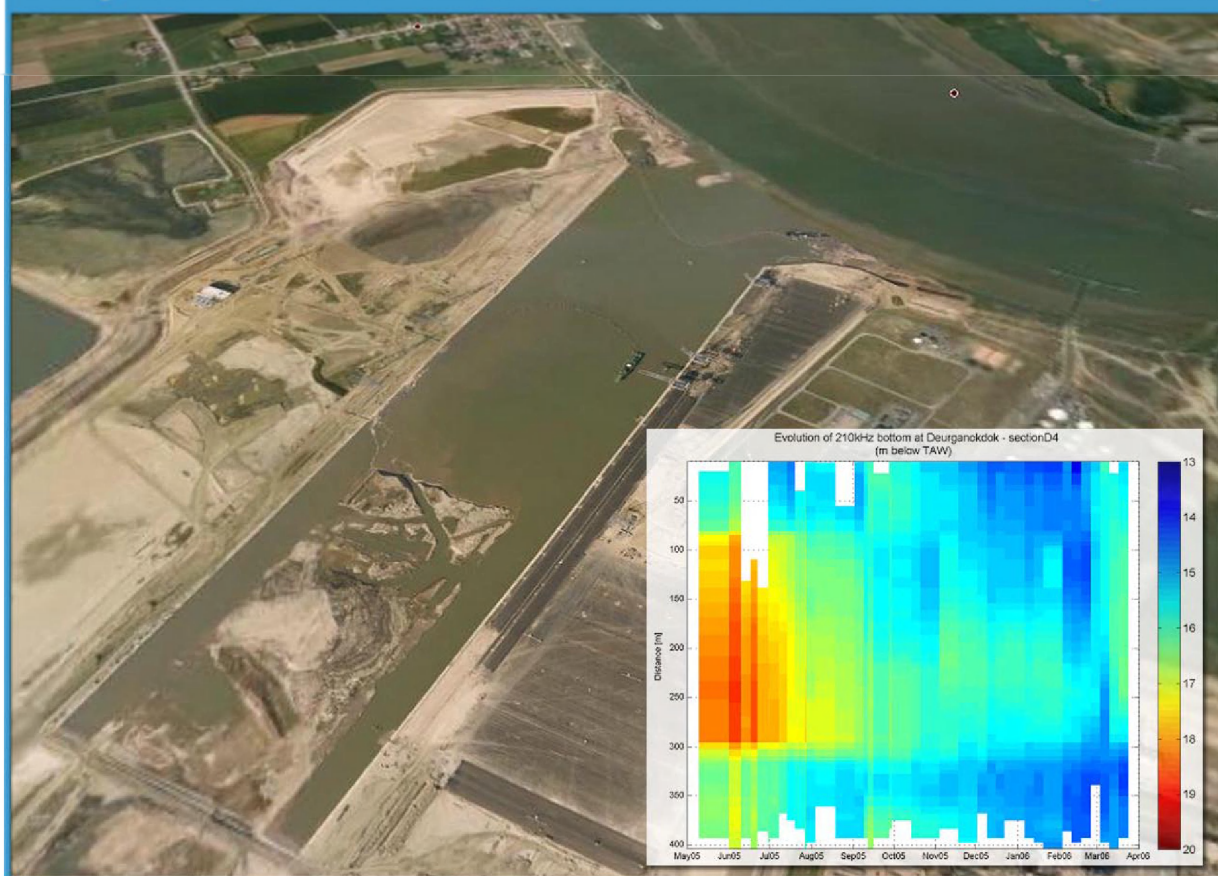


Langdurige metingen Deurganckdok: Opvolging en analyse aanslibbing

Bestek 16EB/05/04

Deurganckdok– Evolution of water-bed interface in a cross-section of Deurganckdok



Deelrapport 1.24 : Sediment jaarbalans 01/04/2008 – 31/03/2009

Report 1.24 : Annual sediment balance 01/04/2008 – 31/03/2009

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GLOSSARY

BIS	Dredging Information System used in the Lower Sea Scheldt
d	Density of dredged sediment [kg/dm ³]
DGD	Deurganckdok
HCBS	High Concentration Benthic Suspensions
M	mass of dry solids [ton]
ρ_s	density of the solid minerals [kg/dm ³]
ρ_w	density of clear water [kg/dm ³]
t _{0d}	Reference situation for densimetric analysis (empty dock)
t _{0e}	Reference situation for volumetric analysis (24 March 2006)
TDS	Ton of dry solids [ton]
V	volume of dredged sediment [m ³]

1. INTRODUCTION

1.1. The assignment

This report is part of the set of reports describing the results of the long-term measurements conducted in Deurganckdok aiming at the monitoring and analysis of silt accretion. This measurement campaign is an extension of the study "Extension of the study about density currents in the Beneden Zeeschelde" as part of the Long Term Vision for the Scheldt estuary. It is complementary to the study 'Field measurements high-concentration benthic suspensions (HCBS 2)'.

The terms of reference for this study were prepared by the 'Departement Mobiliteit en Openbare Werken van de Vlaamse Overheid, Afdeling Waterbouwkundig Laboratorium' (16EB/05/04). The repetition of this study was awarded to International Marine and Dredging Consultants NV in association with WL|Delft Hydraulics and Gems International on 10/01/2006. The project term was repeated twice with an extra year from April 2007 till March 2008, and April 2008 till March 2009.

Waterbouwkundig Laboratorium– Cel Hydrometrie Schelde provided data on discharge, tide, salinity and turbidity along the river Scheldt and provided survey vessels for the long term and through tide measurements. Afdeling Maritieme Toegang provided maintenance dredging data. Agentschap voor Maritieme Dienstverlening en Kust – Afdeling Kust and Port of Antwerp provided depth sounding measurements.

The execution of the study involves a twofold assignment:

- Part 1: Setting up a sediment balance of Deurganckdok covering a period of three years
- Part 2: An analysis of the parameters contributing to siltation in Deurganckdok

1.2. Purpose of the study

The Lower Sea Scheldt (Beneden Zeeschelde) is the stretch of the Scheldt estuary between the Belgium-Dutch border and Rupelmonde, where the entrance channels to the Antwerp sea locks are located. The navigation channel has a sandy bed, whereas the shallower areas (intertidal areas, mud flats, salt marshes) consist of sandy clay or even pure mud sometimes. This part of the Scheldt is characterized by large horizontal salinity gradients and the presence of a turbidity maximum with depth-averaged concentrations ranging from 50 to 500 mg/l at grain sizes of 60 - 100 μm . The salinity gradients generate significant density currents between the river and the entrance channels to the locks, causing large siltation rates. It is to be expected that in the near future also the Deurganckdok will suffer from such large siltation rates, which may double the amount of dredging material to be dumped in the Lower Sea Scheldt.

Results from the study may be interpreted by comparison with results from the HCBS and HCBS2 studies covering the whole Lower Sea Scheldt. These studies included through-tide measurement campaigns in the vicinity of Deurganckdok and long term measurements of turbidity and salinity in and near Deurganckdok.

The first part of the study focuses on obtaining a sediment balance of Deurganckdok. Aside from natural sedimentation, the sediment balance is influenced by the maintenance and capital dredging works. This involves sediment influx from capital dredging works in the Deurganckdok, and internal relocation and removal of sediment by maintenance dredging works. To compute a sediment balance an inventory of bathymetric data (depth soundings), density measurements of the deposited material and detailed information of capital and maintenance dredging works will be made up.

The second part of the study is to gain insight in the mechanisms causing siltation in Deurganckdok, it is important to follow the evolution of the parameters involved, and this on a long and short term basis (long term & through-tide measurements). Previous research has shown the importance of water exchange at the entrance of Deurganckdok is essential for understanding sediment transport between the dock and the Scheldt river.

1.3. Overview of the reports

1.3.1. Reports

Reports of the project for the period April 2006 – March 2009 are summarized in Table 1-1.

Table 1-1: Overview of Deurganckdok Reports

Report	Description
Sediment Balance: Bathymetry surveys, Density measurements, Maintenance and construction dredging activities	
1.1	Sediment Balance: Three monthly report 1/4/2006 – 30/06/2006 (I/RA/11283/06.113/MSA)
1.2	Sediment Balance: Three monthly report 1/7/2006 – 30/09/2006 (I/RA/11283/06.114/MSA)
1.3	Sediment Balance: Three monthly report 1/10/2006 – 31/12/2006 (I/RA/11283/06.115/MSA)
1.4	Sediment Balance: Three monthly report 1/1/2007 – 31/03/2007 (I/RA/11283/06.116/MSA)
1.5	Annual Sediment Balance (I/RA/11283/06.117/MSA)
1.6	Sediment balance Bathymetry: 2005 – 3/2006 (I/RA/11283/06.118/MSA)
1.10	Sediment Balance: Three monthly report 1/4/2007 - 30/06/2007 (I/RA/11283/07.081/MSA)
1.11	Sediment Balance: Two monthly report 1/7/2007 – 31/08/2007 (I/RA/11283/07.082/MSA)
1.12	Sediment Balance: Four monthly report 1/09/2007 – 31/12/2007 (I/RA/11283/07.083/MSA)
1.13	Sediment Balance: Three monthly report 1/1/2008 – 31/03/2008 (I/RA/11283/07.084/MSA)
1.14	Annual Sediment Balance (I/RA/11283/07.085/MSA)
1.20	Sediment Balance: Three monthly report 1/4/2008 - 30/6/2008 (I/RA/11283/08.076/MSA)
1.21	Sediment Balance: Three monthly report 1/7/2008 – 30/9/2008 (I/RA/11283/08.077/MSA)
1.22	Sediment Balance: Three monthly report 1/10/2008 – 31/12/2008 (I/RA/11283/08.078/MSA)

Report	Description
1.23	Sediment Balance: Three monthly report 1/1/2009 – 31/03/2009 (I/RA/11283/08.079/MSA)
1.24	Annual Sediment Balance (I/RA/11283/08.080/MSA)
Factors contributing to salt and sediment distribution in Deurganckdok: Salt-Silt (OBS3A) & Frame measurements, Through tide measurements (SiltProfiling & ADCP) & Calibrations	
2.1	Through tide measurement Siltprofiler 21/03/2006 Laure Marie (I/RA/11283/06.087/WGO)
2.2	Through tide measurement Siltprofiler 26/09/2006 Stream (I/RA/11283/06.068/MSA)
2.3	Through tide measurement Sediview spring tide 22/03/2006 Veremans (I/RA/11283/06.110/BDC)
2.4	Through tide measurement Sediview spring tide 27/09/2006 Parel 2 (I/RA/11283/06.119/MSA)
2.5	Through tide measurement Sediview neap tide (to be scheduled) (I/RA/11283/06.120/MSA)
2.6	Salinity-Silt distribution & Frame Measurements Deurganckdok 13/3/2006 – 31/05/2006 (I/RA/11283/06.121/MSA)
2.7	Salinity-Silt distribution & Frame Measurements Deurganckdok 15/07/2006 – 31/10/2006 (I/RA/11283/06.122/MSA)
2.8	Salinity-Silt distribution & Frame Measurements Deurganckdok 15/01/2007 – 15/03/2007 (I/RA/11283/06.123/MSA)
2.9	Calibration stationary equipment autumn (I/RA/11283/07.095/MSA)
2.10	Through tide measurement Siltprofiler winter (I/RA/11283/07.086/MSA)
2.11	Through tide measurement Salinity Profiling winter (I/RA/11283/07.087/MSA)
2.12	Through tide measurement Sediview winter (I/RA/11283/07.088/MSA)
2.13	Through tide measurement Sediview winter (I/RA/11283/07.089/MSA)
2.14	Through tide measurement Sediview winter (I/RA/11283/07.090/MSA)
2.15	Through tide measurement Siltprofiler (to be scheduled) (I/RA/11283/07.091/MSA)
2.16	Salinity-Silt distribution Deurganckdok summer (21/6/2007 – 30/07/2007) (I/RA/11283/07.092/MSA)
2.17	Salinity-Silt distribution & Frame Measurements Deurganckdok autumn (17/09/2007 - 10/12/2007) (I/RA/11283/07.093/MSA)
2.18	Salinity-Silt distribution & Frame Measurements Deurganckdok winter (18/02/2008 - 31/3/2008) (I/RA/11283/07.094/MSA)
2.19	Calibration stationary & mobile equipment winter (I/RA/11283/07.096/MSA)
2.20	Through tide measurement Sediview DGD during neap tide Spring 2008 (I/RA/11283/08.081/MSA)

Report	Description
2.21	Through tide measurement Sediview DGD during spring tide Spring 2008 (I/RA/11283/08.082/MSA)
2.22	Through tide measurement Sediview DGD during neap tide Summer 2008 (I/RA/11283/08.083/MSA)
2.23	Through tide measurement Sediview DGD during spring tide Summer 2008 (I/RA/11283/08.084/MSA)
2.24	Through tide measurement Sediview DGD during neap tide Autumn 2008 (I/RA/11283/08.085/MSA)
2.25	Through tide measurement Sediview DGD during spring tide Autumn 2008 (I/RA/11283/08.086/MSA)
2.26	Through tide measurement Sediview DGD during neap tide Winter 2009 (I/RA/11283/08.087/MSA)
2.27	Through tide measurement Sediview DGD during spring tide Winter 2009 (I/RA/11283/08.088/MSA)
2.28	Through tide measurement ADCP eddy DGD Summer 2008 (I/RA/11283/08.089/MSA)
2.29	Through tide measurement Siltprofiler DGD Summer 2008 (I/RA/11283/08.090/MSA)
2.30	Through tide measurement Siltprofiler DGD Winter 2009 (I/RA/11283/08.091/MSA)
2.31	Through tide measurement Salinity Profiling DGD Winter 2009 (I/RA/11283/08.092/MSA)
2.32	Salinity-Silt distribution Deurganckdok: Six monthly report 1/4/2008 - 30/9/2008 (I/RA/11283/08.093/MSA)
2.33	Salinity-Silt distribution Deurganckdok: Six monthly report 1/10/2008 – 31/3/2009 (I/RA/11283/08.094/MSA)
2.34	Calibration stationary & mobile equipment Autumn 2008 (I/RA/11283/08.095/MSA)
Boundary Conditions: Upriver Discharge, Salt concentration Scheldt, Bathymetric evolution in access channels, dredging activities in Lower Sea Scheldt and access channels	
3.1	Boundary conditions: Three monthly report 1/1/2007 – 31/03/2007 (I/RA/11283/06.127/MSA)
3.10	Boundary conditions: Three monthly report 1/4/2007 – 30/06/2007 (I/RA/11283/07.097/MSA)
3.11	Boundary conditions: Three monthly report 1/7/2007 – 30/09/2007 (I/RA/11283/07.098/MSA)
3.12	Boundary conditions: Three monthly report 1/10/2007 – 31/12/2007 (I/RA/11283/07.099/MSA)
3.13	Boundary conditions: Three monthly report 1/1/2008 – 31/03/2008 (I/RA/11283/07.100/MSA)
3.14	Boundary conditions: Annual report (I/RA/11283/07.101/MSA)

Report	Description
3.20	Boundary conditions: Six monthly report 1/4/2008 – 30/09/2008 (I/RA/11283/08.096/MSA)
3.21	Boundary conditions: Six monthly report 1/10/2008 – 31/03/2009 (I/RA/11283/08.097/MSA)
Analysis	
4.1	Analysis of Siltation Processes and Factors (I/RA/11283/06.129/MSA)
4.10	Analysis of Siltation Processes and Factors (I/RA/11283/07.102/MSA)
4.20	Analysis of Siltation Processes and Factors (I/RA/11283/08.098/MSA)

1.3.2. Measurement actions

Following measurements have been carried out during the course of this project:

1. Monitoring upstream discharge in the Scheldt river
2. Monitoring Salinity and sediment concentration in the Lower Sea Scheldt taken from on permanent data acquisition sites at Lillo, Oosterweel and up- and downstream of the Deurganckdok.
3. Long term measurement of salinity distribution in Deurganckdok.
4. Long term measurement of sediment concentration in Deurganckdok
5. Monitoring near-bed processes in the central trench in the dock, near the entrance as well as near the landward end: near-bed turbidity, near-bed current velocity and bed elevation variations are measured from a fixed frame placed on the dock's bed.
6. Measurement of current, salinity and sediment transport at the entrance of Deurganckdok for which ADCP backscatter intensity over a full cross section are calibrated with the Sediview procedure and vertical sediment and salt profiles are recorded with the SiltProfiler equipment
7. Through tide measurements of vertical sediment concentration profiles -including near bed highly concentrated suspensions- with the SiltProfiler equipment. Executed over a grid of points near the entrance of Deurganckdok.
8. Monitoring dredging activities at entrance channels towards the Kallo, Zandvliet and Berendrecht locks
9. Monitoring dredging and dumping activities in the Lower Sea Scheldt

In situ calibrations were conducted on several dates to calibrate all turbidity and conductivity sensors (see Table 1-1 for relevant reports).

1.4. Structure of the report

This report is the sediment balance of the Deurganckdok for the period of April 2008 till March 2009. For convenience and to study trends, the data of April 2007 – March 2008 are included as well. However, the focus is on the former measurement year though. The first chapter comprises an introduction. The second chapter describes the project. Chapter 3 describes the methodology.

The measurement results and processed data are presented in Chapter 4, whereas chapter 5 gives a preliminary analysis of the data.

2. SEDIMENTATION IN DEURGANCKDOK

2.1. Project Area: Deurganckdok

Deurganckdok is a tidal dock situated at the left bank in the Lower Sea Scheldt, between Liefkenshoek and Doel. Deurganckdok has the following characteristics:

1. The dock has a total length of 2750 m and is 450 m wide at the Scheldt end and 400 m wide at the inward end of the dock
2. The bottom of Deurganckdok is provided at a depth of -17m TAW in the transition zones between the quay walls and the central trench. The bottom in the central trench is designed at -19 m TAW .
3. The quay walls reach up to $+9\text{m TAW}$

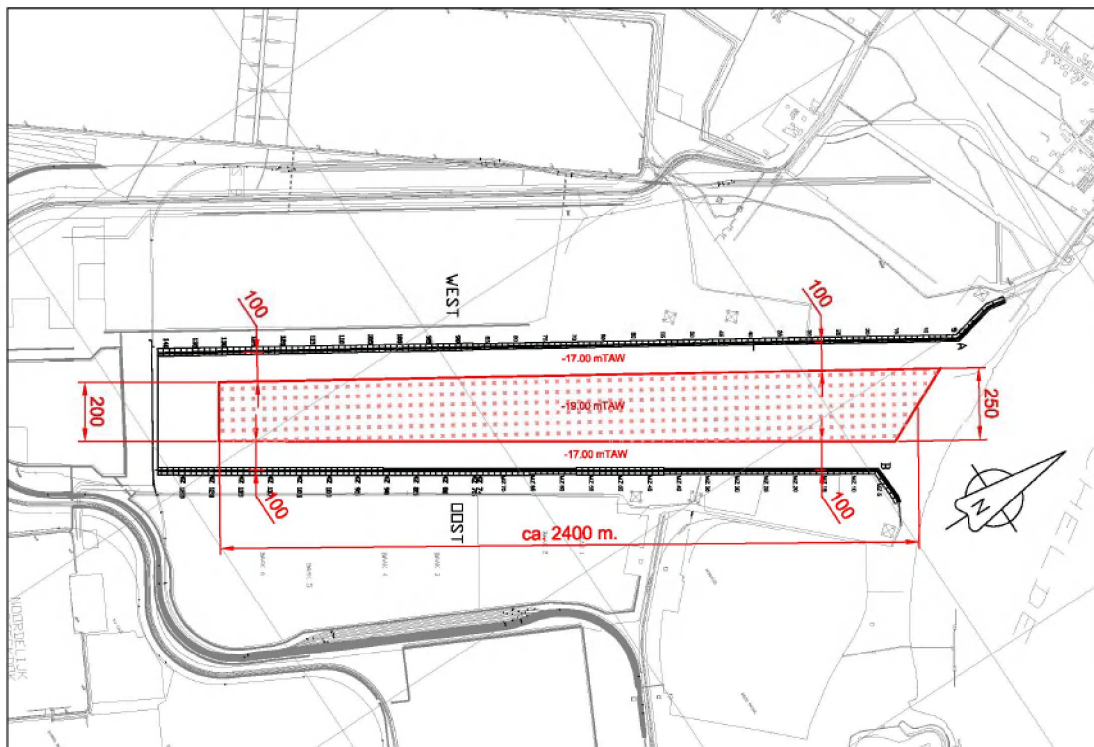


Figure 2-1: Overview of Deurganckdok

The dredging of the dock is performed in 3 phases. On 18 February 2005 the dike between the Scheldt and the Deurganckdok was breached. On 6 July 2005 Deurganckdok was officially opened. The second dredging phase was finalized a few weeks later. The first terminal operations have started since. In February 2007, the third dredging phase started and is finalised by February 2008.

2.2. Overview of the studied parameters

The first part of the study aims at determining a sediment balance of Deurganckdok and the net influx of sediment. The sediment balance comprises a number of sediment transport modes: deposition, influx from capital dredging works, internal replacement and removal of sediments due to maintenance dredging (Figure 2-2).

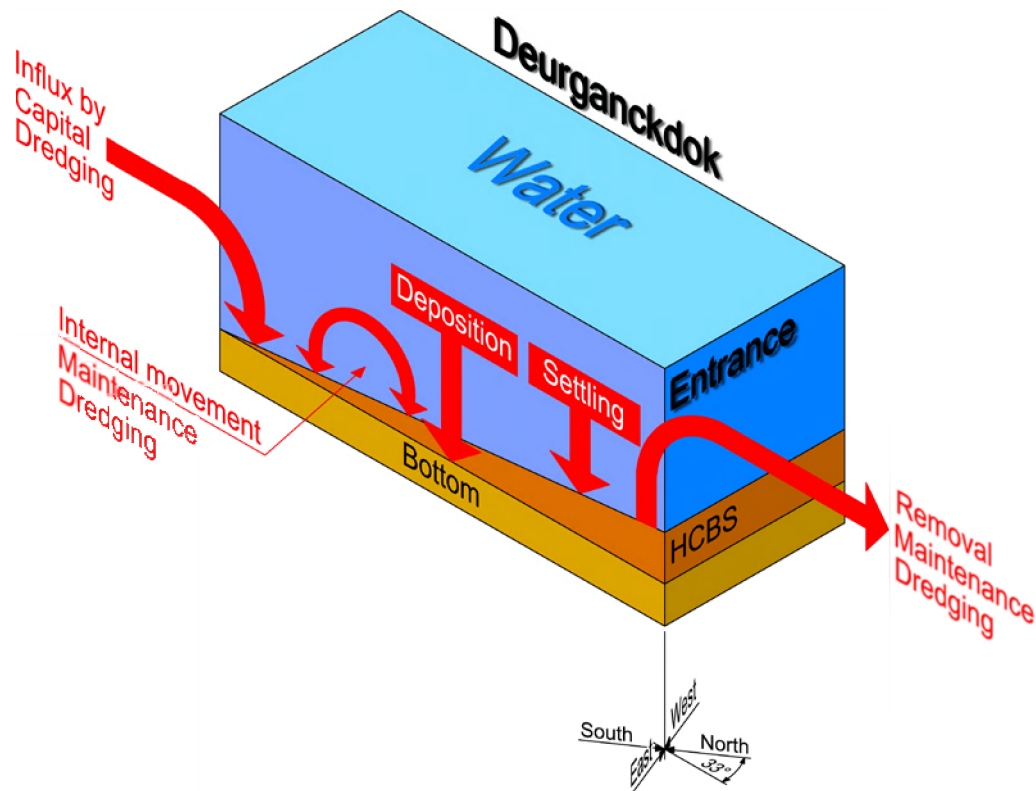


Figure 2-2: Elements of the sediment balance

A net deposition can be calculated from a comparison with a chosen initial condition t_0 (Figure 2-3). The mass of deposited sediment is determined from the integration of bed density profiles recorded at grid points covering the dock. Subtracting bed sediment mass at t_0 leads to the change in mass of sediments present in the dock (mass growth). Adding cumulated dry matter mass of dredged material removed since t_0 and subtracting any sediment influx due to capital dredging works leads to the total cumulated mass entered from the Scheldt river since t_0 .

