd_NAP.txt
2019-11-19 00:00:00	5029450	11567857	50365.14	56148.14	375133.2	381620.2	191119_6508_OSS_MB_Rd_NAP.txt
2020-02-14 00:00:00	4911449	11550588	50350.18	56052.18	375150.6	381615.6	200214_6685_OSS_MB_Rd_NAP.txt

Table A.3. Overview of local survey data of the Inloop van Ossenisse (small survey data). Coordinates are in Amersfoort RD, EPSG:28992.

DATE	N. OF POINTS	AREA	XMIN	XMAX	YMIN	YMAX	FILENAME
2016-04-28 00:00:00	1810630	2001835	49218.28	52580.28	374081.2	376142.2	ios_b_t1_XYZ.txt
2016-04-28 00:00:00	19768592	29612708	45351.26	55781.02	373253.5	379536.4	20160428_IOS_Z_MB_300_1x1RD.txt
2016-05-13 00:00:00	1969704	2238264	49159.96	52599.96	374037.9	376164.9	ios_b_t3_xyz.txt
2016-05-26 00:00:00	1964887	2295678	49148.87	52601.87	374060.6	376197.6	ios_b_t4_xyz.txt
2016-06-13 00:00:00	3312012	3724584	48992.73	53046.73	373825.2	376361.2	ios_b_t5_xyz.txt
2016-07-05 00:00:00	19824198	29665473	45351.26	55780.26	373252.9	379534.9	ios_z_t6_XYZ.txt

2016-08-01 00:00:00	3324840	3743896	48992.73	53047.73	373825.2	376361.2	ios_B_t7.txt
2016-09-02 00:00:00	3337321	3734589	48992.73	53046.73	373825.2	376361.2	IOS_B_t8_XYZ.txt
2017-04-04 00:00:00	3310626	3730263	48992.73	53046.73	373825.3	376361.3	IOS_B_t9_XYZ.txt
2017-04-26 00:00:00	3326004	3730868	48992.73	53046.73	373825.2	376361.2	ios_B_t10.txt
2017-05-10 00:00:00	3317389	3733658	48992.73	53045.73	373825.3	376361.3	ios_B_t11.txt
2017-05-24 00:00:00	3331366	3743783	48992.73	53047.73	373825.2	376361.2	ios_b_t12_xyz.txt
2017-06-12 00:00:00	3315421	6913112	48727.14	53036.14	373825.2	376633.2	ios_b_t13_XYZ.txt
2017-07-22 00:00:00	19863532	50368827	45248.23	55778.23	373255.9	379949.9	ios_z_t14_xyz.txt
2017-08-14 00:00:00	3317857	3742486	48992.73	53047.31	373825.3	376361.5	ios_b_t15_XYZ.txt
2017-09-14 00:00:00	3307900	3737554	48992.76	53046.34	373825.2	376361.5	ios_b_t16_XYZ.txt
2017-10-13 00:00:00	3314863	3737355	48993.73	53046.73	373825.3	376360.3	ios_B_t17.txt
2018-01-04 00:00:00	19966125	50038745	45351.26	55784.75	373255.9	379946	IOS_Z_t18_XYZ.txt
2018-03-21 00:00:00	3303592	3720926	48993.76	53046.31	373826.2	376360.5	ios_b_t19_xyz.txt
2018-05-28 00:00:00	3307088	3755416	48992.73	53046.31	373825.2	376361.5	ios_b_t20_XYZ.txt
2018-08-24 00:00:00	3312184	3739243	48992.76	53046.33	373825.2	376361.5	ios_b_t21_xyz.txt
2018-11-26 00:00:00	3293041	3718391	48992.73	53046.31	373825.2	376361.5	ios_B_t22_xyz.txt
2019-02-23 00:00:00	15890346	29614325	45352.26	55781.84	373257.6	379528.8	stiossg_t24_xyz.txt
2019-06-11 00:00:00	15918121	29732412	45352.26	55783.26	373254.5	379533.5	stiossg_t34_xyz.txt

Deltares is an independent institute for applied research in the field of water and subsurface. Throughout the world, we work on smart solutions for people, environment and society.

Deltares

www.deltares.nl