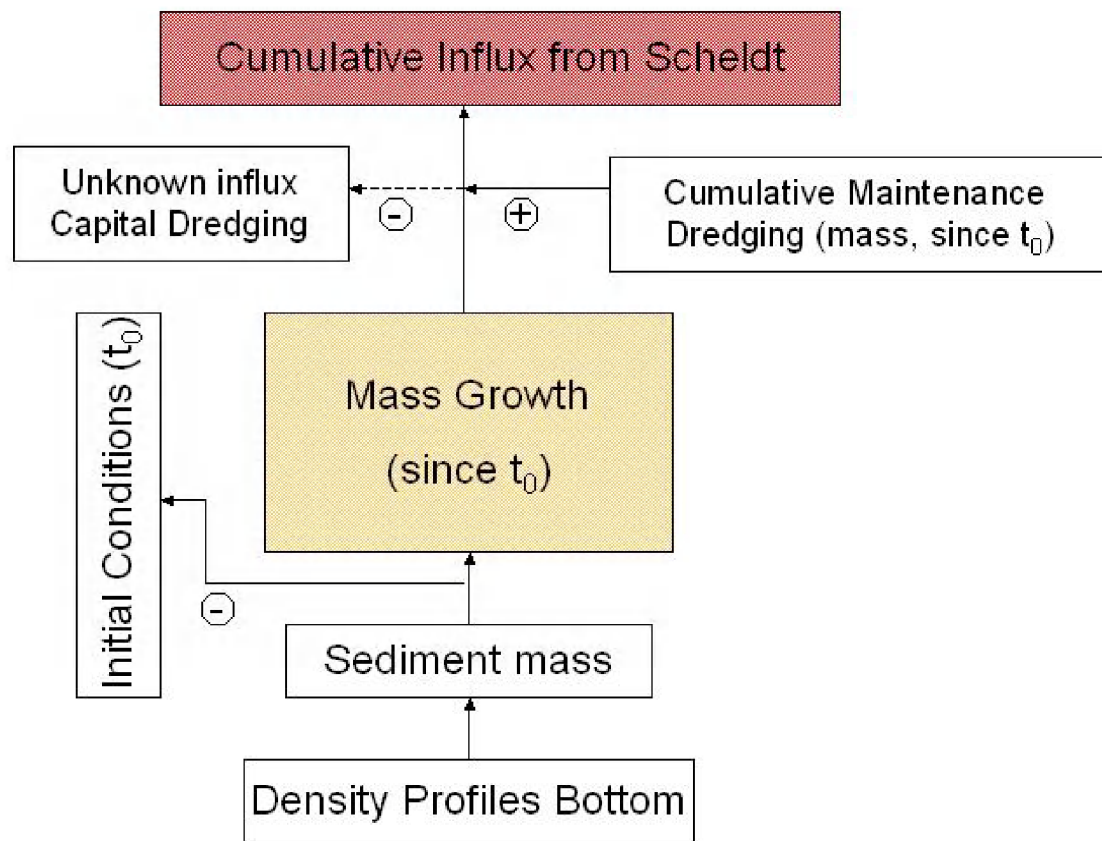


Figure 2-3: Determining a sediment balance

The main purpose of the second part of the study is to gain insight in the mechanisms causing siltation in Deurganckdok. The following mechanisms will be aimed at in this part of the study:

- Tidal prism, i.e. the extra volume in a water body due to high tide
- Vortex patterns due to passing tidal current
- Density currents due to salt gradient between the Scheldt river and the dock
- Density currents due to highly concentrated benthic suspensions

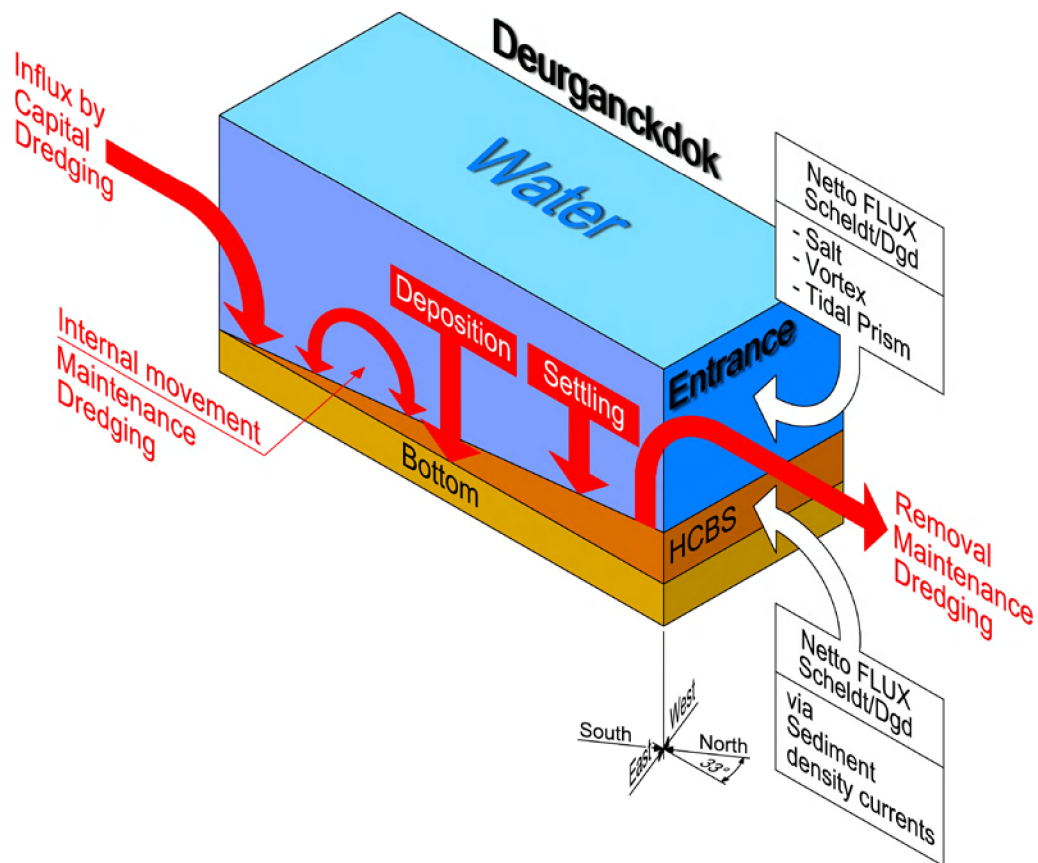


Figure 2-4: Transport mechanisms

These aspects of hydrodynamics and sediment transport have been landmarks in determining the parameters to be measured during the project. Measurements will be focused on three types of timescales: one tidal cycle, one neap-spring cycle and seasonal variation within one year.

Following data are being collected to understand these mechanisms:

- Monitoring upstream discharge in the Scheldt river.
- Monitoring Salt and sediment concentration in the Lower Sea Scheldt at permanent measurement locations at Oosterweel, up- and downstream of the Deurganckdok.
- Long term measurement of salt and suspended sediment distribution in Deurganckdok.
- Monitoring near-bed processes (current velocity, turbidity, and bed elevation variations) in the central trench in the dock, near the entrance as well as near the current deflecting wall location.
- Dynamic measurements of current, salt and sediment transport at the entrance of Deurganckdok.
- Through tide measurements of vertical sediment concentration profiles -including near bed high concentrated benthic suspensions.
- Monitoring dredging activities at entrance channels towards the Kallo, Zandvliet and Berendrecht locks as well as dredging and dumping activities in the Lower Sea Scheldt.
- In situ calibrations were conducted on several dates to calibrate all turbidity and conductivity sensors.

3. MEASUREMENTS

3.1. Depth soundings

The client executes dual-frequency echo-sounder measurements on a frequently basis. F. De Cock (Agentschap voor Maritieme Dienstverlening en Kust – Afdeling Kust) communicated that these measurements are carried out with a 210-33 kC Echo sounder using Qinsy software. The depth sounding measurements are executed in a grid configuration, consisting of sections perpendicular and parallel to the quay wall.

Table 3-1: Overview of the available depth soundings suitable for analysis 01/10/2008 – 31/12/2008

date	type of measurement	signal	Source
13/03/2008*	dual frequency 210-33 kHz	210	Afdeling Kust
11/04/2008	dual frequency 210-33 kHz	210	Afdeling Kust
9/05/2008	dual frequency 210-33 kHz	210	Afdeling Kust
4/06/2008	dual frequency 210-33 kHz	210	Afdeling Kust
15/07/2008	dual frequency 210-33 kHz	210	Afdeling Kust
11/08/2008	dual frequency 210-33 kHz	210	Afdeling Kust
26/08/2008	dual frequency 210-33 kHz	210	Afdeling Kust
3/09/2008	dual frequency 210-33 kHz	210	Afdeling Kust
22/09/2008	dual frequency 210-33 kHz	210	Afdeling Kust
6/10/2008	dual frequency 210-33 kHz	210	Afdeling Kust
20/10/2008	dual frequency 210-33 kHz	210	Afdeling Kust
7/11/2008	dual frequency 210-33 kHz	210	Afdeling Kust
28/11/2008	dual frequency 210-33 kHz	210	Afdeling Kust
15/01/2009	dual frequency 210-33 kHz	210	Afdeling Kust
11/02/2009	dual frequency 210-33 kHz	210	Afdeling Kust
03/03/2009	dual frequency 210-33 kHz	210	Afdeling Kust
17/03/2009	dual frequency 210-33 kHz	210	Afdeling Kust

*= reference situation depth soundings: t_{0e}

To calculate a sediment balance it is necessary to analyse the measurements in stationary situation, with no alteration in boundary conditions being dredging operations. Every period is characterized by a depth sounding measurement before ('inpeiling') and one after ('uitpeiling').

A number of analyses were done using the depth soundings in Table 3-1. The raw depth sounding data was processed in ESRI ArcGIS. The 210 kC signal is used in the following analyses as it gives an indication of the water-bed interface.

A reference level was chosen from all depth sounding measurements. The previous annual report used the earliest measurement as reference level, i.e. 24 March 2006. In February 2008, the capital dredging of the dock was finalized such that a significant larger measurement area became applicable. A new reference situation, initial condition t_{0e} , therefore seemed plausible for which the depth sounding of 13 March 2008 was selected. However, when dealing with different measurement years (2007-2009), a single reference situation needed to be selected; it was decided to use the design depth of the dock.

A number of analyses were performed in ArcGIS 9 and a Matlab environment to produce maps, figures and tables with relevant information concerning elevation, elevation changes and volumetric growth (§4.2 to §4.4).

3.2. Density measurements

Density measurements are necessary to calculate a sediment balance of dry weight of sediment per surface unit. In order to measure bulk densities, two devices were used, i.e. the Navitracker and the Densitune. The former device was applied until the end of August 2008, after which the Densitune was used. The application of different devices is related to a contract change for density measurements in the harbour of Zeebrugge. Some information on both devices is given below.

3.2.1. Navitracker

The Navitracker is a patented system to measure the density of fluid mud suspensions, by means of a gamma-density meter. It has been used by the Flemish authorities over 20 years to determine the nautical bed for the port of Zeebrugge.

The Navitracker system can be operated by a computer controlled winch to tow it through the mud (horizontal mode). The Navitracker is equipped with the following sensors:

- The Gamma ray density sensor, mounted on a fork-like tow fish, gives density information.
- The depth sensor gives information of the depth of the sensor.
- The position of the fish is calculated out of the length of the winch cable. Together with the position of the tow fish, following the density level, a dual frequency echo sounder is used to map the hard bottom and the top of the mud. With a speed of 2 to 3 knots, large areas can be covered.

For these measurements the Navitracker was used in a vertical profiling mode, with the probe in vertical position in order to penetrate the soft bottom. The vertical density profiler is used to measure density in thick mud layers with high densities.

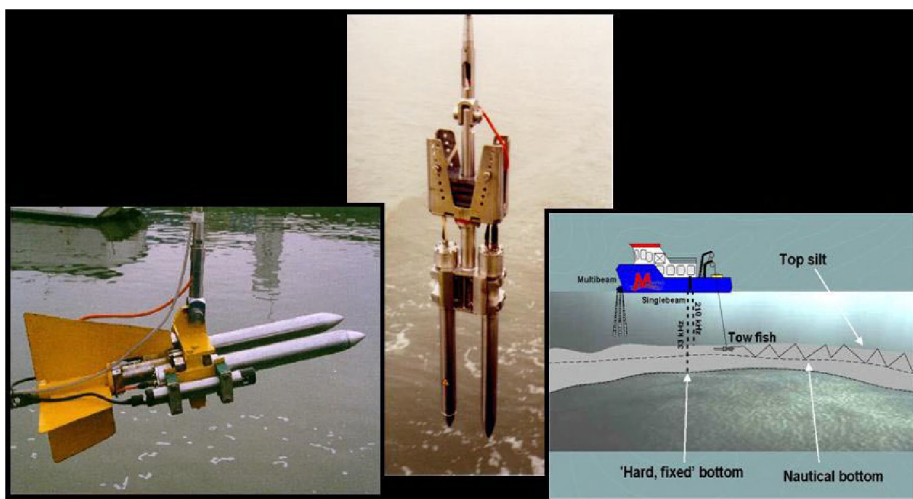


Figure 3-1: Navitracker

The Navitracker was calibrated in the laboratory for measuring high densities, formed by very dense water-mud mixtures. For this reason the Navitracker did not detect subtle variations in density caused by changes in salinity. The density deviated from 1.000 ton/m³ only in the presence of a high concentration of sediments.

The Navitracker has a sampling frequency of 10 measurements per second.

3.2.2. DensiTune

The DensiTune is a patented system to determine the internal density of liquid silt layers. The measurement system is based on the “tuning fork” principles. One of the legs vibrates with a specific frequency, and the other leg responds with a frequency which depends on the density of the medium in which the DensiTune is inserted. The system measures vertical density profiles in liquid silt layers while lowered.

From previous research (IMDC, 2005), it could be observed that the DensiTune measured higher densities at a specific depth in comparison to the Navitracker. DensiTune therefore identifies densities less deep than Navitracker, i.e. around 25 cm.

3.2.3. Data analysis

The resulting density profiles were processed in a Matlab environment and visualized in Matlab and ESRI ArcGIS. Equal density layers were computed. Volume and density information was used to calculate masses of silt. All masses are given in ton of dry solids (TDS) characterized by a density of 2.65 kg/dm³. The water-bed interface is defined as the layer with a density of 1.03 kg/dm³.

To calculate the local sediment mass in the dock, or zones of it, each measured density profile was integrated over its depth. The unmeasured part of the water column, covering the distance between the deepest sampling point and the design depth, needed to be estimated (if not measured). This sediment concentration was estimated as being constant for the unmeasured depth range and being proportional to the deepest measured concentration. As proportionality, a value of 1.02 was applied which was determined from a preliminary analyses of the density profiles near the bottom (measured by Navitracker). A horizontal distribution of the sediment mass was subsequently obtained by cubic interpolation between the profiling locations onto a grid with a resolution of 5 m.

In this measurement campaign, Navitracker measurements were performed on:

- 28 April 2008;
- 5 June 2008;
- 11 August 2008;
- 26 August 2008

DensiTune measurements were performed at the following dates:

- 11 September 2008;
- 20 October 2008;
- 6 November 2008;
- 30 January 2009; and
- 12 March 2009.

As a reference situation the empty dock will be used at the design depth. The design depths for the different zones are shown in Table 3-2. The different zones are described in §4.1.

Table 3-2: Reference Situation Density Measurements (t_{0d})

Zone	Design Depth (mTAW)
Central trench	-19
Berthing zones and transition zones to central trench	-17
Sill	-13.5
Transition sill to navigation channel	Not applicable

3.3. Maintenance Dredging Data

All maintenance dredging (except sweep beam) activities in Deurganckdok were collected in the BIS-system. This system gives a standardised output per week, that states the weight, volume and V^1 removed/dumped in every 5*5m grid cell in the area. In case the density of the dredged sediment in the hopper bin is larger or equal to 1.6 kg/dm³, V' is equal to the volume in the bin. In case the density is smaller than 1.6 kg/dm³, V' is equal to the reduced volume which is defined as the volume the dredged sediment would have in case the density would be equal to 2 kg/dm³ (AWZ 2000). These dredged volumes are important to have an overall view on the sediment balance. Maintenance dredging occurred between 11 February and 2 March 2009.

The available data on sweep beam activity is not collected in the BIS-system. However, the mode of operation of the sweep beam is explained:

- On the sill (zone 1 & 2): the sediment is swept into the Lower Sea Scheldt
- Inside the dock: the sweep beam sweeps the berthing zones next to the quay walls and moves sediment into the central trench

Therefore an overview is given in Table 3-3 of where and when a sweep beam dredger was working in Deurganckdok (DGD) or on the sill of Deurganckdok (sill DGD) for the period March 2008-2009.

Table 3-3: Sweep beam maintenance dredging activities in Deurganckdok and on the sill of Deurganckdok between April 2008 and March 2009 (source: Afdeling Maritieme Toegang)

From	Till	Duration (days)	Location
1/04/2008	5/04/2008	5	northern/southern quays (zones A-D)
7/04/2008	9/04/2008	3	Sill DGD + northern/southern quays (zones A-D)
14/04/2008	16/04/2008	3	Sill DGD + sediment bump at 2/3'rd of the dock
21/04/2008	21/04/2008	1	Sill DGD
28/04/2008	28/04/2008	1	Sill DGD
5/05/2008	5/05/2008	1	Sill DGD
19/05/2008	20/05/2008	2	Sill DGD
26/05/2008	27/05/2008	2	Sill DGD
2/06/2008	2/06/2008	1	Sill DGD
23/6/2008	23/6/2008	1	Sill DGD

¹ V' = Reduced Volume

<i>From</i>	<i>Till</i>	<i>Duration (days)</i>	<i>Location</i>
30/6/2008	30/6/2008	1	Sill DGD
7/07/2008	7/07/2008	1	sill DGD
14/07/2008	14/07/2008	1	sill DGD + northern/southern quays (first third of dock from entrance)
16/07/2008	17/07/2008	2	sill DGD + northern/southern quays (first third of dock from entrance)
22/07/2008	26/07/2008	5	sill DGD + northern/southern quays (first third of dock from entrance)
28/07/2008	28/07/2008	1	Sill DGD
5/08/2008	5/08/2008	1	Sill DGD
11/08/2008	11/08/2008	1	Sill DGD
18/08/2008	18/08/2008	1	Sill DGD
25/08/2008	30/08/2008	6	sill DGD + northern/southern quays (first half of dock from entrance)
1/9/2008	1/09/2008	1	Sill DGD
5/09/2008	6/09/2008	2	Sill DGD
8/09/2008	11/09/2008	4	Sill DGD
17/09/2008	20/09/2008	4	sill DGD + northern/southern quays (first half of dock from entrance)
22/09/2008	27/09/2008	6	sill DGD + northern/southern quays (first four-fifth of dock from entrance)
6/10/2008	11/10/2008	5	sill DGD
13/10/2008	18/10/2008	6	sill DGD + northern/southern quays (first two-third of dock from entrance)
20/10/2008	24/10/2008	5	sill DGD + northern (zoneA) / southern (zones A-B) quays
27/10/2008	31/10/2008	5	sill DGD + northern/southern quays (zones A-D)
3/11/2008	8/11/2008	6	sill DGD + northern/southern quays (zones A-D)
17/11/2008	18/11/2008	2	Sill DGD
24/11/2008	25/11/2008	2	Sill DGD
9/12/2008	12/12/2008	4	Sill DGD
15/12/2008	20/12/2008	6	Sill DGD
5/01/2009	5/01/2009	1	sill DGD
12/01/2009	12/01/2009	1	sill DGD
19/01/2009	19/01/2009	1	sill DGD
28/01/2009	29/01/2009	2	sill DGD
2/02/2009	3/02/2009	2	sill DGD
9/02/2009	10/02/2009	2	sill DGD
16/02/2009	17/02/2009	2	sill DGD
23/02/2009	24/02/2009	2	sill DGD
2/03/2009	3/03/2009	2	sill DGD
10/03/2009	11/03/2009	2	sill DGD
16/03/2009	16/03/2009	1	sill DGD
23/03/2009	24/03/2009	2	sill DGD
30/03/2009	31/03/2009	2	sill DGD

3.4. Overview of activities and processes

To facilitate the data analysis in Chapter 5, Table 3-4 gives an overview of all conducted measurements and human interferences on the natural siltation in the dock. This makes it possible to identify periods of undisturbed siltation of specific zones in the dock, i.e. without any dredging operations. In this way, it is possible to distinguish between the "natural" siltation and "gross" siltation; the latter indicates that human interferences are included in the measurement results too. This is especially important for the determination of the natural volumetric siltation rate, as discussed in §5.2.

Table 3-4: Overview of measurements and dredging activities in Deurganckdok

activity	April 07		May 07		June 07		July 07		August 07		September 07	
	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 31	1 - 15	16 - 30
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												

activity	October 07		November 07		December 07		January 08		February 08		March 08	
	1 - 15	16 - 31	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 31	1 - 15	16 - 28	1 - 15	16 - 31
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												

4. SEDIMENT BALANCE ANALYSES

4.1. Project Area: (Sub)Zones and Sections

To calculate volumes and masses for the sediment balance of Deurganckdok it is necessary to subdivide it into 5 zones:

- Zone 1: Between the sill and the navigation channel in the Lower Sea Scheldt.
- Zone 2: Sill at entrance DGD designed at -13.5 m TAW.
- Zone 3: Central trench in DGD with a design depth at -19 m TAW (including slope to -17 m TAW)
- Zone 4: Transition between central trench and berthing zones with a design depth at -17.00 m TAW: on both (North (N) and South (Z)) sides of DGD (55 m wide).
- Zone 5: Berthing zones next to quay walls on both (North (N) and South (Z)) sides of DGD (40 m wide)

Zones 3, 4 and 5 are subdivided into subzones A, B, C, D and E. This is shown in Figure 4-1.

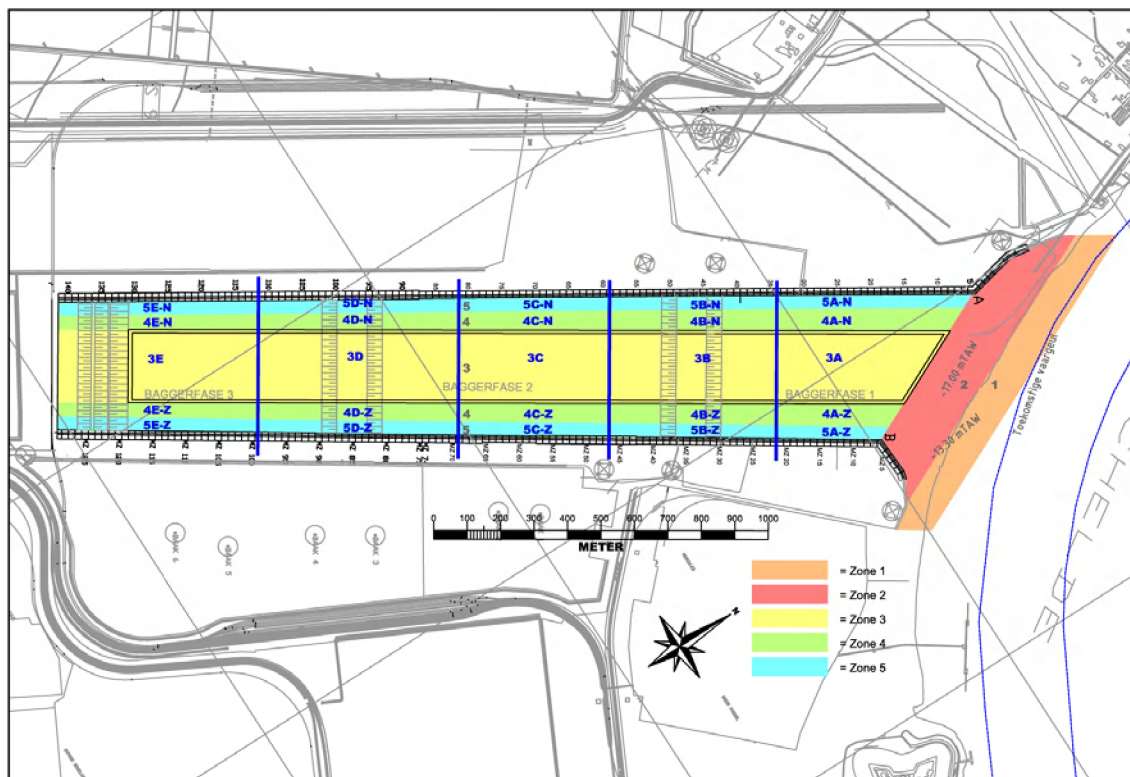


Figure 4-1: Deurganckdok: Zones and Subzones

Sections are defined for this whole area (Figure 4-2):

- D sections are oriented perpendicular to the quay walls inside the dock and parallel to the navigation channel outside the dock (sill and Scheldt). The origin of the sections is taken on the quay wall at the left bank (West side) looking outwards.
- L Sections are oriented along the centerline of the dock and run from the navigation channel towards the inland end of the dock, in anticipation of the realisation of the third phase of Deurganckdok. The origin is situated on the intersection between each L section and section D10.

The coordinates of these sections are given in Table 4-1.

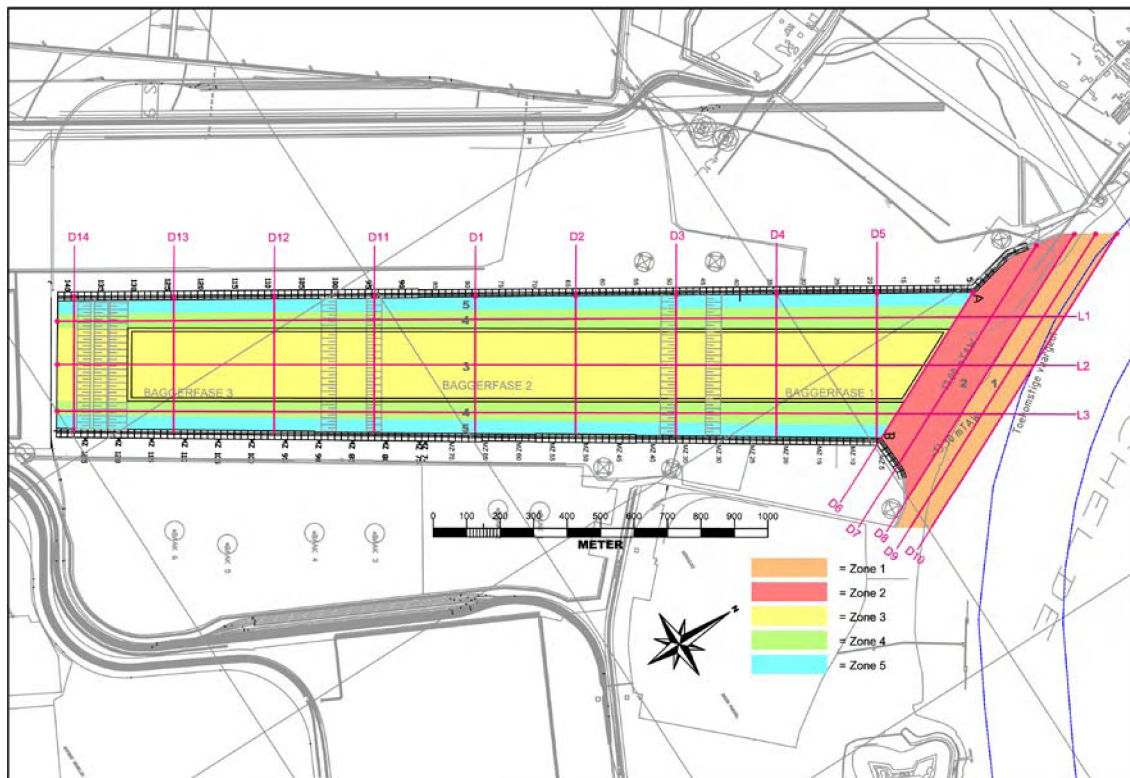


Figure 4-2: Deurganckdok: D and L Sections

Table 4-1: Coordinates of Sections [UTM ED50]

Name	Origin		End	
	Easting	Northing	Easting	Northing
D Sections				
D1	587773	5683253	588123	5683037
D2	587929	5683510	588283	5683290
D3	588084	5683767	588444	5683544
D4	588239	5684023	588604	5683797
D5	588394	5684280	588765	5684051
D6	588542	5684526	588772	5684062
D7	588521	5684761	588864	5684068
D8	588552	5684875	588972	5684027
D9	588585	5684930	589047	5683994
D10	588617	5684984	589081	5684047
D11	587615	5682997	587962	5682783
D12	587459	5682742	587802	5682529
D13	587300	5682487	587642	5682276
D14	587143	5682232	587482	5682023
L Sections				
L1	588748	5684720	587180	5682151
L2	588825	5684565	587290	5682082
L3	588901	5684410	587409	5682007

4.2. Depth of the water-bed interface (210 kC)

This is shown as a GIS grid map generated directly from the depth sounding data. The initial and final bathymetries are shown in Figure 4-3, and the enlarged format can be found in APPENDIX A. Only these depth soundings are considered in this report because the annual trend is aimed at. All other collected depth sounding dataset can be found in IMDC (2009a-d).

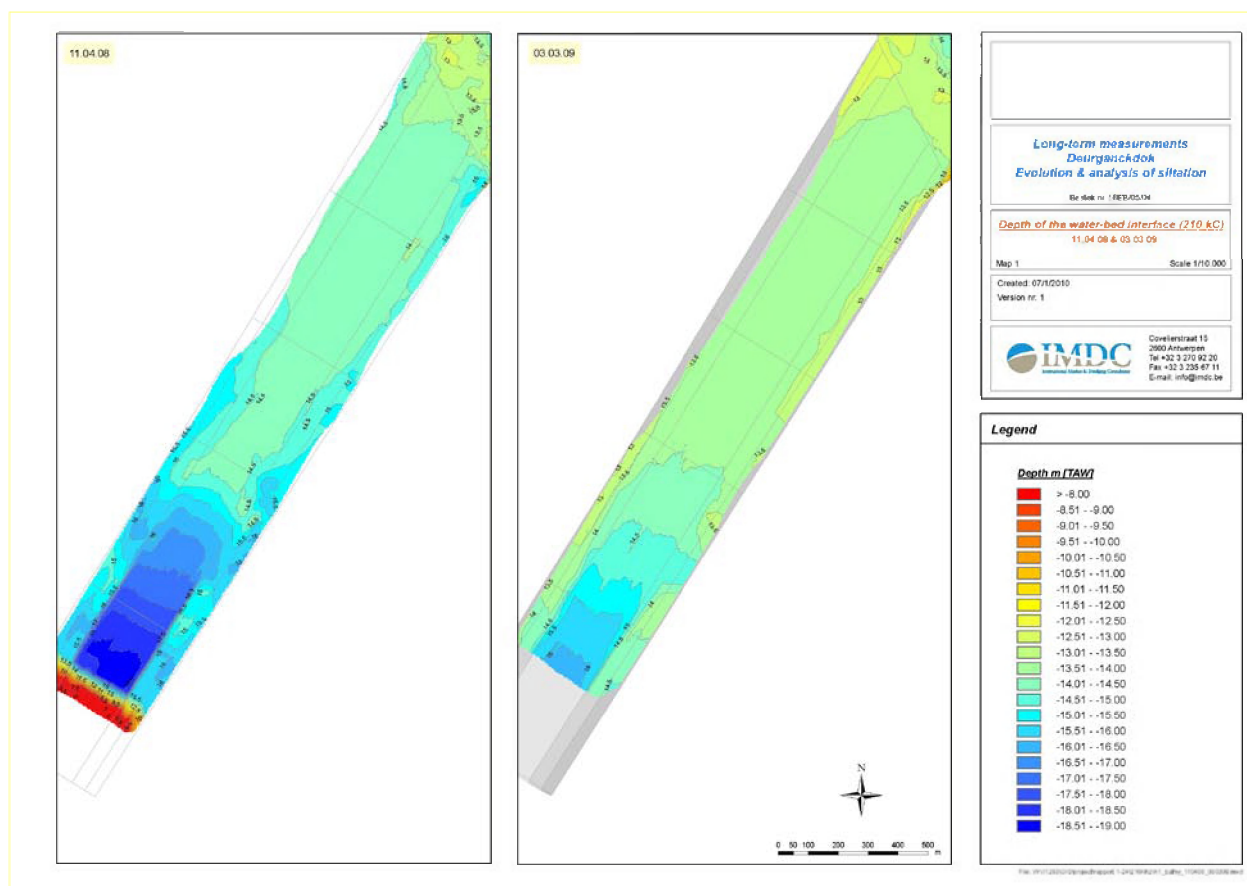


Figure 4-3: Example of a map showing depth of water-bed interface (210 kC) for 11/4/08 and 3/3/09

4.3. Evolution of water-bed interface (210 kC)

GIS grid maps show the difference charts for every depth sounding in relation to a reference situation. Figure 4-4 shows such a difference chart covering the period of one year. Note that intermediate difference charts can be found in IMDC (2009a-d).

The difference in depth between subsequent depth soundings for 210 kC measurements is also shown for all predefined sections. Graphs show a colour plot with Time in the X-axis, Distance to origin of section in the Y-axis and the depth of the top layer [m TAW] as a colour plot.

The origin for the D sections is the northern quay wall. The origin of the L sections is the intersection between the L section with the Scheldt edge of zone 1. An example for sections is shown in Figure 4-5. The description of the sections is given in § 4.1.

Maps and graphs are shown in APPENDIX B.

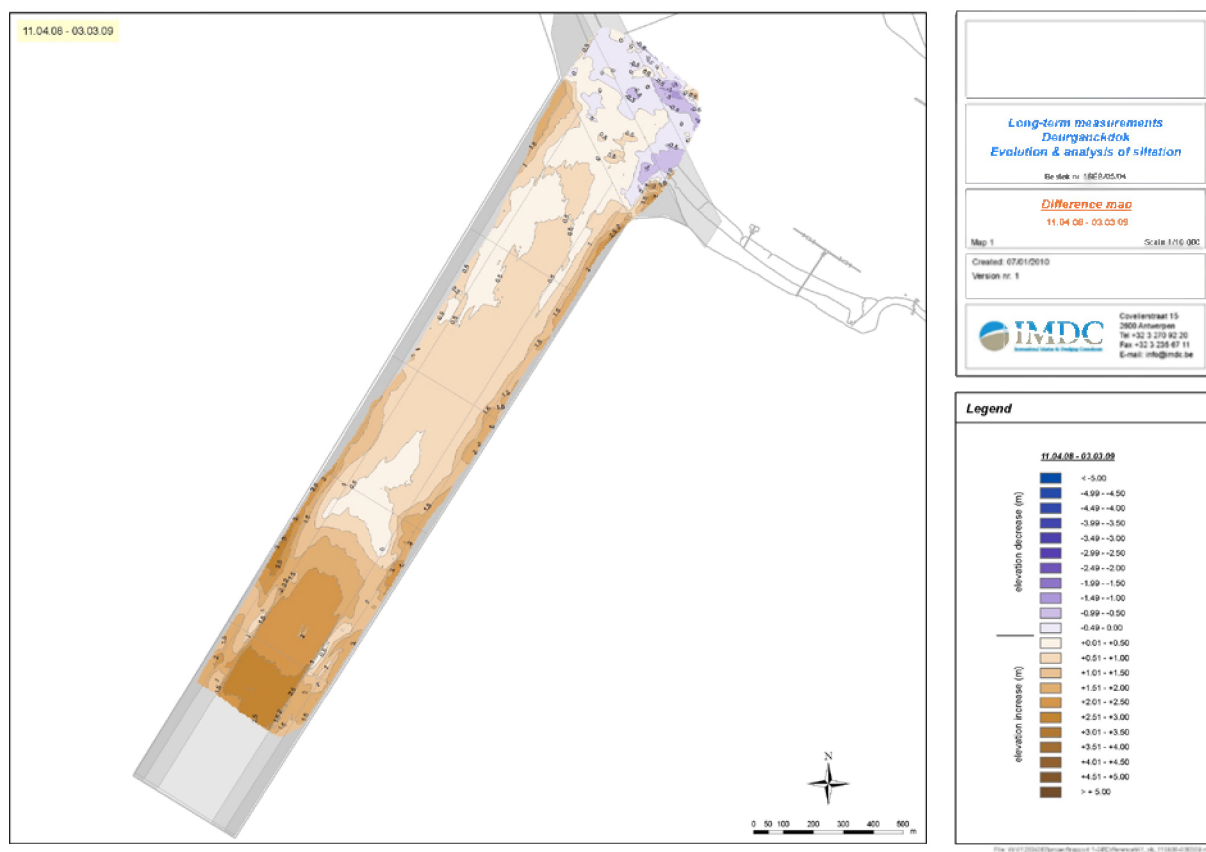


Figure 4-4: Difference charts of the depth sounding on 3/03/09 in reference to 11/04/08

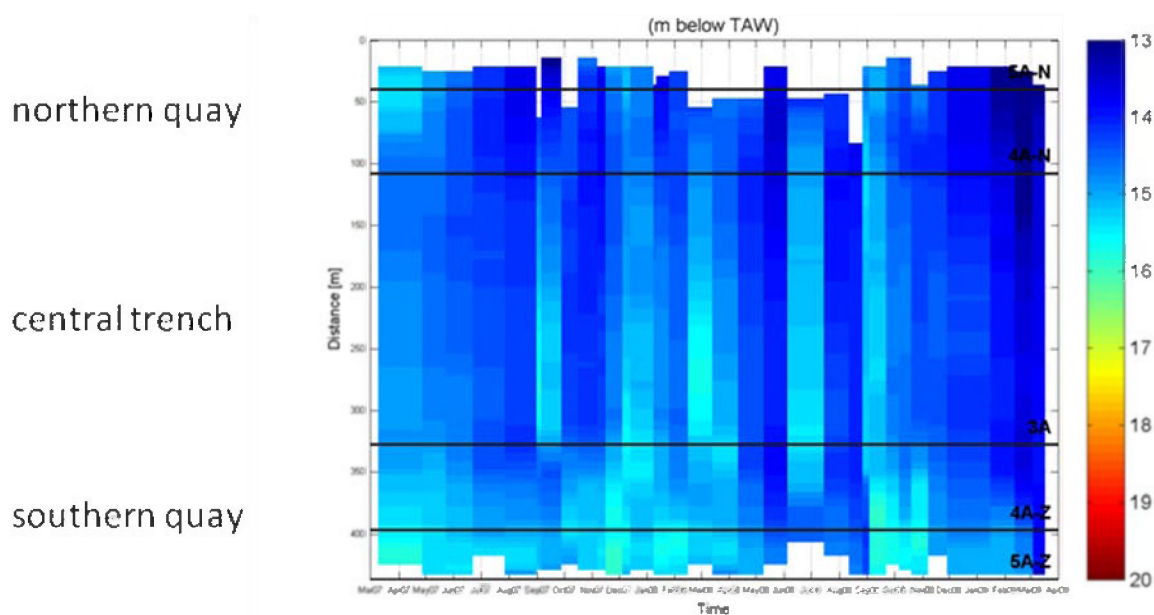


Figure 4-5: Graph of Evolution of the water-bed interface (210 kC) for section D5

4.4. Volumetric siltation rates [cm/day] in different zones and sections

A table with monthly average siltation rates for all (sub)zones is also given in APPENDIX C.

Graphs in APPENDIX C show two parameters:

- Average siltation rates [cm/day]: The average siltation rate is the difference in the depth of the water-bed interface and is calculated only for those zones and subzones that have at least a 50% surface area overlap between two subsequent depth soundings. This is done for all successive depth soundings. It is shown in the plots as a bar and is positive for sedimentation and negative for erosion or removal.
- Cumulative bed level change [m]: an initial situation (t_0) is used as baseline. Starting from this reference level the evolution of the average bed level elevation is shown for the particular (sub)zone.

Dredging events from the BIS system are marked on each of these graphs. This is computed for all zones, subzones, sections and Deurganckdok as a whole. As an example we show siltation rate and cumulative bed level change for zone 3a in Figure 4-6.

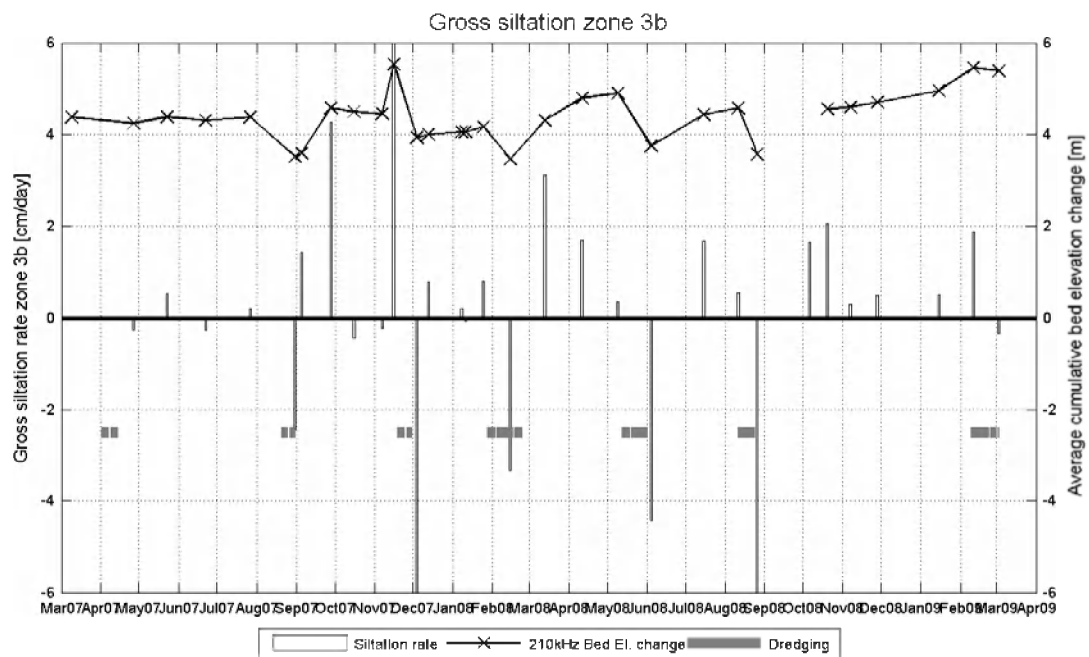


Figure 4-6: Volumetric siltation rate for zone 3B

4.5. Average net mass evolution

The average net mass growth [TDS/m²] in all zones and subzones is based on density profile measurements (measured sediment mass). The actual sediment mass present in the dock and measured by density profiling does not take the removed dredged material into account. The mass removed by dredging can be computed from BIS data (dredged material mass). Only zones spatially covered for 50% and more by density measurements are considered for sediment mass calculations. Unmeasured parts of these zones retrieve a value for the calculations (in order to close the mass balance of the zone), being the average mass per square meter based on the actual density measurements of the considered zone.

By adding measured mass to dredged material mass, the total accumulated mass and hence the growth can be shown (see Figure 4-7). In case this *total mass* can be computed for the complete dock (or a zone) for two subsequent measurements, an estimation of the net sediment flux into the dock (or zone) during the intermediate period is given by the difference of both total mass values. The net sediment flux into an area can also be defined as the net mass growth (kg/m^2 or Ton Dry Solids/ m^2). Division of the net mass growth of a zone by the number of days in between measurements leads to the averaged net mass growth rate. Note that the last measurement of the previous measurement campaign, i.e. 6 November 2008, is added to the present data series in order to have a good view on the net mass evolution.

Averaged net mass growth rate [$\text{kg/m}^2/\text{day}$] is computed for each zone and subzone and is shown in APPENDIX D. An example is shown for zone 3C in Figure 4-8.

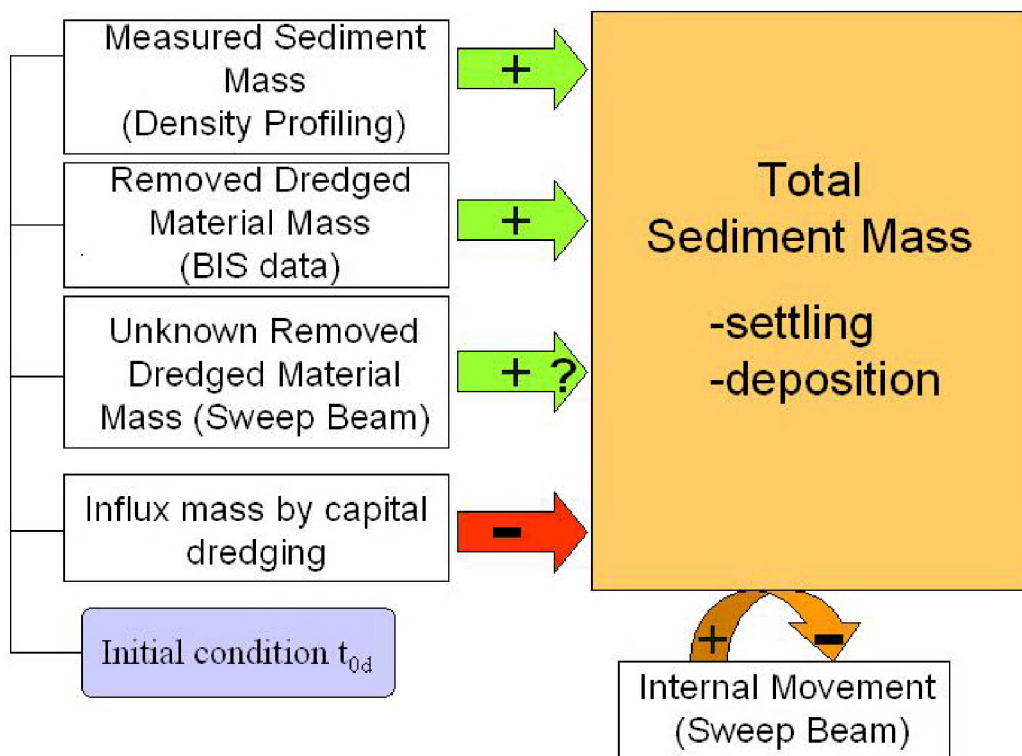


Figure 4-7: Flow chart with different elements contributing to total sediment mass for (sub)zones and total area

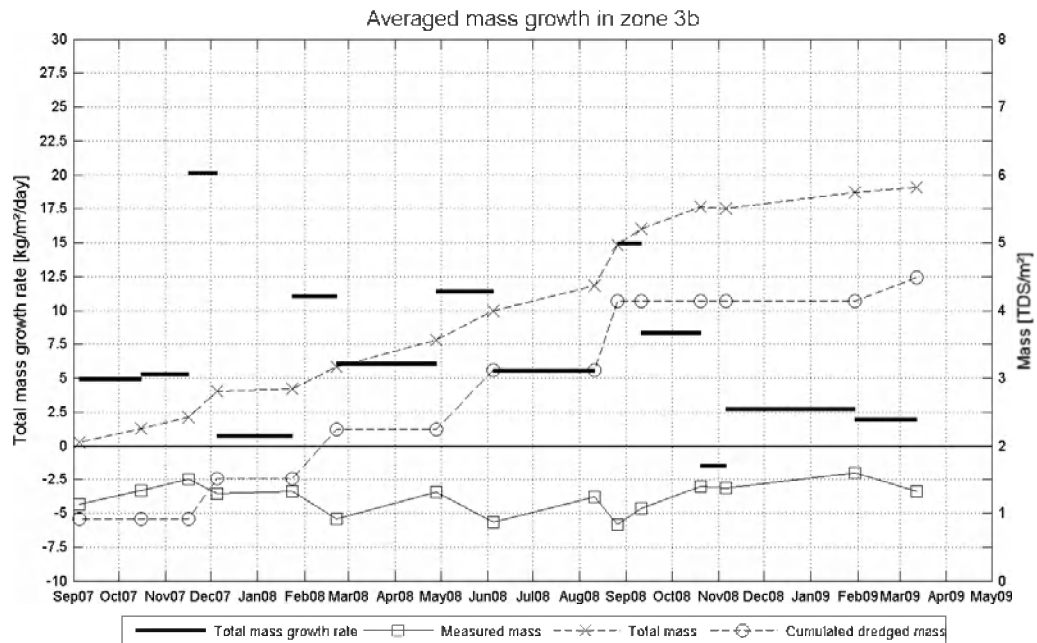


Figure 4-8: Example of averaged mass growth and mass evolution for subzone 3B

Clearly, the sediment mass balance is incomplete because sediment fluxes cannot be derived from the sweep beam data (of which no mass or volume information is available). Internal movements of sediment by the sweep beam (berthing zones to central trench) and removal of sediments from the sill into the Lower Sea Scheldt definitely influence the mass balance for (sub)zones and the total dock.

A table in APPENDIX D gives an overview for all zones and subzones for the following parameters, and this only if data is available for at least 50 % of this (sub)zone:

- Measured Sediment mass [TDS/m²]
- Dredged Material mass (absolute) [TDS]
- Total Sediment mass [TDS/m²]
- Growth rate [kg/m²/day]
- Total area [ha]
- Covered area [ha]: area covered by density profiles
- Percent of zone covered [%]

5. PRELIMINARY ANALYSIS OF THE DATA

5.1. Introduction

This chapter discusses the measurements on a yearly basis. Three-monthly trends that are already covered in previous reports are not dealt with, cf. IMDC (2009a-d). Instead, more long-term evolutions are focused, or evolutions and phenomena bridging these three-monthly periods.

With respect to the data analysis and its interpretation, it is important to keep in mind the different contributing terms in the sediment mass balance of each defined zone in the Deurganckdok:

$$\frac{dM_s}{dt} = R_{\text{siltation}} - R_{\text{erosion}} \pm R_{\text{sweepbeam}} - R_{\text{maintenance}} \pm R_{\text{capitaldredging}}$$

with:

- M_s = local amount of sediment mass [TDS]
- $R_{\text{siltation}}$ = sediment mass flux from siltation [TDS/day]
- R_{erosion} = sediment erosive flux [TDS/day]
- $R_{\text{sweepbeam}}$ = mass flux from sweep beam dredging operations [TDS/day]
- $R_{\text{maintenance}}$ = mass flux from maintenance dredging [TDS/day]
- $R_{\text{capitaldredging}}$ = mass flux from capital dredging [TDS/day]

It is important to note that observations of bed level changes (from depth soundings and density measurements) refer to the gross effect of all contributing terms. Strictly seen, the siltation rate is only observed when no other process takes place at a specific location. With respect to the erosive flux, it is expected that flow velocities and shear forces are so low that erosion can be neglected from the mass balance.

The siltation in Deurganckdok can in fact be described in both a volumetric and a densimetric manner. The sediment volume is difficult to interpret because sediment volume is not conservative, i.e. sedimentation and consolidation increases the local sediment concentration. Sediment mass is therefore a better way of studying the siltation in the dock. However, due to the vast amount of depth soundings performed in this study and their additional information to density measurements, it is interesting to look at these data too.

Firstly, the 'volumetric siltation rate' is computed from the temporal bed level change as obtained from the depth soundings. Because different processes result in these observations, it is crucial to understand what is meant by the computed 'volumetric siltation rate'. For that reason, some definitions are considered important for the data interpretation:

- natural siltation rate: is computed from a time period in which only siltation occurs and no other process;
- gross siltation rate: is computed from a time period in which other processes occur besides the natural siltation;

The difference between these two definitions is schematised in Figure 5-1. Note that the gross siltation rate may also be larger than the natural one due to e.g. sweep beam activities, which may import sediment into the considered dock zone.

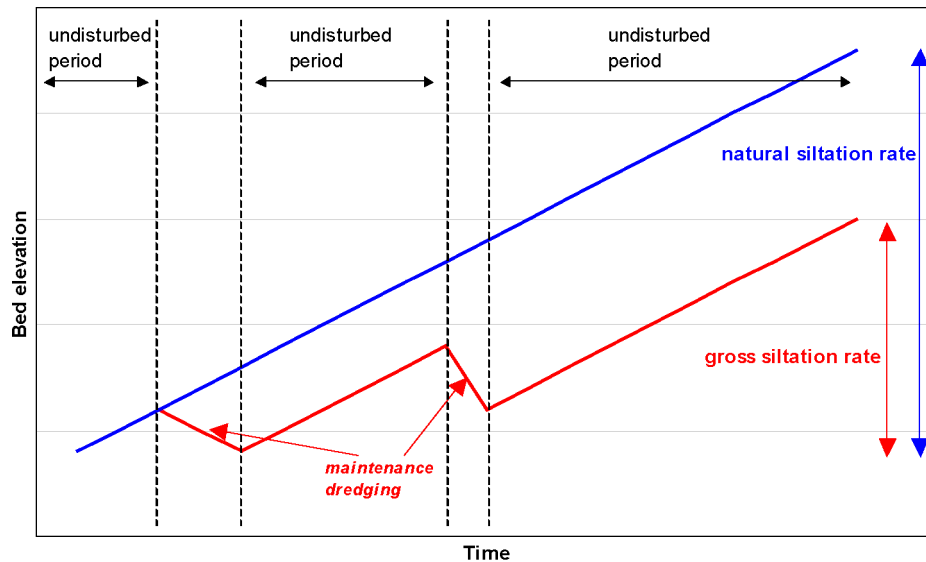


Figure 5-1: difference between natural and gross (volumetric) siltation rate

Secondly, the sediment mass distribution and its temporal evolution are studied. Here, densimetric growth rates can be calculated for the different dock zones. Because dredged mass is known, the sediment mass settled in a specific time frame can be computed, similar to the volumetric siltation rate as shown in Figure 5-1. Hence, according to Figure 5-2, the total sediment mass deposition rate (i.e. the densimetric growth rate) is to be computed as:

$$R_{\text{siltation}} = \frac{M_{\text{meas},2} - M_{\text{meas},1} + M_{\text{dredge}}}{t_2 - t_1}$$

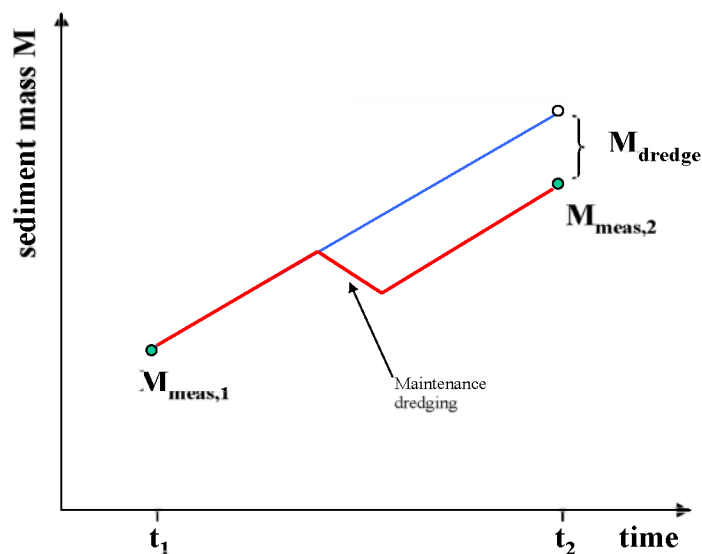


Figure 5-2: Principle of total deposited sediment mass calculated from the measured mass M_{meas} and dredged mass M_{dredge}

Seen the nature of collected data and their relation to the sediment balance, the chapter below will discuss the following topics:

- changes in elevation of the water-bed interface, i.e. the volumetric siltation rate;
- the accumulation of sediment mass in the dock, i.e. the densimetric siltation rate; and
- the dredged sediment mass.

5.2. Volumetric analysis

Depth sounding data was processed to show the evolution of the bed level as detected by the 210 kHz sounder. If more than 50% of the area of a (sub)zone was covered, an average bed level change was calculated. These data can be found in APPENDIX C.

Below, the natural and the gross yearly averaged siltation rates are discussed.

5.2.1. Gross yearly averaged siltation rate

To compute a gross yearly averaged siltation rate for every zone of the dock, the subsequent bed level measurements are used. This gross siltation rate is valid for the time period between these subsequent depth soundings. As a consequence, effects from dredging activities are included in these results. The obtained siltation rates therefore refer to a *gross yearly averaged siltation rate*. The results are shown in Table 5-1, which indicates that, in general, gross siltation rates are very small and positive. The mean gross siltation rate measured 0.2 cm/day, averaged over zones A, B and C. The temporal evolution of the sediment bed level indeed indicates that the levels observed in April 2008 are smaller than those of March 2009 (see Appendix B.1), which is in agreement with the positive value for mean gross siltation rate. Table 5-1 also shows that the gross siltation rate generally increases when going further inside the dock. This is in contradiction to the natural siltation rate as discussed in §5.2.2.

Table 5-1: gross yearly averaged siltation rates for every zone

ZONE	gross yearly averaged siltation rate [cm/day]
3a	0.14
3b	0.18
3c	0.19
3d	0.48
3e	0.51
4Na	0.23
4Nb	0.18
4Nc	0.34
4Nd	0.41
4Ne	0.91
4Za	0.21
4Zb	0.23
4Zc	0.29
4Zd	0.35
5Na	0.46
5Nb	0.50

ZONE	<i>gross yearly averaged siltation rate [cm/day]</i>
5Nc	0.57
5Nd	0.63
5Za	0.53
5Zb	0.55
5Zc	0.49
5Zd	0.51

5.2.2. Natural siltation rate

The observed siltation rates in §5.2.1 are the result of many processes of which natural siltation is only one. Human interferences such as maintenance and sweep beam dredging indeed largely influence the sediment balance of the dock. Whereas the maintenance dredging removes sediment from the dock, sweep beam dredging along the quays simply relocates the sediment towards the central trench (where it is removed by a subsequent maintenance dredging operation).

Quantifying the natural siltation is important as it determines the necessary dredging frequency. To do so, it is essential to identify undisturbed periods in which no human interferences took place. From the observed bed elevation trend during such a period, the natural siltation rate can be calculated. Remark that siltation rates depend on local bathymetric and hydrodynamic conditions. Hence, it is important to acknowledge that calculated siltation rates cannot be generalised. The calculations however return an order of magnitude for the siltation rates and allow the investigation of any spatial distribution of this process variable.

When investigating the siltation in zones A - C (cf. APPENDIX C.4), four periods can be identified being undisturbed by maintenance dredging, i.e.

- Period 1: 11/4/2008 – 9/5/2008;
- Period 2: 4/6/2008 – 11/8/2008;
- Period 3: 26/8/2008 – 20/10/2008; and
- Period 4: 7/11/2008 – 15/1/2009.

Comparing Table 5-1 with Table 5-2 reveals that the natural siltation rate is larger than the gross yearly averaged siltation rate. This is simply due to the absence of dredging activities. Table 5-2 also clearly indicates that natural siltation rates in the central trench, observed in Period 2 and Period 3, are significantly larger than those of the other two observation periods. This can be attributed to the intensity of dredging. Periods 2 and 3 showed dredging activities of a couple of days prior to the time periods of analysis, whereas Periods 1 and 4 experienced (i) dredging taking place more than two weeks before the measurements, and (ii) dredging amounts in the order of 80,000 TDS being smaller than those for the other two periods. As a result, the initial bed level in the central trench was lower for Periods 2 and 3 than for the other periods; it is therefore assumed that the trench acted more as a sediment trap in which sediment rapidly accumulated and resulted in larger siltation rates. Siltation rates in Period 3 were much larger than for Period 2 because more than 2.5 times the dredged mass of Period 2 was removed.

Table 5-2 also indicates that the natural siltation rate decreased when going from the sill to the back-end of the dock, although it was not as obvious as from previous measurements (cf. IMDC, 2007n). A gradient in the transverse direction was only clear for (again) Periods 2 and 3. Such a transverse trend could also be observed in the period April 2006 – March 2007 (IMDC, 2007e).

In 2004, sediment transport simulations of Deurganckdok were performed in order to investigate natural siltation rates (IMDC, 2004). The applied mathematical model indicated that the first one third of the dock, near the Scheldt, was characterised with a siltation rate of 1.4 cm/day and decreased when going more inside the dock. This spatial trend of siltation rates inside the dock is similar to the present observations in Periods 2 and 3, being unaffected by preceding dredging actions.

Further, the hydrodynamic sediment transport model returned an estimation of the sedimentation volume to be dredged annually. It was calculated at approximately 4.3 million m³/year if the sediment is dredged immediately (at a bulk density of around 1.15 kg/l) after sedimentation. This results in an area-averaged mean volume of 3.4 m³/m².year to be dredged. The actual observations return a value of 2.4, 4.0, 4.6 and 2.6 m³/m².year when using the natural siltation rates for Periods 1-4 respectively. Clearly, an absolute correspondence between the simulation study and the actual measurements is not present. The order of magnitude and the trends are however quite similar.

Table 5-2: natural siltation rates obtained from undisturbed measurement periods

ZONE	Natural siltation rates [cm/day]			
	11/4/08 - 9/5/08	4/6/08 - 11/8/08	26/8/08 - 20/10/08	7/11/08 - 15/1/09
3a	0.49	1.59	1.38	0.63
3b	0.35	1.22	1.77	0.51
3c	0.25	0.80	1.85	0.61
3d	0.77	0.31	1.17	1.22
4Na	1.86	1.03	1.08	1.09
4Nb	0.77	0.89	0.92	0.79
4Nc	0.97	0.67	0.70	0.90
4Nd	0.18	0.18	0.23	0.98
4Za	1.70	1.37		0.92
4Zb	1.09	1.00		1.21
4Zc	0.59	0.23	0.08	0.76
4Zd	0.06	0.11	0.22	0.54

5.3. Densimetric siltation rate

The volumetric siltation rate, computed from 210 kHz depth sounding profiles, does not reveal the amount of mass that settled. Information on the consolidation process remains unknown too. For that reason, a densimetric analysis is performed as well. Below, both the dredging and the sediment mass accumulation in the dock are discussed.

5.3.1. Dredged sediment mass

From the BIS data (see Table 5-3), it can be concluded that almost 1.1 million TDS was dredged over the entire measurement period. This is approximately 14.5% more sediment mass withdrawn from the dock in comparison with the corresponding measurement period of 2007-2008 (IMDC, 2007n). According to Table 5-3, intense weekly dredging occurred in the second half of May 2008 and the second half of August 2008 during which 45% of the annual total amount was removed

from the dock. These weeks of intense dredging were characterised by dredged masses of more than 140,000 TDS per week. Other periods with dredged masses exceeding 100,000 TDS per week are the second half of May 2008 and the second half of February 2009. When the geographical distribution of dredged mass in the Deurganckdok is considered, it was observed that 80% of the total mass originated from zones 3A, 3B, 3C and 3D, being the central trench of the dock. Subzone 4NA contributed more than 4% to the total dredged amount.

Table 5-3: Amounts of dredged mass per zone and dredging period

ZONE	Total dredged mass in covered area (TDS)										Total (TDS)	%
	12-May-08	19-May-08	26-May-08	11-Aug-08	18-Aug-08	20-Oct-08	09-Feb-09	16-Feb-09	24-Feb-09	02-Mar-09		
1	0	0	0	39	0	0	28	0	0	0	67	0.0
2	523	989	746	483	346	0	115	673	623	0	4497	0.4
3a	59931	36320	21332	59941	80335	0	7478	12311	35768	2122	315538	28.9
3b	34338	36401	25286	33300	77573	0	2268	9991	25328	1597	246082	22.5
3c	17708	25536	20847	11229	55195	25424	2341	7773	18303	1151	185506	17.0
3d	946	5952	8877	3508	13759	53894	3608	12843	17634	779	121799	11.1
3e	0	0	541	0	0	0	283	499	1987	0	3311	0.3
4Na	8337	4706	2455	11052	6768	0	5137	9582	1789	0	49826	4.6
4Nb	5739	5745	5503	5866	2514	0	4629	12123	629	0	42748	3.9
4Nc	2594	2216	2962	1249	421	23	3763	7966	537	0	21733	2.0
4Nd	39	157	1242	0	75	101	2700	6081	281	0	10677	1.0
4Ne	0	0	64	0	0	0	65	9	16	0	155	0.0
4Za	7668	6137	1054	8679	1918	0	1930	6477	1438	0	35300	3.2
4Zb	5496	8591	887	5103	2083	0	3055	7731	749	0	33695	3.1
4Zc	949	3290	239	487	803	1	2500	5327	217	0	13813	1.3
4Zd	302	230	15	13	0	27	1514	5288	217	0	7605	0.7
4Ze	0	0	2	0	0	0	56	22	15	0	94	0.0
5Na	3	0	0	0	0	0	0	0	0	0	3	0.0
5Nc	0	0	0	0	0	0	0	4	0	0	4	0.0

Total	144573	136270	92053	140949	241789	79470	41468	104701	105533	5649	1092453
%	13.2	12.5	8.4	12.9	22.1	7.3	3.8	9.6	9.7	0.5	

5.3.2. Densimetric growth rate

Appendix D.3 shows the time evolution of the settled sediment mass as quasi linearly increasing in time. In mid-August 2008, a jump in the temporal trend occurred due to the change of density measurement technique, i.e. changing from Navitracker to the DensiTune device, see §3.2. Note that this was pronounced for the measurements in the central trench only. The range of observed growth rates for some zones in the central trench are shown in Table 5-4. Similarly to the natural siltation rates, the growth rates become smaller when going more inside the dock.

Table 5-4: Range of densimetric growth rates in the central trench area

ZONE	kg/m ² /day
3A	5 - 15
3B	0 - 12.5
3C	0 - 7.5 à 10

Previous results showed a mass growth rate in the central trench (zones 3A, 3B and 3C) in the range of 11 to 20 kg/m²/day for the period November – December 2007 and January – February 2008 when dredging activities occurred. Without any dredging activities, total sediment mass growth rates approximately ranged between 2 and 8 kg/m²/day in the central trench (see also Table 5-5).

In the measurement year 2008-2009 (Table 5-5), the increased growth rate due to dredging has been observed as well. In the central trench, densimetric growth rates artificially increased by 5-10 kg/m²/day, which was (in order of magnitude) in accordance to previous measurements. This significant difference can be attributed to a combination of the two dredging processes, i.e. hopper and sweepbeam maintenance dredging. Whereas sweepbeam operations result in an artificial influx of sediment in the central trench, the continuous hopper maintenance dredging in this period leads to a lower bed level and, therefore, to a possible more rapid siltation.

Densimetric growth rates were smaller near the quays in comparison to the values observed in the central trench, and generally measured up to 7.5 kg/m²/day. These observations are in accordance to the measurements in 2007-2008 (see IMDC, 2007n).

Table 5-5: Influence of dredging on densimetric growth rates in the central trench area (3A-C)

kg/m ² /day	2007 - 2008	2008 - 2009
no dredging	2 – 8	1 – 15
dredging	11 – 20	8 – 25
difference	~10	~5 à 10

5.3.3. Total deposited mass

An overview of the total mass settled over time is shown in Table 5-6 and Table 5-7. Zones 3A-D and 4ZB-D have been covered for more than 85%, whereas the other zones show coverages of at least 50%. Additionally, total masses are given for subzones of zone 5 too of which the zone coverage was more than 50%. For these subzones, the coverage never exceeded 85% though.

From Table 5-7, it is concluded once more that the settled mass decreased from zone A to D. This confirms again the hypothesis of a gradual decrease in siltation with distance from the Scheldt river.

Table 5-6: Total sediment mass (measured + dredged, in 10^3 TDS) in some zones

	28-Apr-08	05-Jun-08	11-Aug-08	26-Aug-08	11-Sep-08	20-Oct-08	06-Nov-08	30-Jan-09	12-Mar-09
3a	441	491	552	622	656	711	705	746	762
3b	391	439	480	546	572	608	605	630	639
3c	328	357	382	419	437	462	483	504	530
3d	162	171	173	185	199	216	249	298	322
3e					130	139	160	419	285
4Na	79	85	94	99	107	113	113	126	130
4Nb	63	70	78	81	85	93	91	97	108
4Nc	43	46	51	50	49	62	55	57	69
4Nd	24	22	28	29	24	35	30	38	45
4Ne					27	29		58	78
4Za	45	49	57	58	67	64	65	74	82
4Zb	50	57	62	63	70	74	71	77	89
4Zc	32	30	34	35	36	42	43	47	59
4Zd	21	18	22	21	23	30	31	41	51
4Ze					17	32	40	72	44
5Na					18				
5Nb	17	10	16		16	15	14	18	22
5Nc	10	8	13	15	9	16	11	12	19
5Nd	8	6	12		5		9	16	22
5Zb	12	15	17	17	15	12	10	17	22
5Zc	11	8	12	13	13	13	13	13	19
5Zd	8	5	12		13	14	13	10	27
Total	1743	1887	2095	2255	2587	2780	2810	3368	3425

Table 5-7: Mass settled per subzone in zones 3 and 4 (measured + dredged, in 10^3 TDS)

	settled mass (10^3 TDS)									Total
	22-Feb-08	28-Apr-08	05-Jun-08	11-Aug-08	26-Aug-08	11-Sep-08	20-Oct-08	06-Nov-08	30-Jan-09	
	28-Apr-08	05-Jun-08	11-Aug-08	26-Aug-08	11-Sep-08	20-Oct-08	06-Nov-08	30-Jan-09	12-Mar-09	
zone A	59	59	80	72	48	62	-7	61	31	465
zone B	55	62	53	71	36	48	-8	38	32	387
zone C	48	31	33	37	19	44	14	26	51	303
zone D	31	5	11	13	11	35	29	67	42	244
Total	192	156	178	193	113	189	28	192	155	1396

6. SEDIMENT MASS BALANCE: LIMITATIONS

As mentioned in Chapter 1.2, the aim of this study is twofold. Firstly, setting up the sediment balance of the Deurganckdok is focused. Secondly, the mechanisms causing siltation in the dock are to be investigated. The latter is the subject of other reports (see §1.3), and the confrontation of both the sediment balance and the siltation contributing factors for the period 2008-2009 will be dealt with in Report 4.20 “Analysis of Siltation Processes and Factors” (I/RA/11283/08.098/MSA).

The actual report aims at quantifying the different processes that contribute to the sediment balance in order to compute the sediment influx from the Scheldt. The different contributions are schematically shown in Figure 2-2 and the sediment balance equation is to be found in §5.1.

In contradiction to previous measurement campaigns, the 2008-2009 campaign covered an entire year of densimetric measurements enabling the setup of a mass balance. Different processes of the sediment transport have been considered densimetrically, such as:

- maintenance dredging;
- capital dredging;
- settling and consolidation (measured indirectly by the local sediment densities)

Only one process has been inadequately described, i.e. the sweep beam actions. Although the depth of the rake or plough and its location is known, it is difficult to estimate the transport capacity of it. The question indeed remains whether the rake introduces a momentum so the sediment flows in the direction of the rake movement, or the rake pushes the sediment. The sweep beam data has therefore only been used for data interpretation.

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IMDC (2006d) Langdurige metingen Deurganckdok: Opvolging en analyse aanslibbing. Deelrapport 2.4 Through tide measurement Sediview spring tide 27/09/2006 Parel 2 (I/RA/11283/06.119/MSA).

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IMDC (2007c) Langdurige metingen Deurganckdok: Opvolging en analyse aanslibbing. Deelrapport 1.3 Sediment Balance: Three monthly report 1/10/2006 – 31/12/2006 (I/RA/11283/06.115/MSA)

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APPENDIX A.

DEPTH OF THE WATER-BED INTERFACE (210 KC)

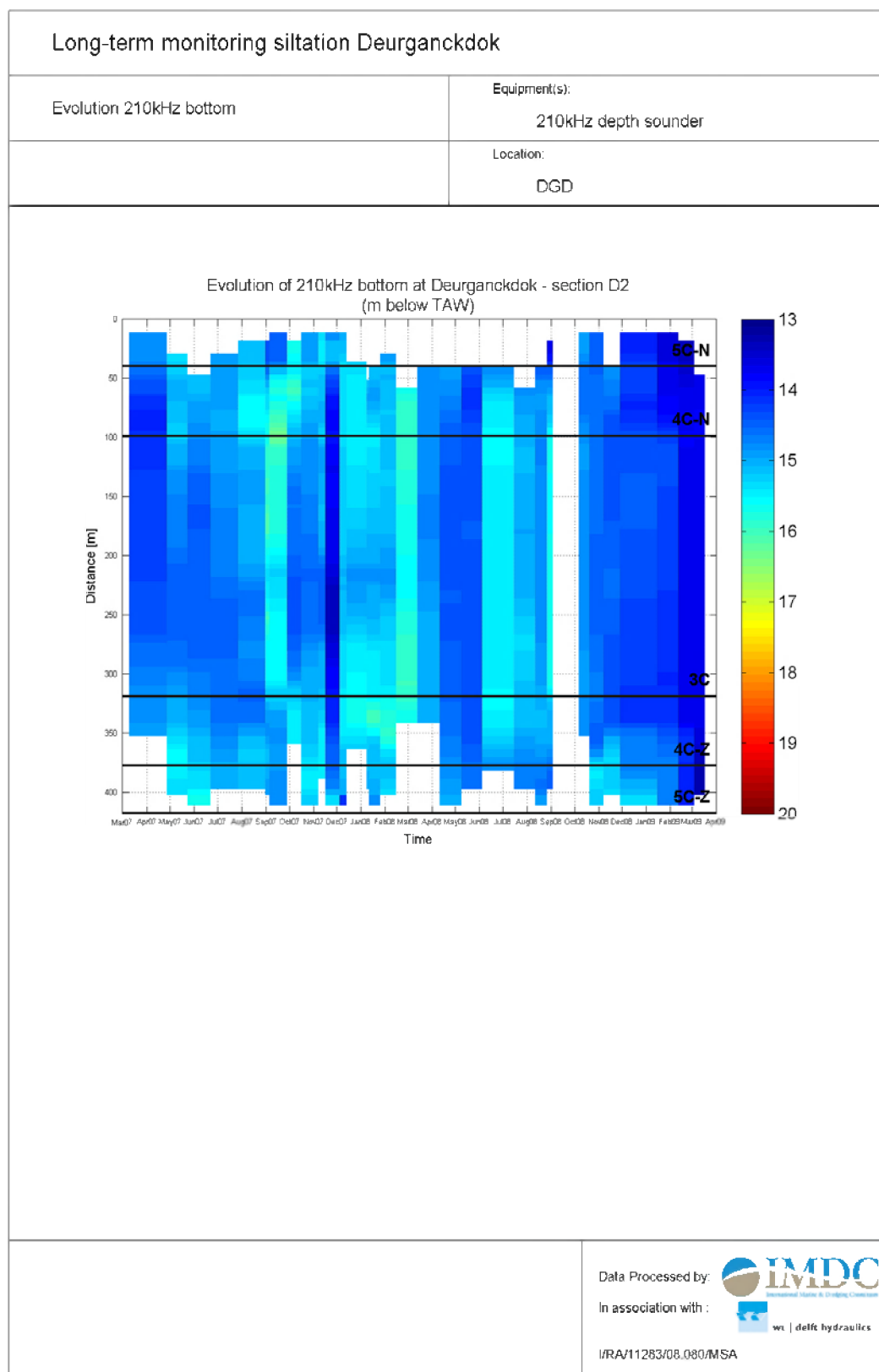
APPENDIX B.

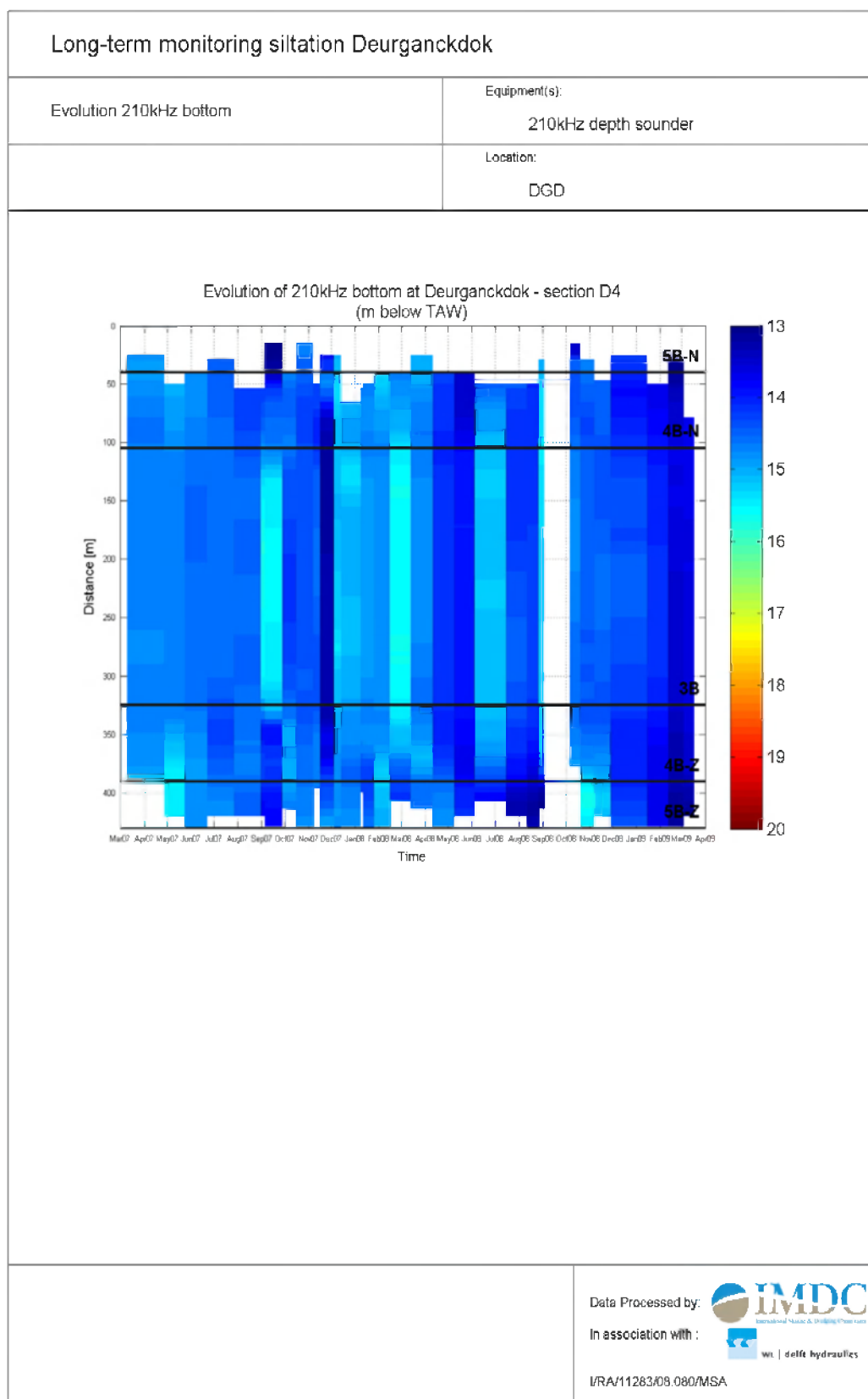
EVOLUTION OF DEPTH OF WATER-BED INTERFACE

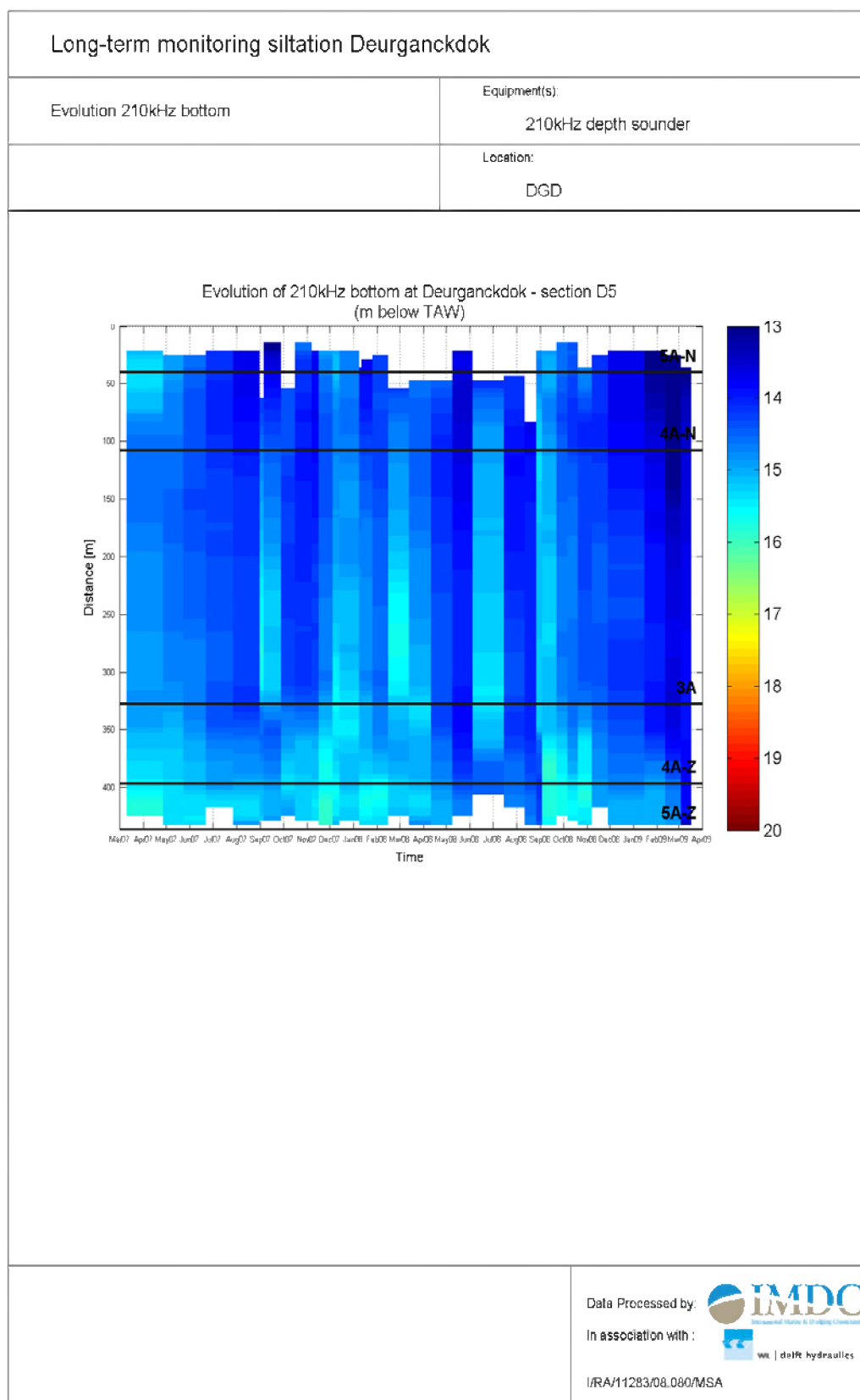
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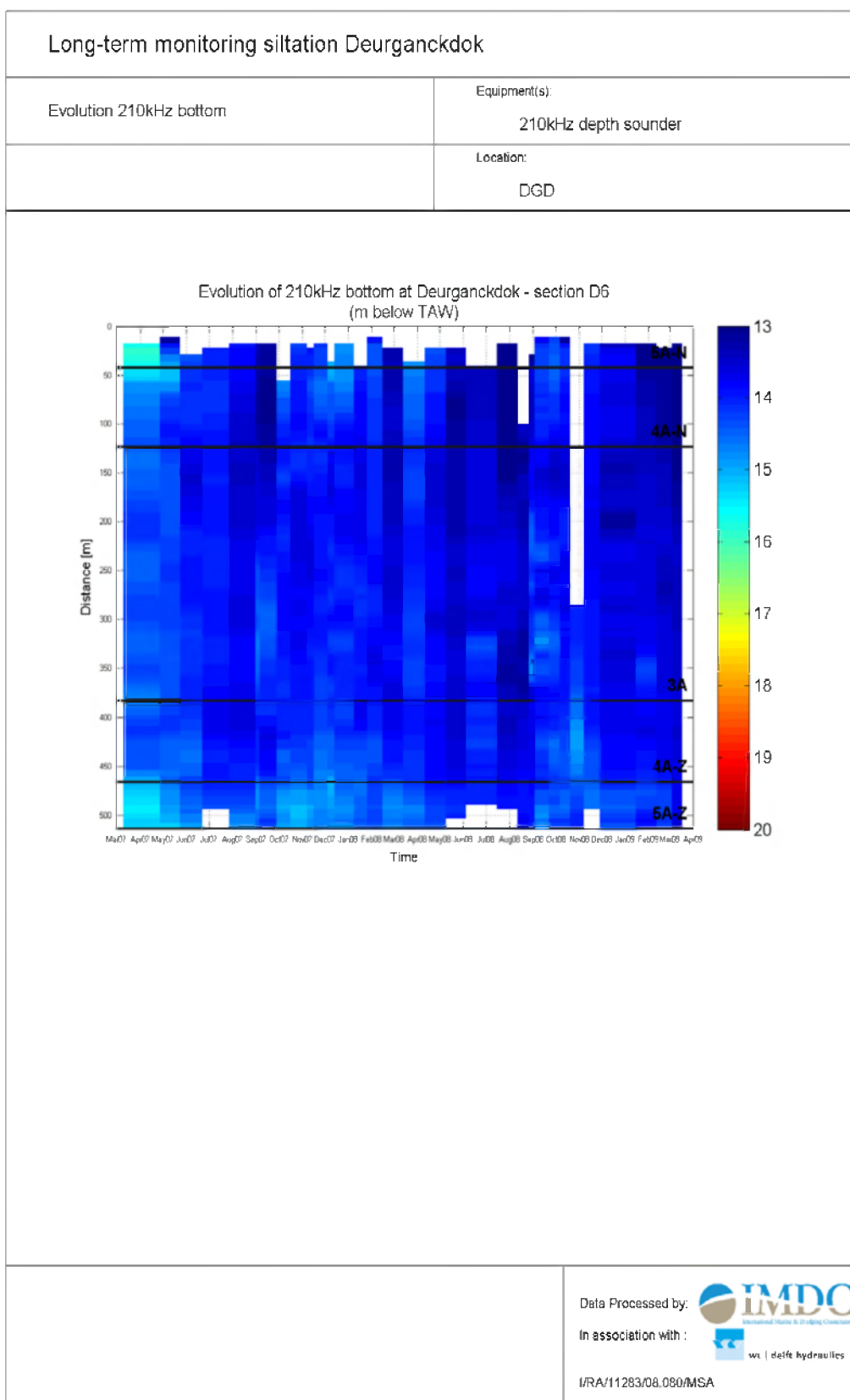
B.1 Difference maps

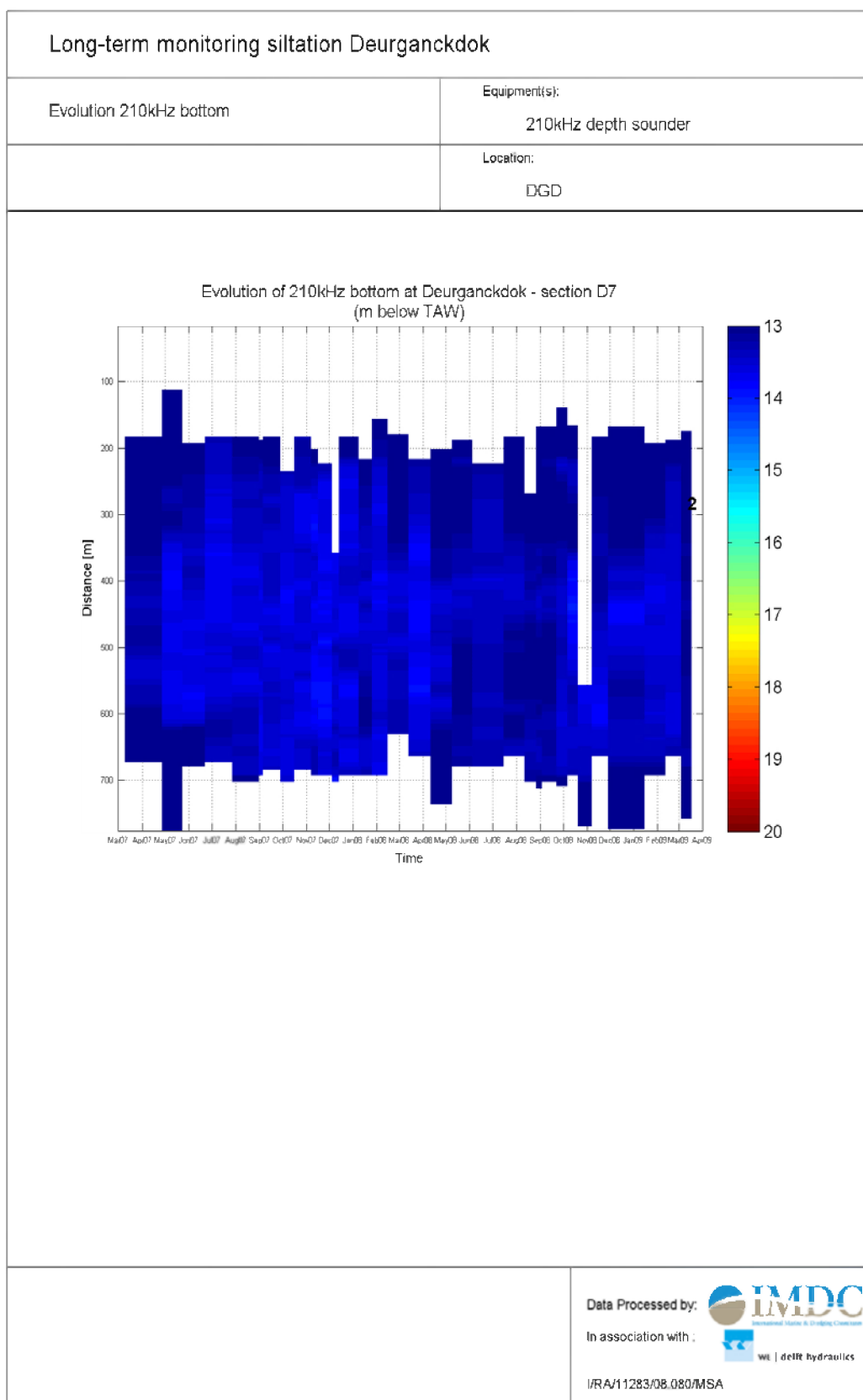
B.2 Bed elevation evolution per section











Long-term monitoring siltation Deurganckdok

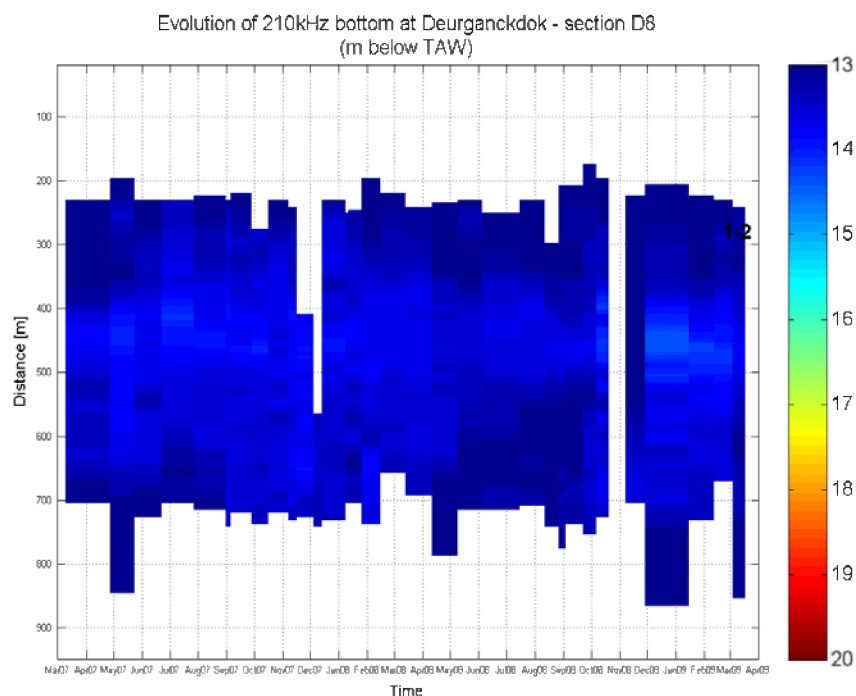
Evolution 210kHz bottom

Equipment(s):

210kHz depth sounder

Location:

DGD



Data Processed by

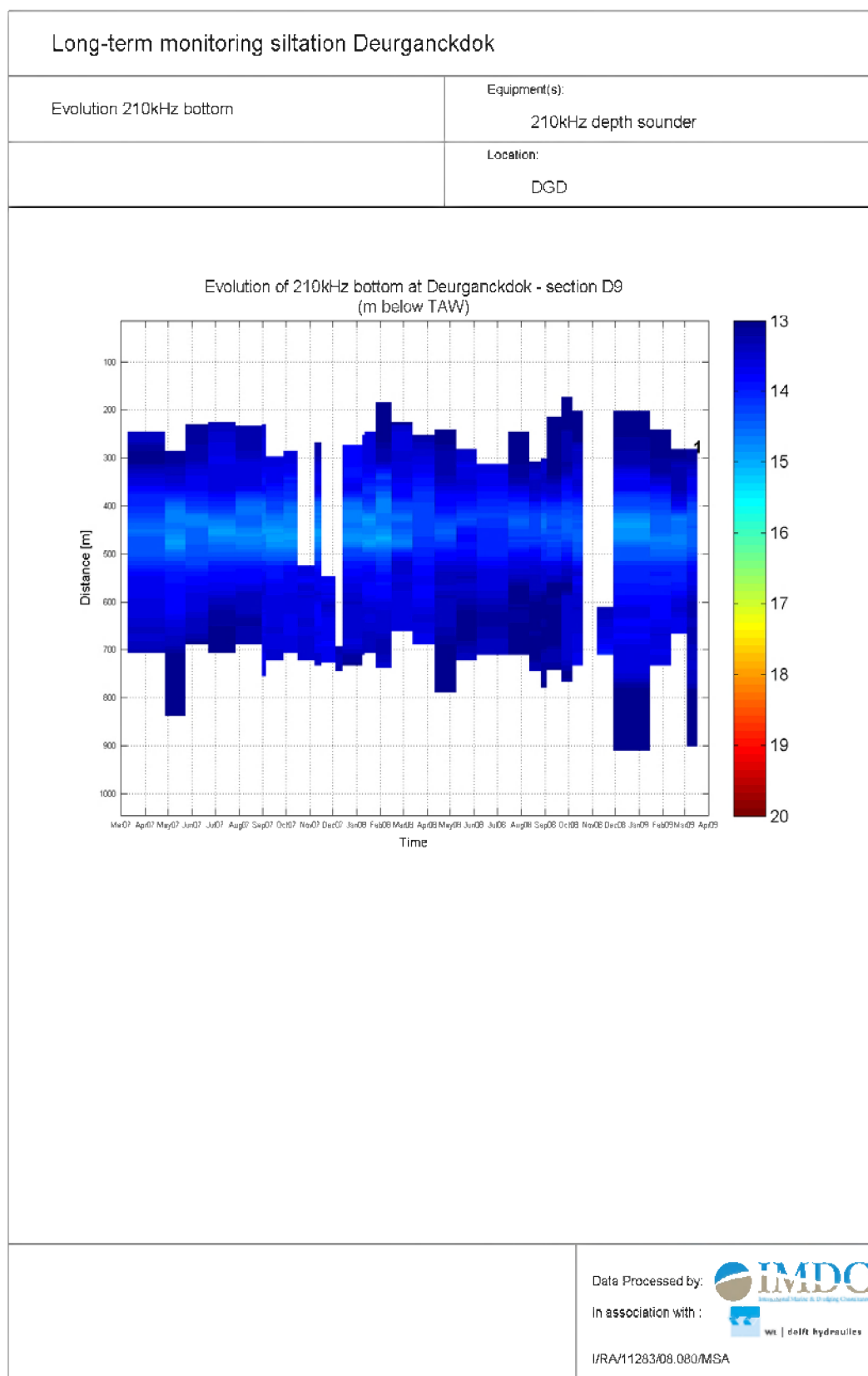


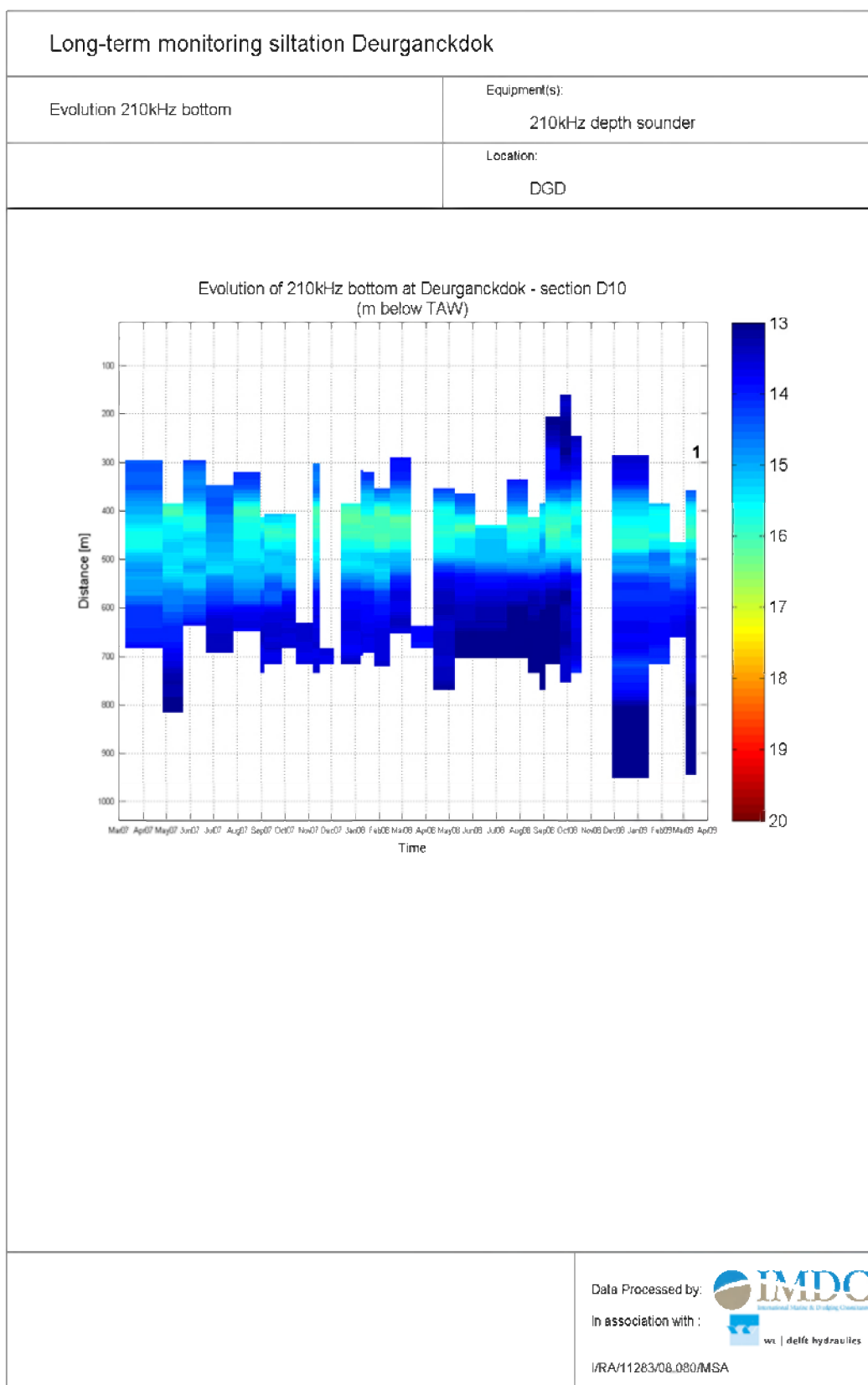
In association with :



wl | delft hydraulics

I/RA/11283/08.080/MSA





Long-term monitoring siltation Deurganckdok

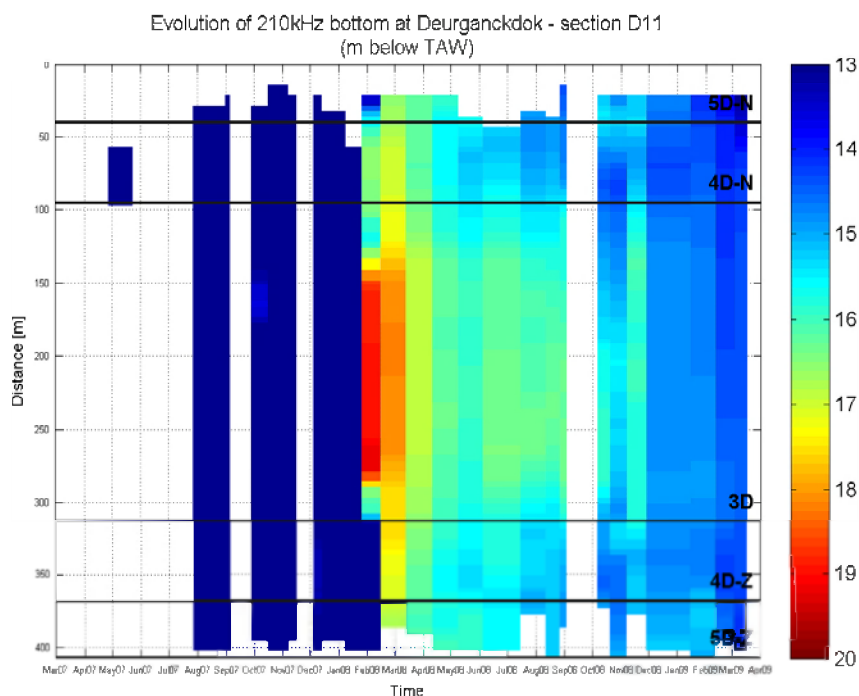
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Equipment(s):

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Location:

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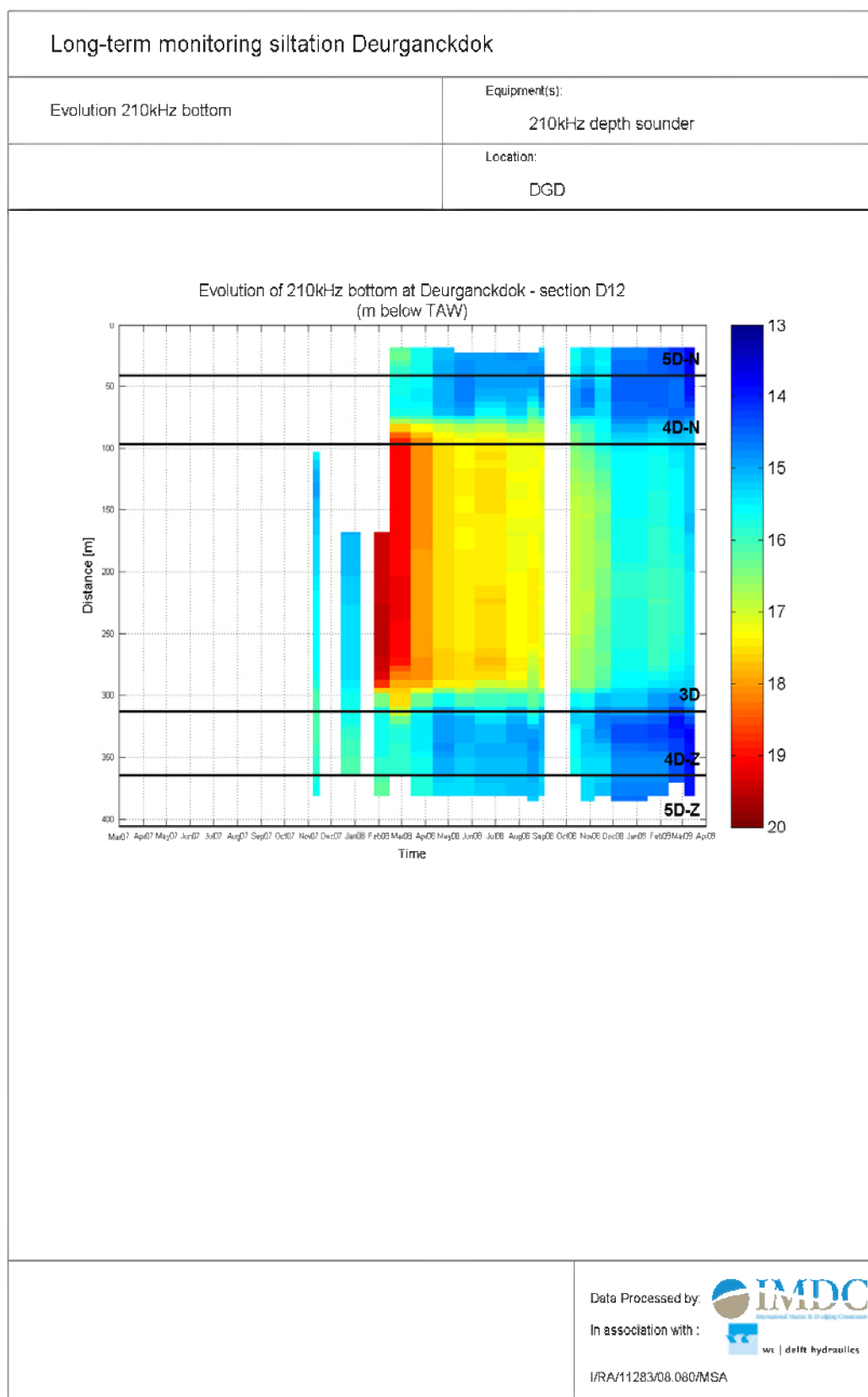
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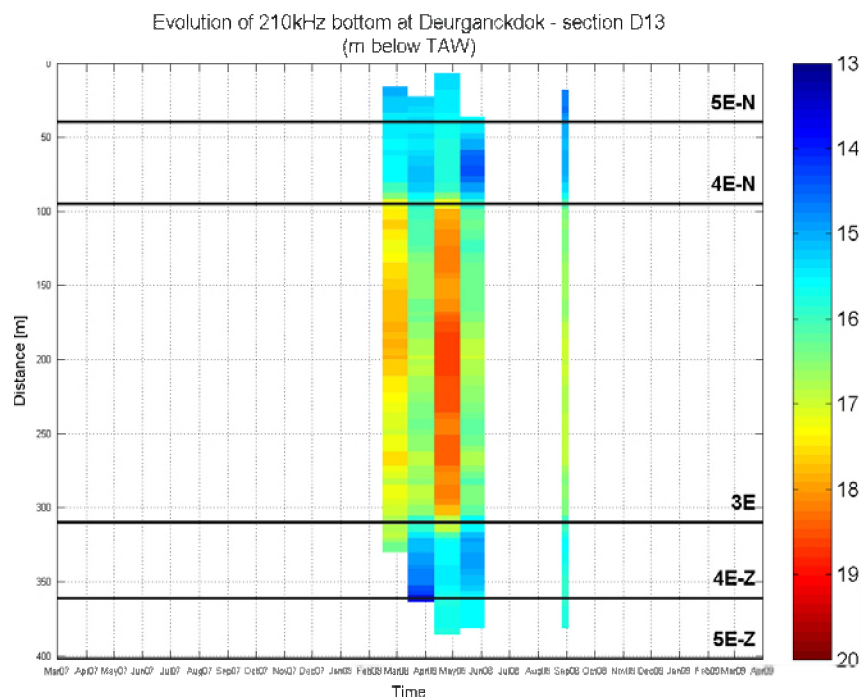
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Equipment(s):

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Location:

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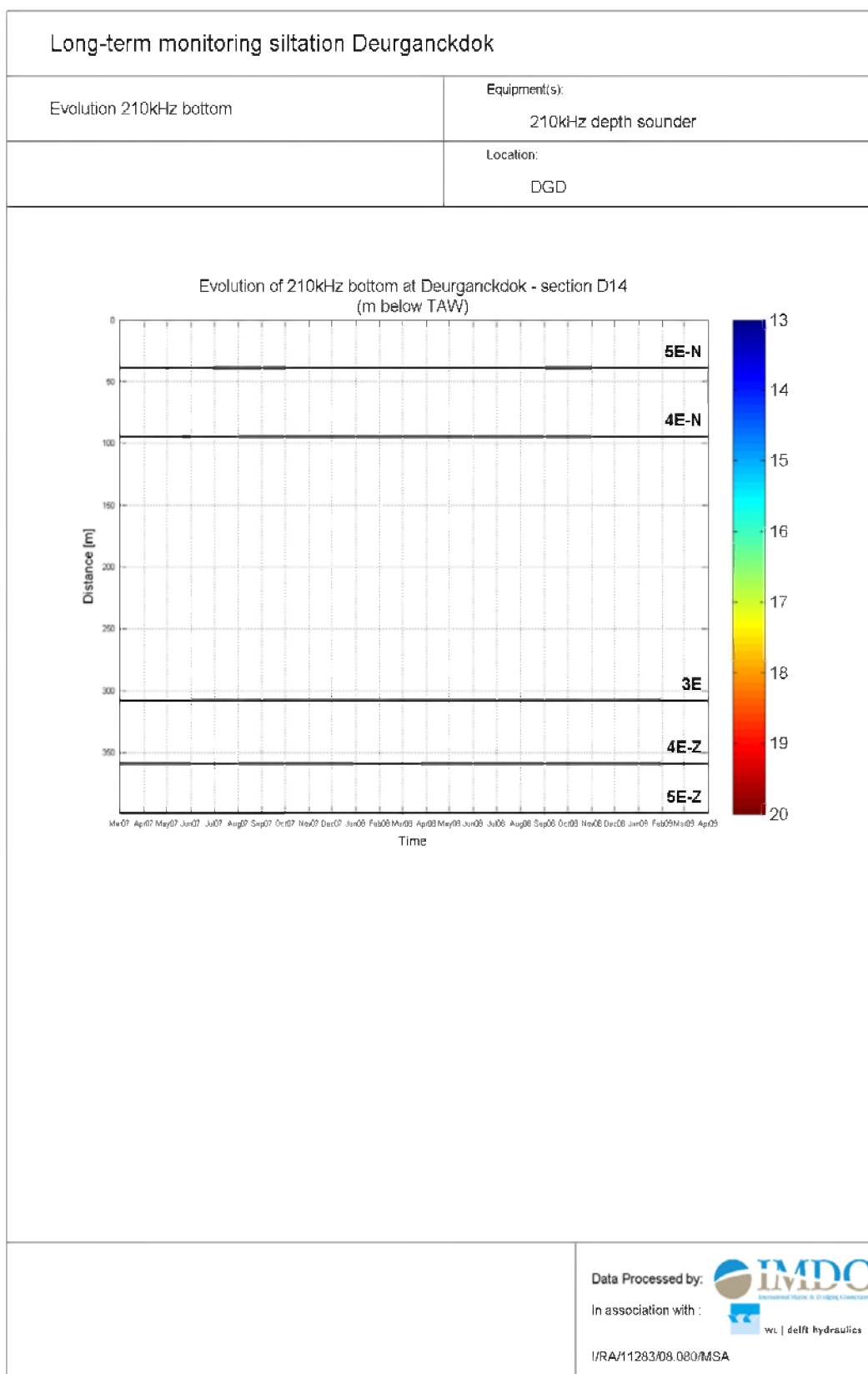
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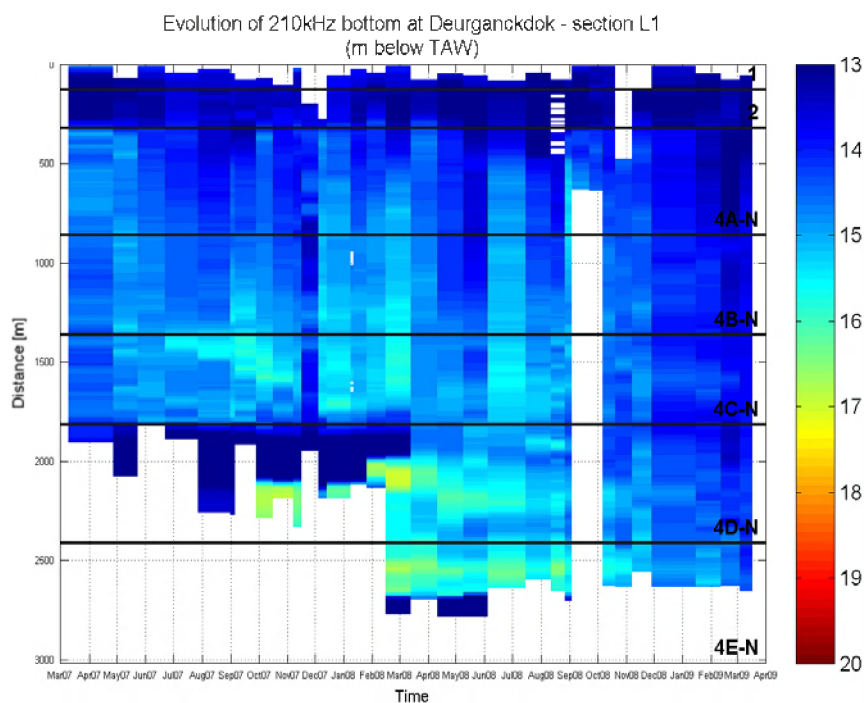
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Equipment(s):

210kHz depth sounder

Location:

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Data Processed by:



In association with:



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Long-term monitoring siltation Deurganckdok

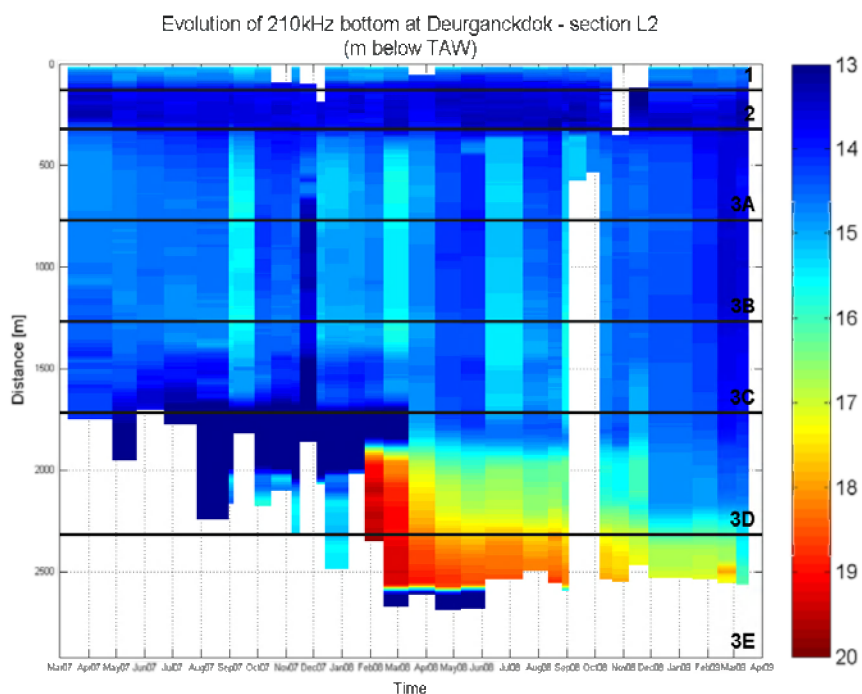
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Equipment(s):

210kHz depth sounder

Location:

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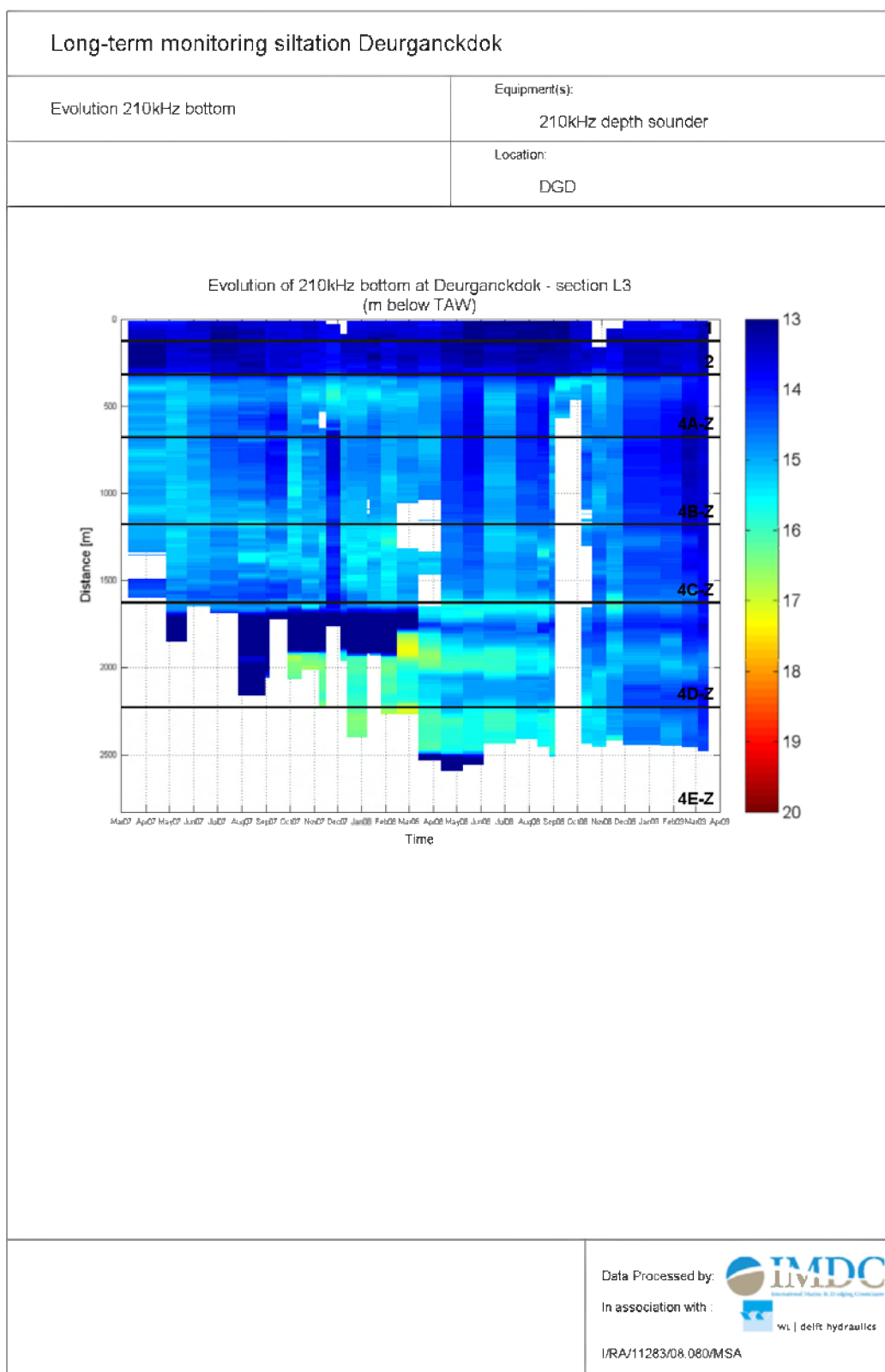
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APPENDIX C.

VOLUMETRIC SILTATION RATES IN DIFFERENT ZONES AND SECTIONS

C.1 Siltation rates (tabular)

1/ Per zone (cm/day)

	11-Apr-08	09-May-08	04-Jun-08	15-Jul-08	11-Aug-08	26-Aug-08	03-Sep-08	22-Sep-08	06-Oct-08	20-Oct-08	07-Nov-08	28-Nov-08	15-Jan-09	11-Feb-09	03-Mar-09
1	0.44	-	-	-	-	-	0.04	0.10	-1.87	-	-	2.29	-	-	0.00
2	2.11	-0.21	-0.72	0.46	0.04	1.21	-1.69	0.92	-2.13	-	0.06	3.60	-1.85	-0.47	4.31
3a	1.96	0.49	-4.23	2.29	0.53	-7.53	1.58	-	1.45	1.10	0.38	0.56	0.66	1.44	-0.86
3b	1.71	0.35	-4.43	1.67	0.54	-6.66	-	-	1.67	2.07	0.29	0.49	0.52	1.88	-0.33
3c	1.55	0.25	-4.19	0.96	0.56	-4.64	-	-	1.89	1.72	-0.62	1.30	0.31	1.91	-0.24
3d	1.92	0.77	-0.86	0.56	-0.08	-0.63	-	-	1.16	1.22	-1.81	4.00	0.00	1.22	-0.14
3e	1.45	0.51	-	-	-	-	-	-	-	-	-	-	-	-	-
4Na	1.51	1.86	-3.44	1.66	0.07	-7.98	6.24	0.77	0.99	-1.36	0.93	1.91	0.74	1.70	-1.78
4Nb	1.80	0.77	-3.68	1.23	0.38	-4.05	-	-	0.89	1.03	0.06	1.90	0.31	1.68	-0.98
4Nc	-0.23	0.97	-2.69	0.59	0.78	-0.03	-	-	0.48	1.34	-1.35	2.45	0.22	1.23	-0.08
4Nd	0.30	0.18	0.23	0.50	-0.32	2.02	-	-	-0.13	1.28	-1.97	3.03	0.09	1.47	-0.20
4Ne	1.37	0.91	-	-	-	-	-	-	-	-	-	-	-	-	-
4Za	2.03	1.70	-3.64	1.75	0.79	-5.58	-5.53	-	1.14	-1.74	1.95	2.06	0.42	1.42	0.04
4Zb	1.60	1.09	-3.40	1.41	0.37	-3.74	-	-	0.37	-2.21	0.92	3.26	0.32	1.93	-0.69
4Zc	1.26	0.59	-2.15	0.67	-0.43	1.27	-	-	-	0.30	-1.49	2.43	0.04	1.50	1.39
4Zd	0.96	0.06	0.10	0.39	-0.31	1.75	-	-	0.08	0.63	-0.91	2.18	-0.18	1.01	0.88
4Ze	4.98	-2.22	-	-	-	-	-	-	-	-	-	-	-	-	-
5Na	-	2.25	-	-	-	-1.07	-	0.56	3.06	-	-0.42	2.47	1.05	1.76	-
5Nb	-	-	-	-	-	0.27	-	-	-0.18	-1.58	-	1.67	-	1.05	-
5Nc	-0.65	-	-	-	-	0.94	-	-	-2.19	1.14	-	1.13	0.62	1.73	-
5Nd	-0.42	-	-	-	-	0.46	-	-	-0.94	1.50	-1.59	3.13	0.65	1.74	2.17
5Ne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5Za	0.46	2.30	-	1.01	0.14	-0.04	-24.25	-	-	-0.12	2.84	2.02	0.67	1.45	3.64

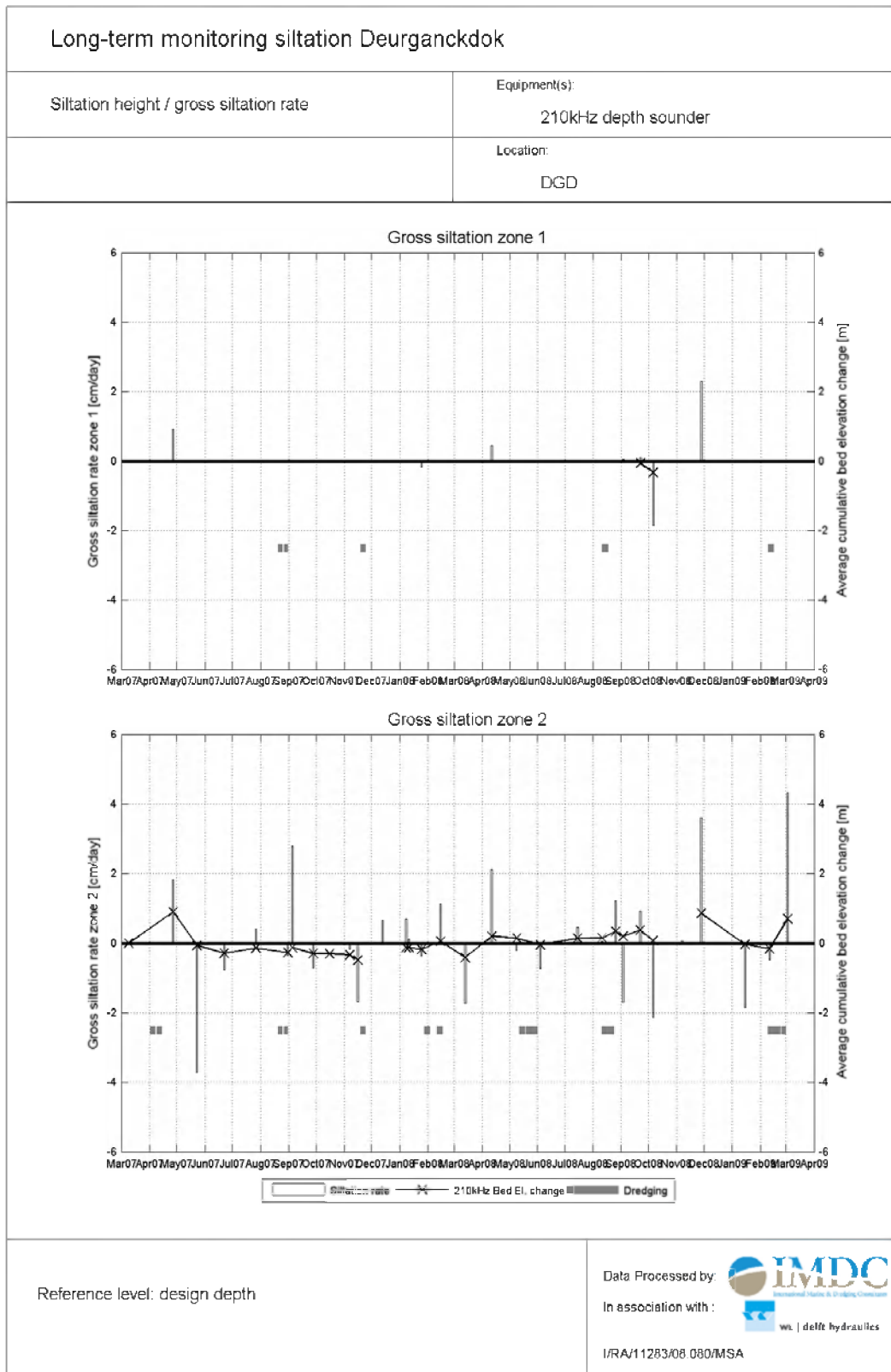
1/ Per zone (cm/day)

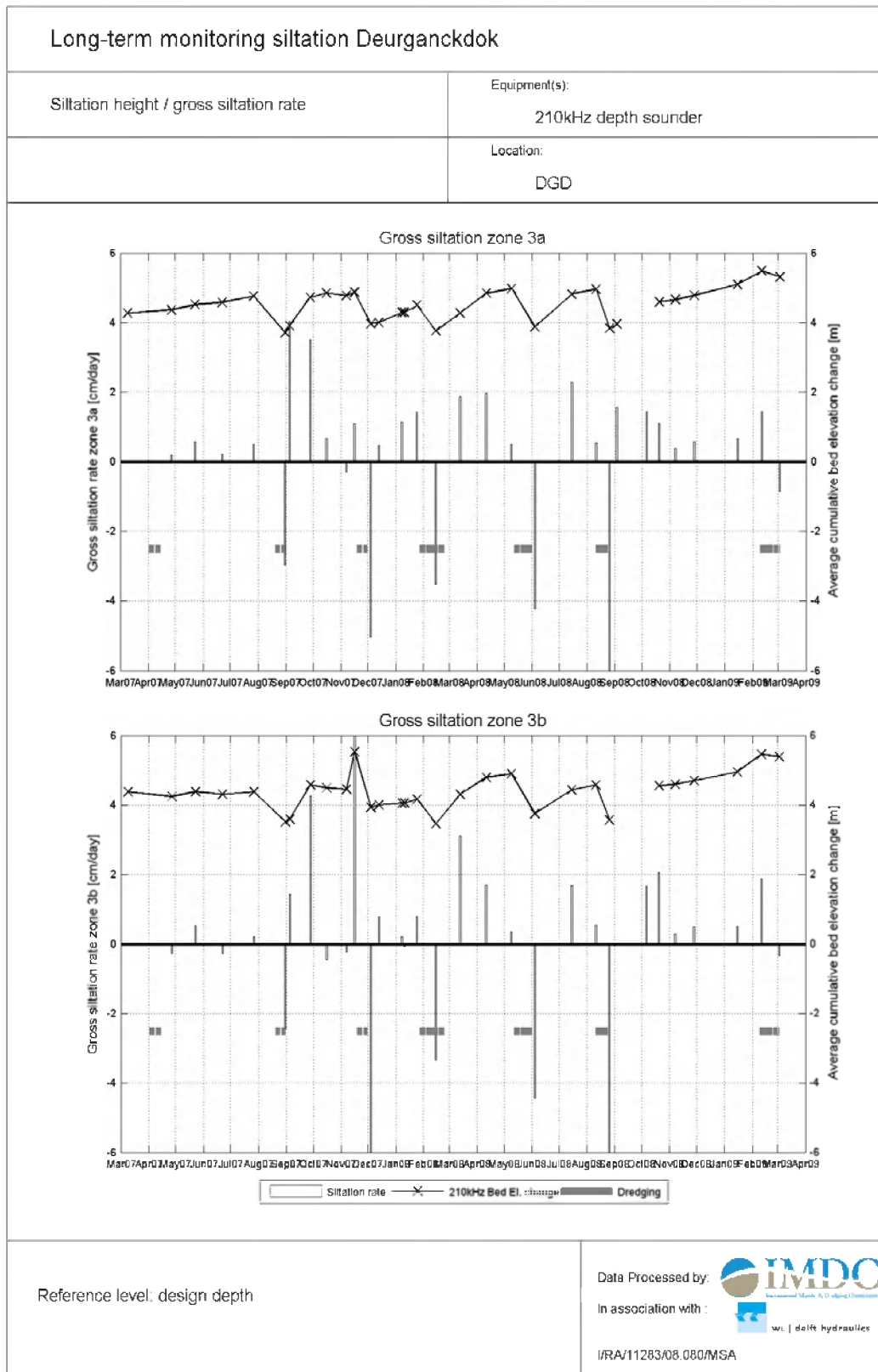
	11-Apr-08	09-May-08	04-Jun-08	15-Jul-08	11-Aug-08	26-Aug-08	03-Sep-08	22-Sep-08	06-Oct-08	20-Oct-08	07-Nov-08	28-Nov-08	15-Jan-09	11-Feb-09	03-Mar-09
5Zb	0.45	1.81	-	0.47	0.26	-	-	-	-	-2.24	1.00	3.24	1.34	1.79	0.76
5Zc	0.68	0.77	-	-	-0.02	2.13	-	-	-	-0.73	-2.63	2.52	0.27	2.07	3.65
5Zd	0.77	0.21	0.42	-	0.36	1.06	-	-	-	-0.12	-	0.98	-0.20	1.05	2.85
5Ze	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

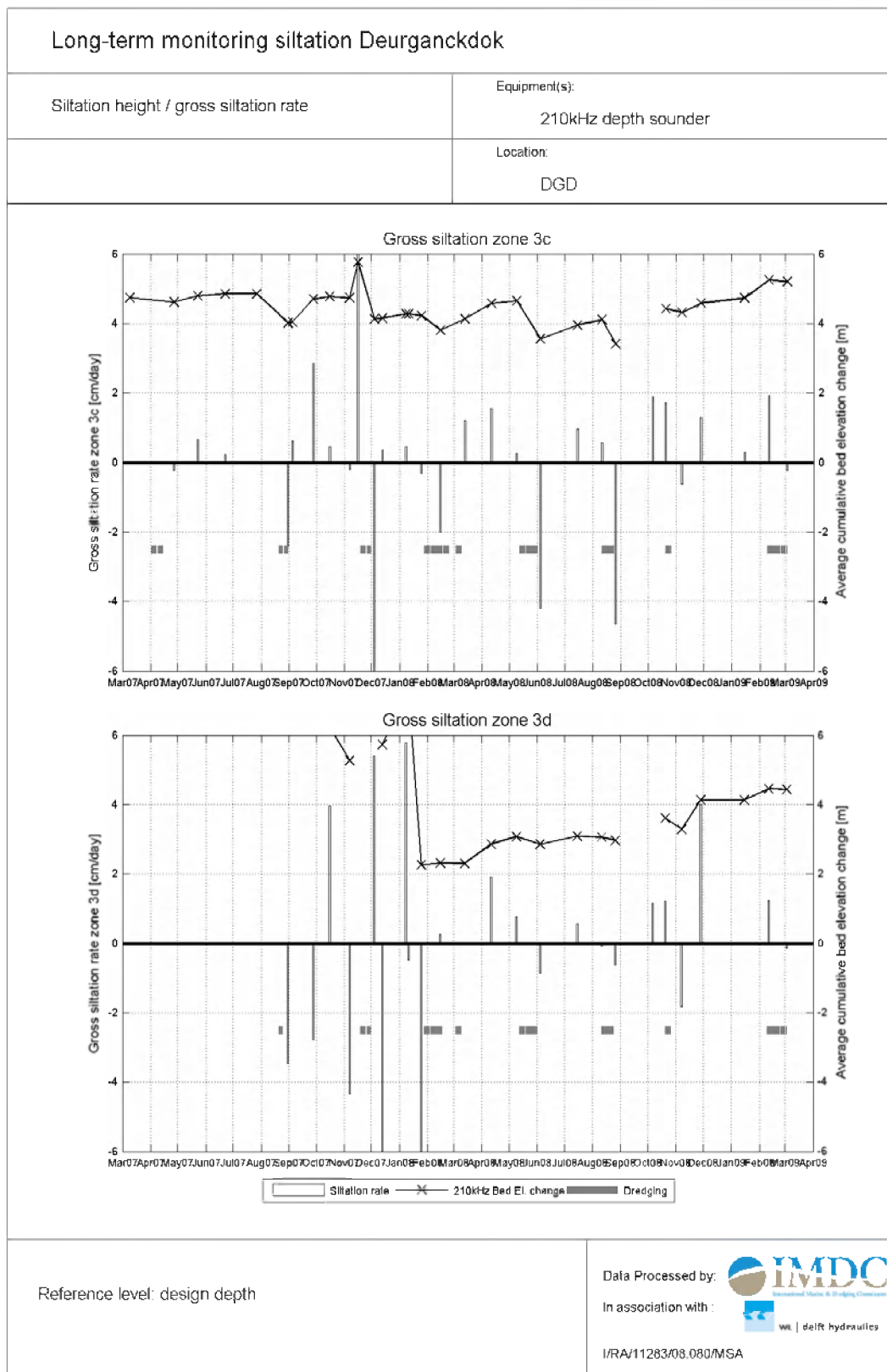
2/ Per section (cm/day)

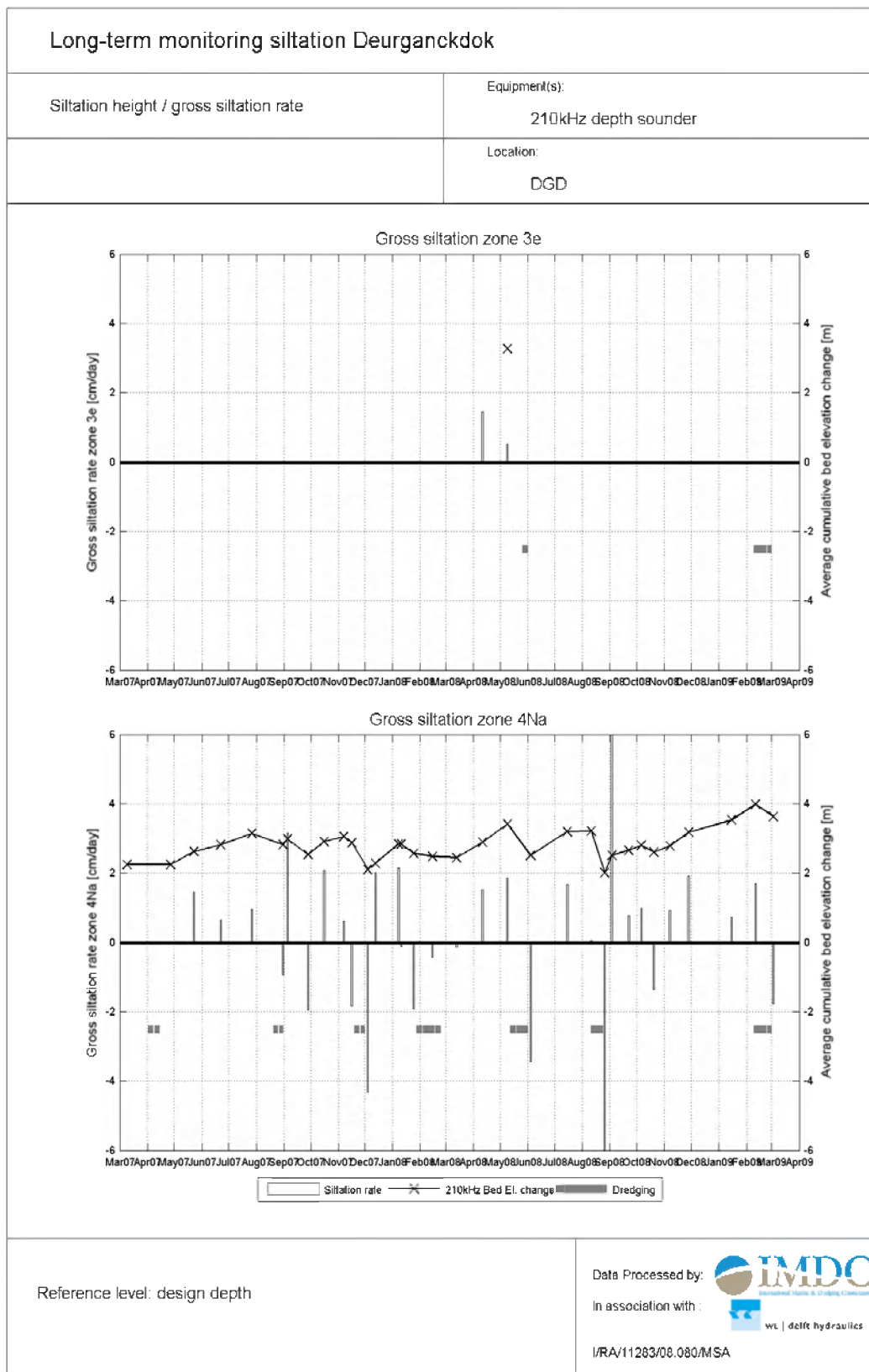
	11-Apr-08	09-May-08	04-Jun-08	15-Jul-08	11-Aug-08	26-Aug-08	03-Sep-08	22-Sep-08	06-Oct-08	20-Oct-08	07-Nov-08	28-Nov-08	15-Jan-09	11-Feb-09	03-Mar-09
D1	0.61	0.79	-2.90	0.65	0.34	-1.39	-	-	0.99	1.15	-2.49	2.63	0.39	1.34	0.19
D2	1.11	0.59	-3.90	0.88	0.73	-3.07	-	-	1.22	1.24	0.27	0.93	0.42	1.57	0.46
D3	1.51	0.44	-3.85	1.37	0.48	-4.98	-	-	1.19	0.53	0.62	1.10	0.57	1.90	-0.52
D4	1.96	1.20	-4.28	1.97	0.47	-6.86	-	-	1.22	-0.17	0.28	1.53	0.60	1.83	-0.63
D5	1.65	1.65	-4.27	2.08	0.21	-5.96	-2.65	2.36	0.92	0.03	1.18	0.95	0.61	1.47	-0.62
D6	1.26	1.43	-1.20	0.94	-0.34	-2.86	-2.57	0.10	1.09	-	-0.06	1.25	0.12	0.38	1.24
D7	2.26	-0.42	-1.00	0.72	-0.14	2.10	-2.62	1.07	-3.22	-	0.31	3.85	-2.04	-0.54	5.31
D8	0.39	-0.69	-	0.06	-	0.39	-0.51	0.64	-2.45	-	1.88	2.59	-2.49	-	1.65
D9	0.48	-	-	-	-	-	0.03	-0.33	-1.48	-	-	2.11	-	-	-0.05
D10	-	-	-	-	-	-	-	-	-	-	-	1.48	-	-	0.27
D11	2.08	0.84	-0.72	0.69	0.04	0.34	-	-	0.93	1.49	-3.37	3.90	0.09	1.54	0.22
D12	1.80	0.25	-0.42	0.49	-0.19	0.44	-	-	0.43	1.36	1.11	2.98	-0.20	0.61	1.63
D13	-3.94	4.09	-	-	-	-0.18	-	-	-	-	-	-	-	-	-
D14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L1	1.86	0.89	-3.35	1.19	-0.39	-1.15	-	-	0.70	-0.57	0.53	1.89	0.20	1.08	-0.39
L2	2.30	0.49	-3.25	1.26	-0.21	-3.45	-	-	1.21	0.45	0.73	1.19	0.28	1.21	0.42
L3	1.92	0.35	-2.24	0.97	0.09	-1.78	-	-	0.25	-0.90	0.10	2.51	0.04	1.22	0.63

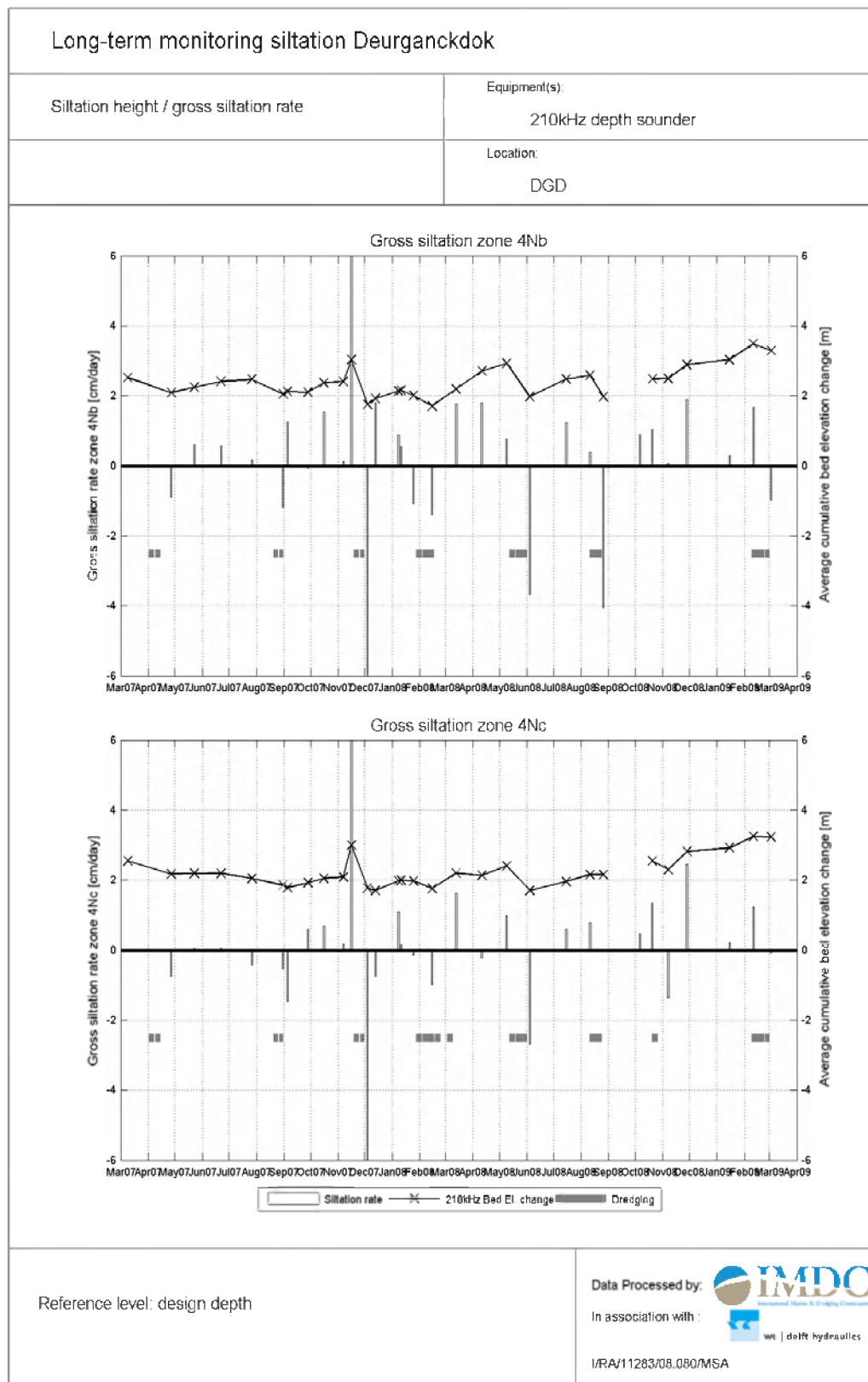
C.2 Water-bed interface evolution for ali zones

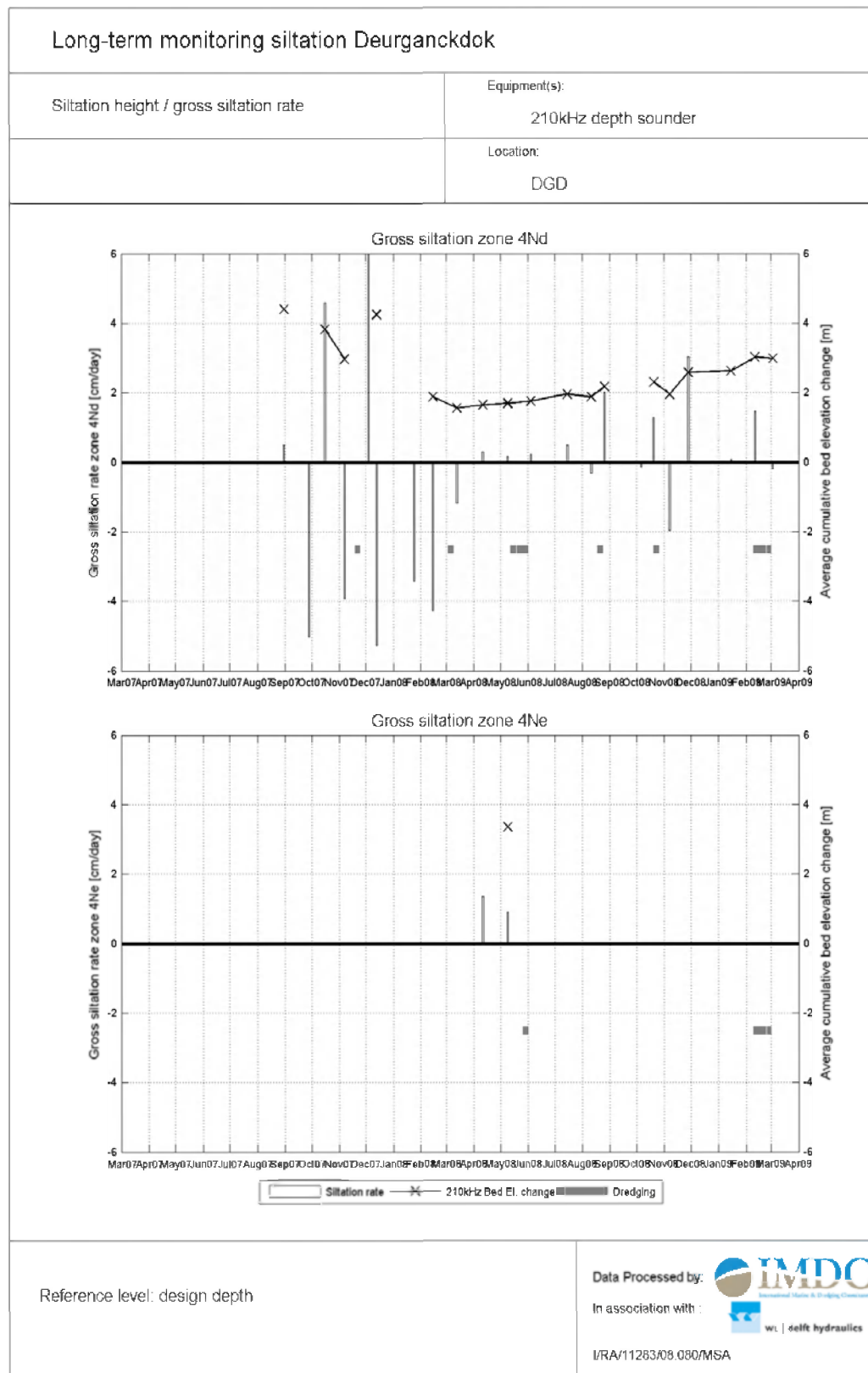


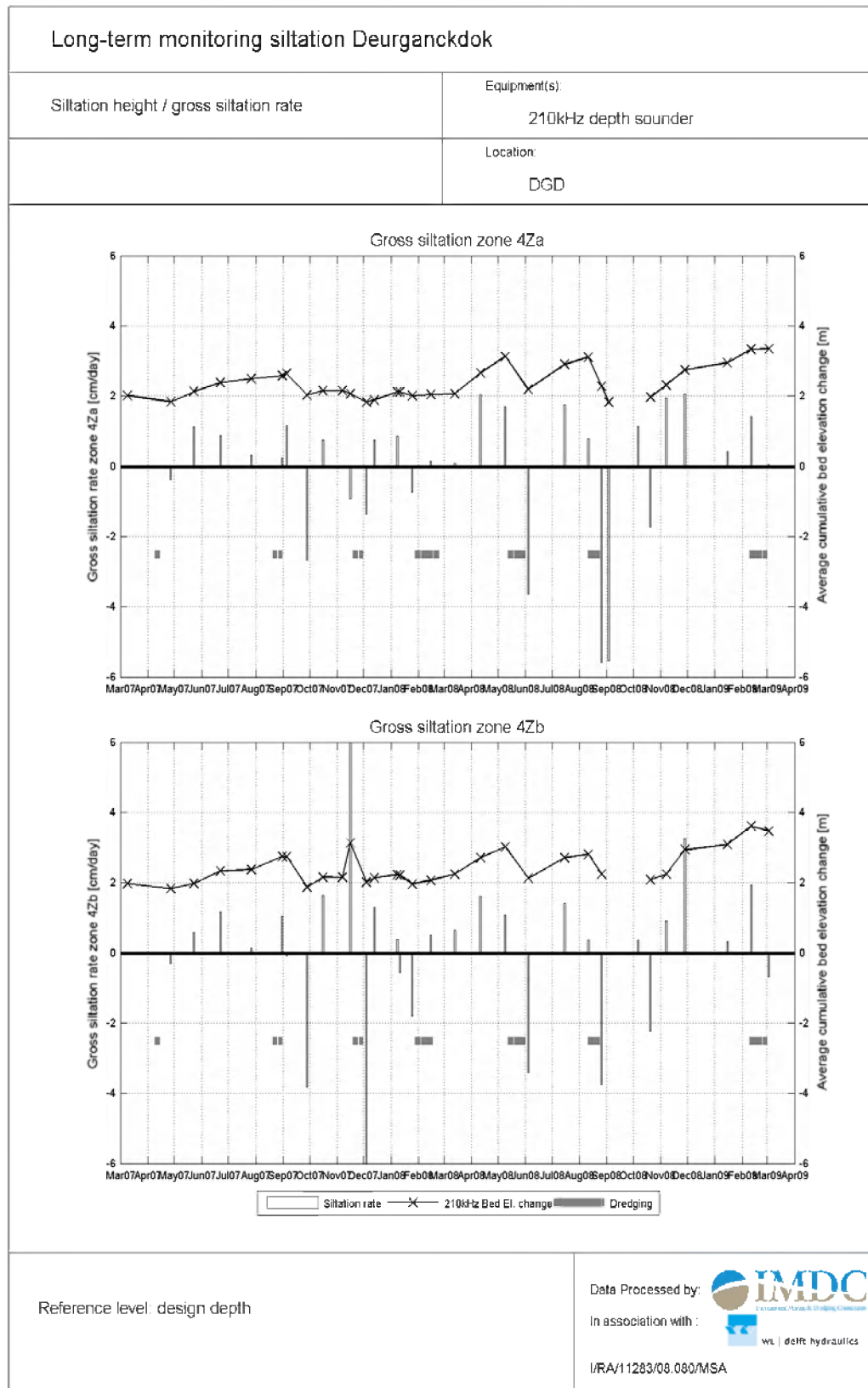


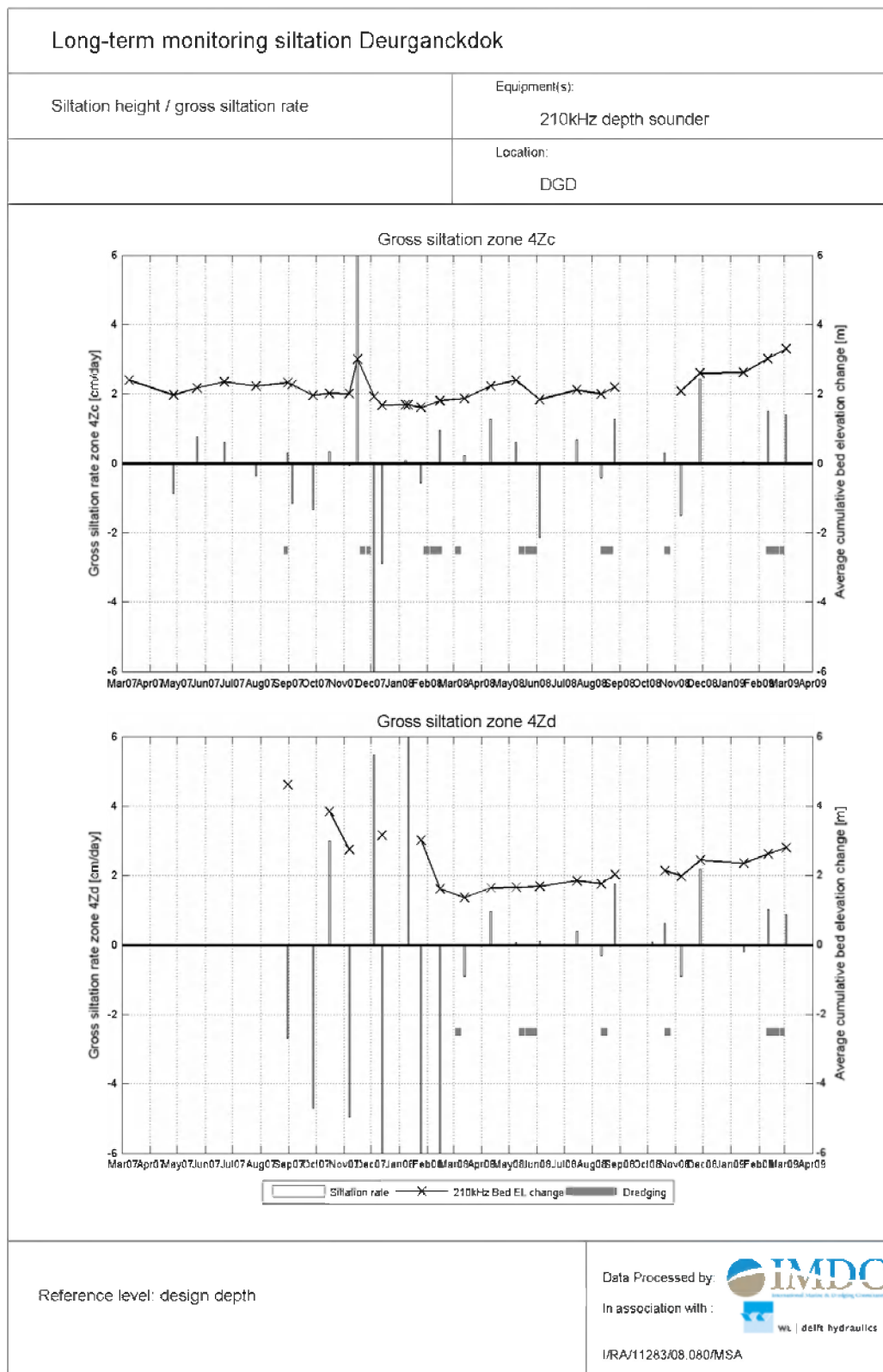


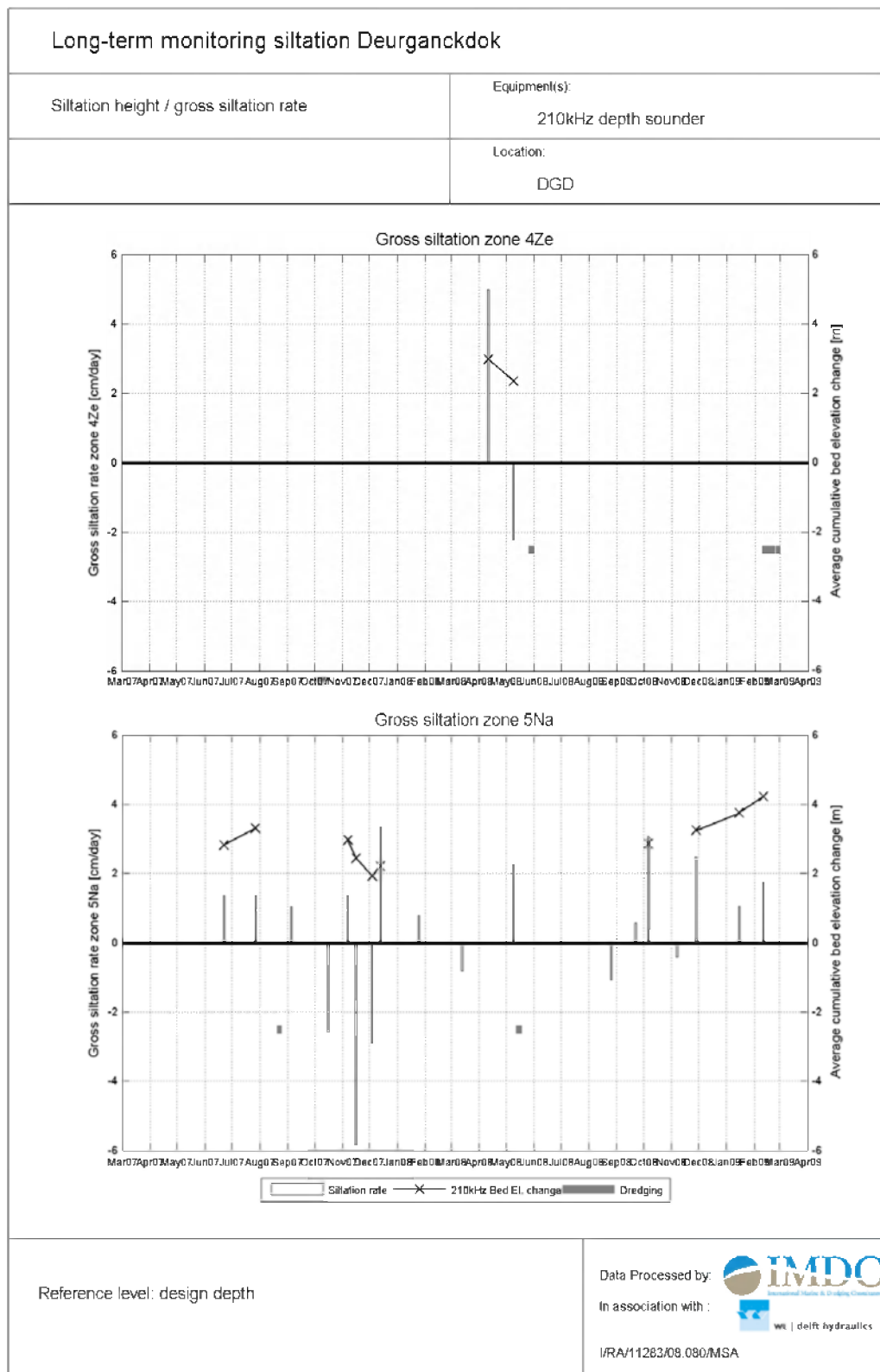


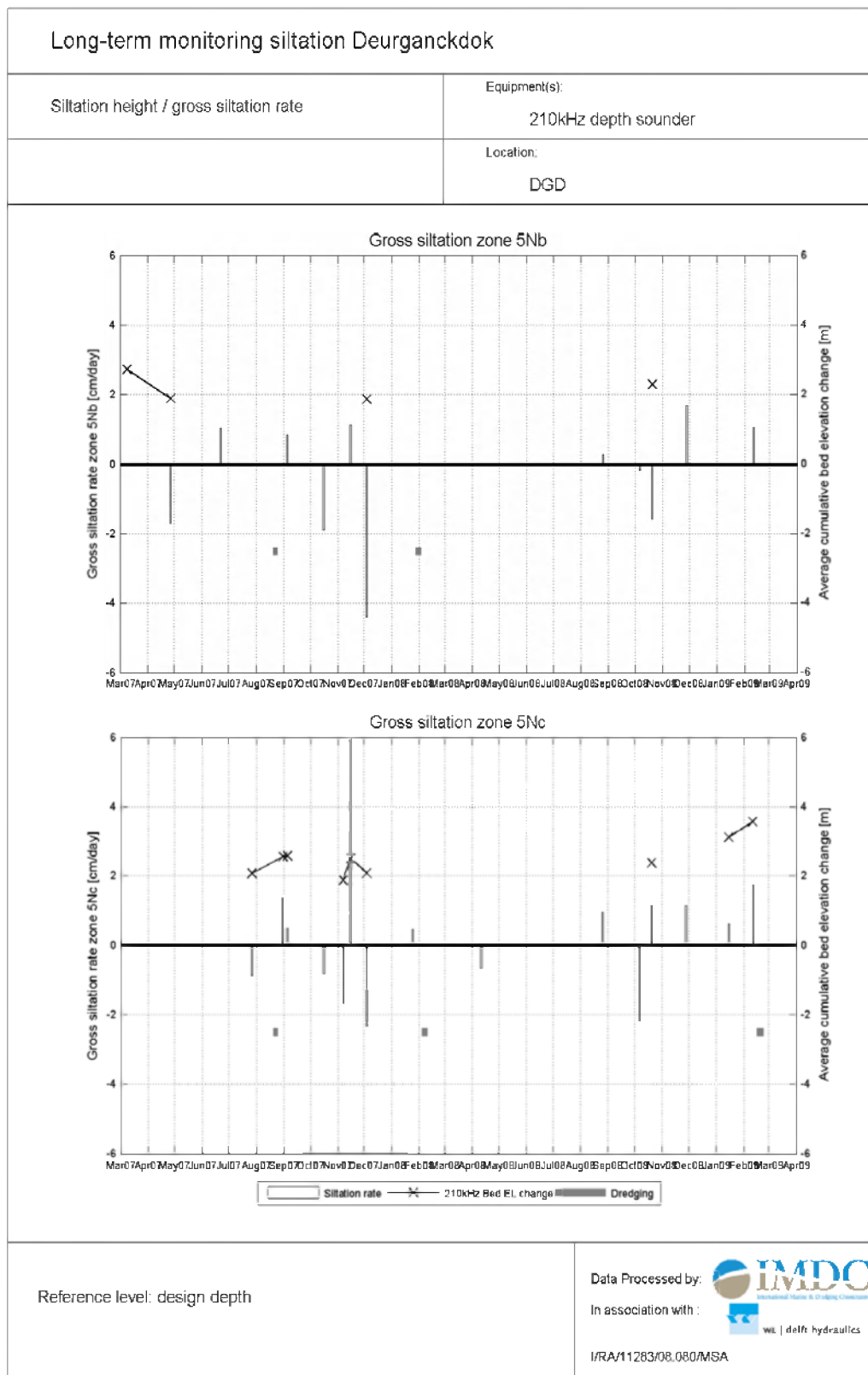


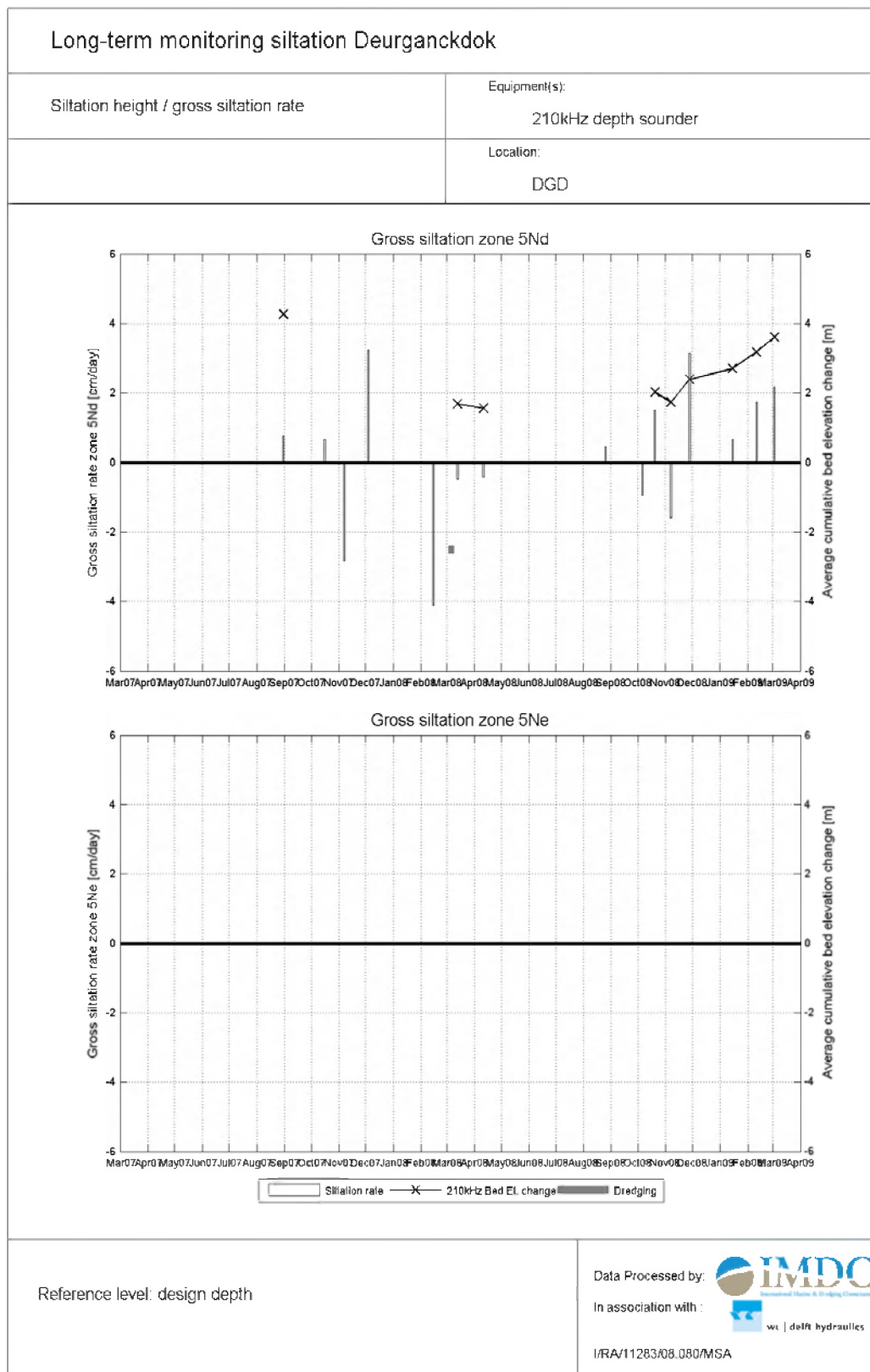


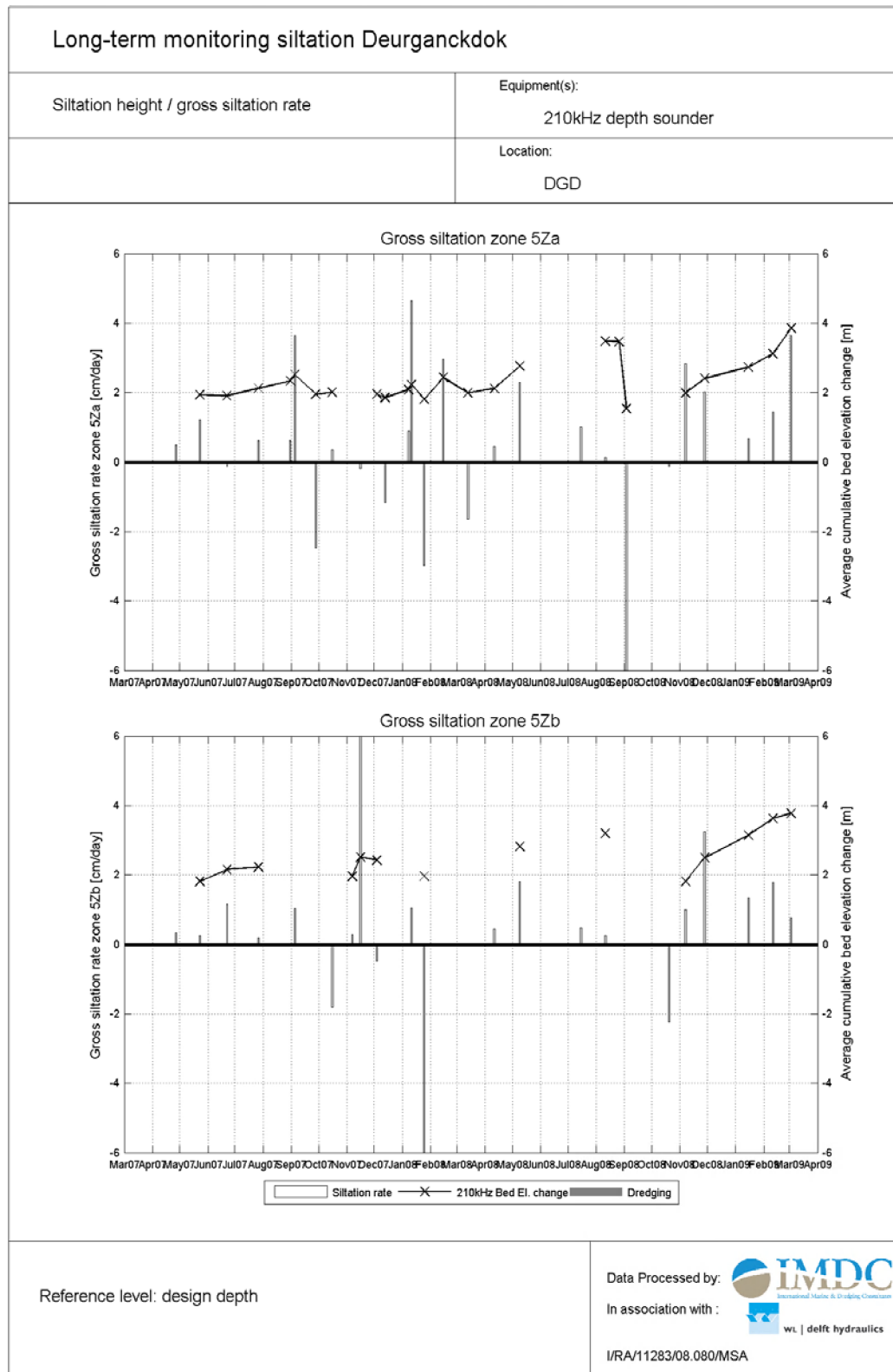


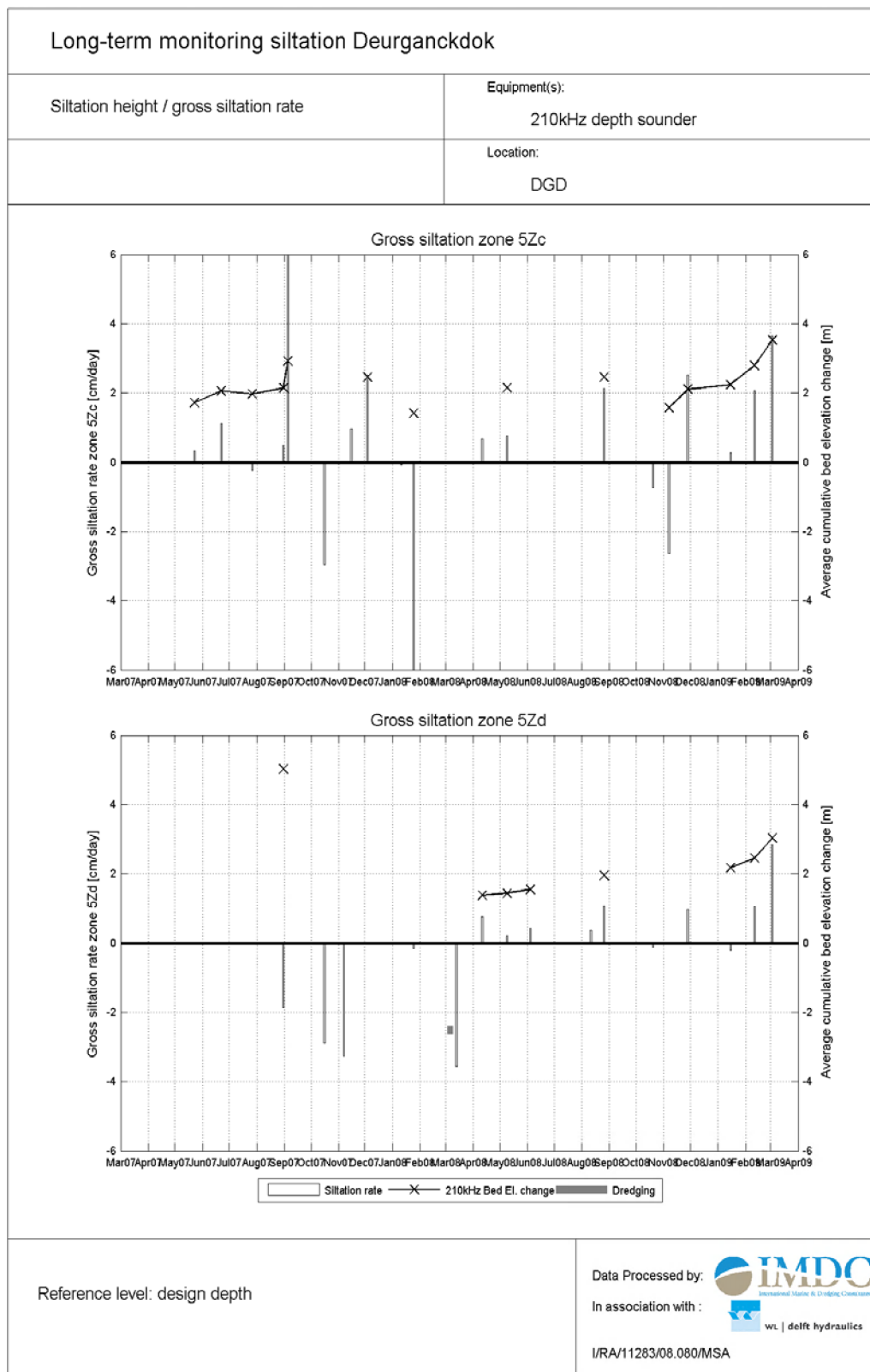


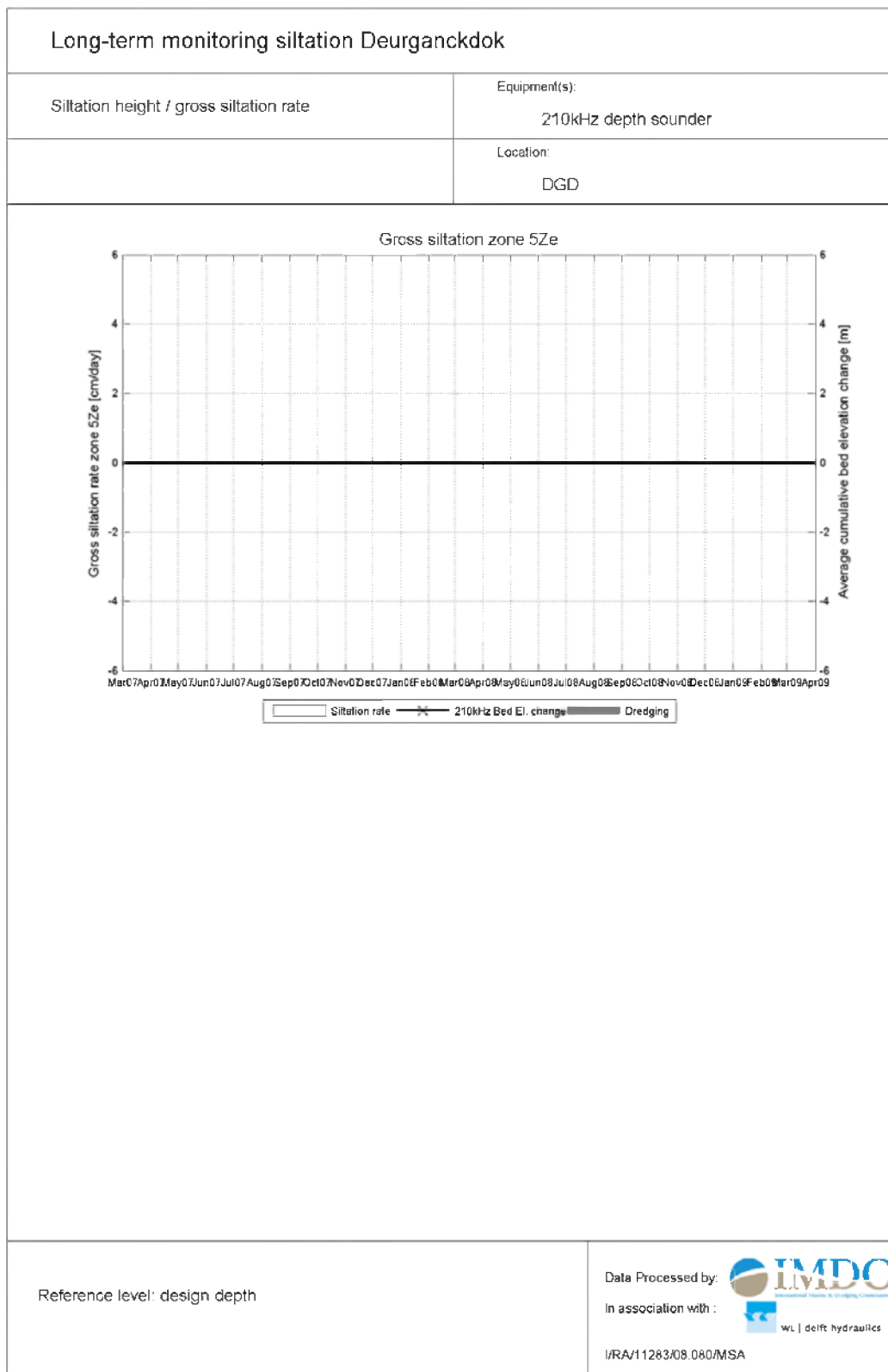




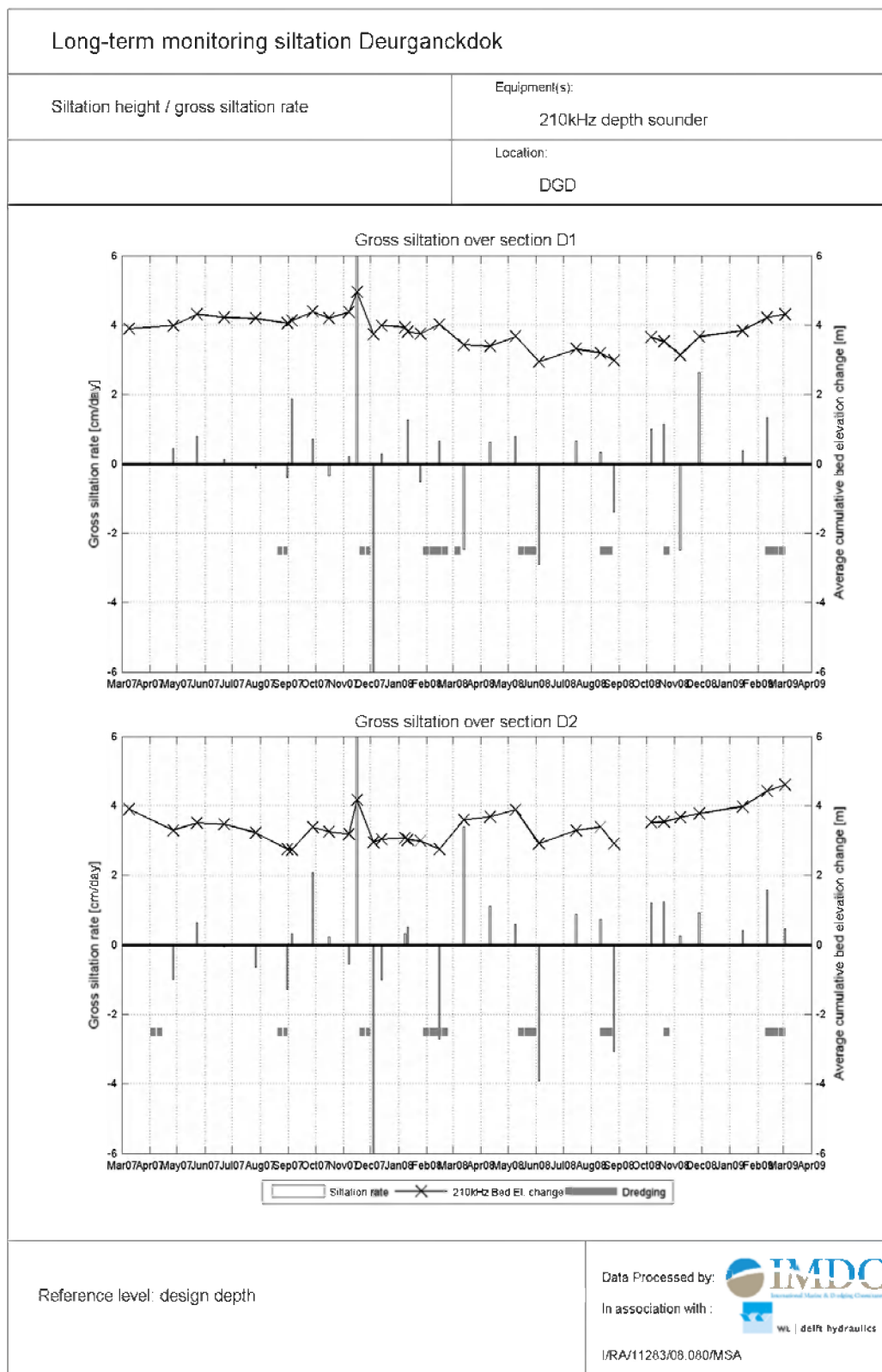


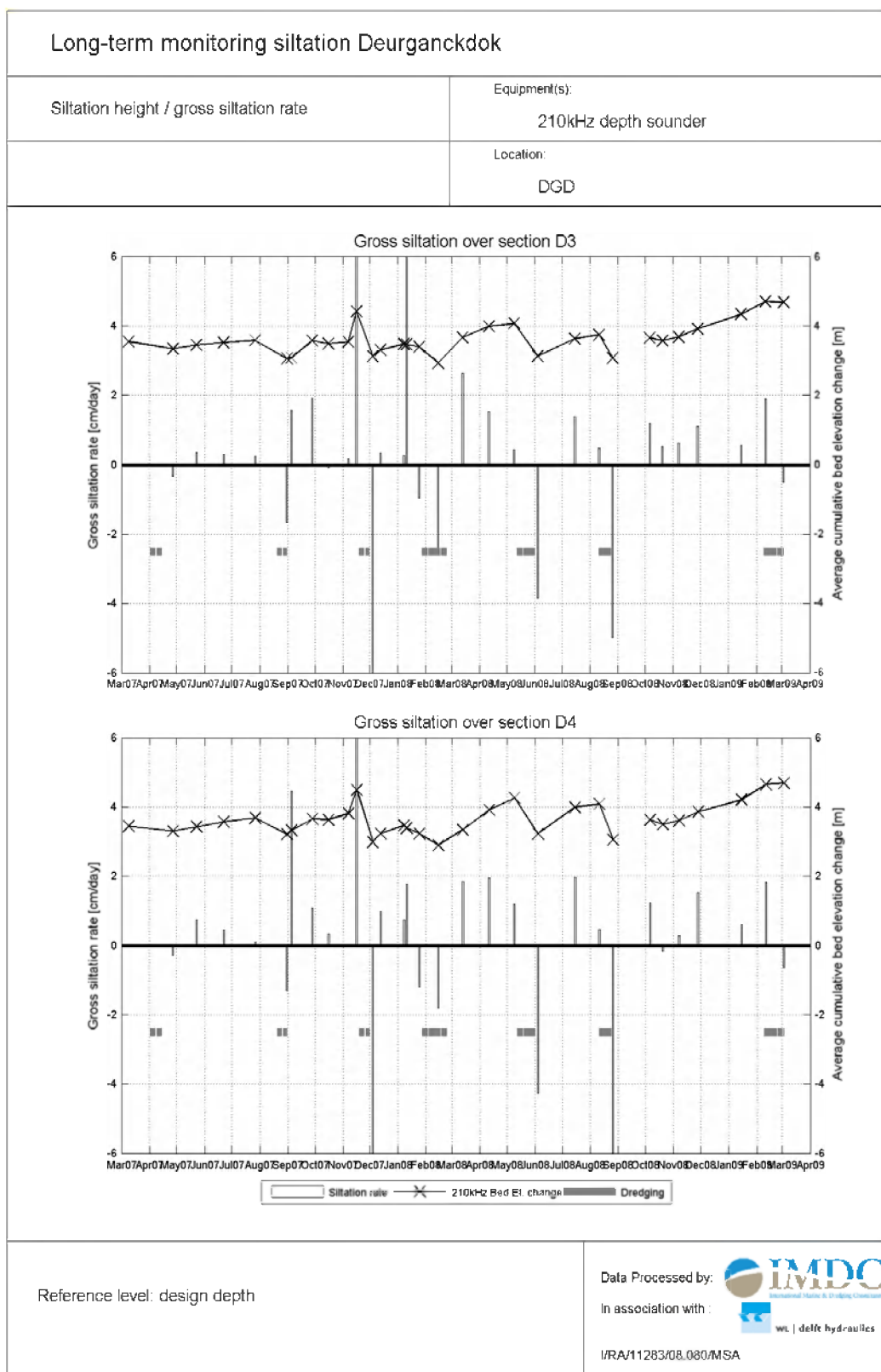


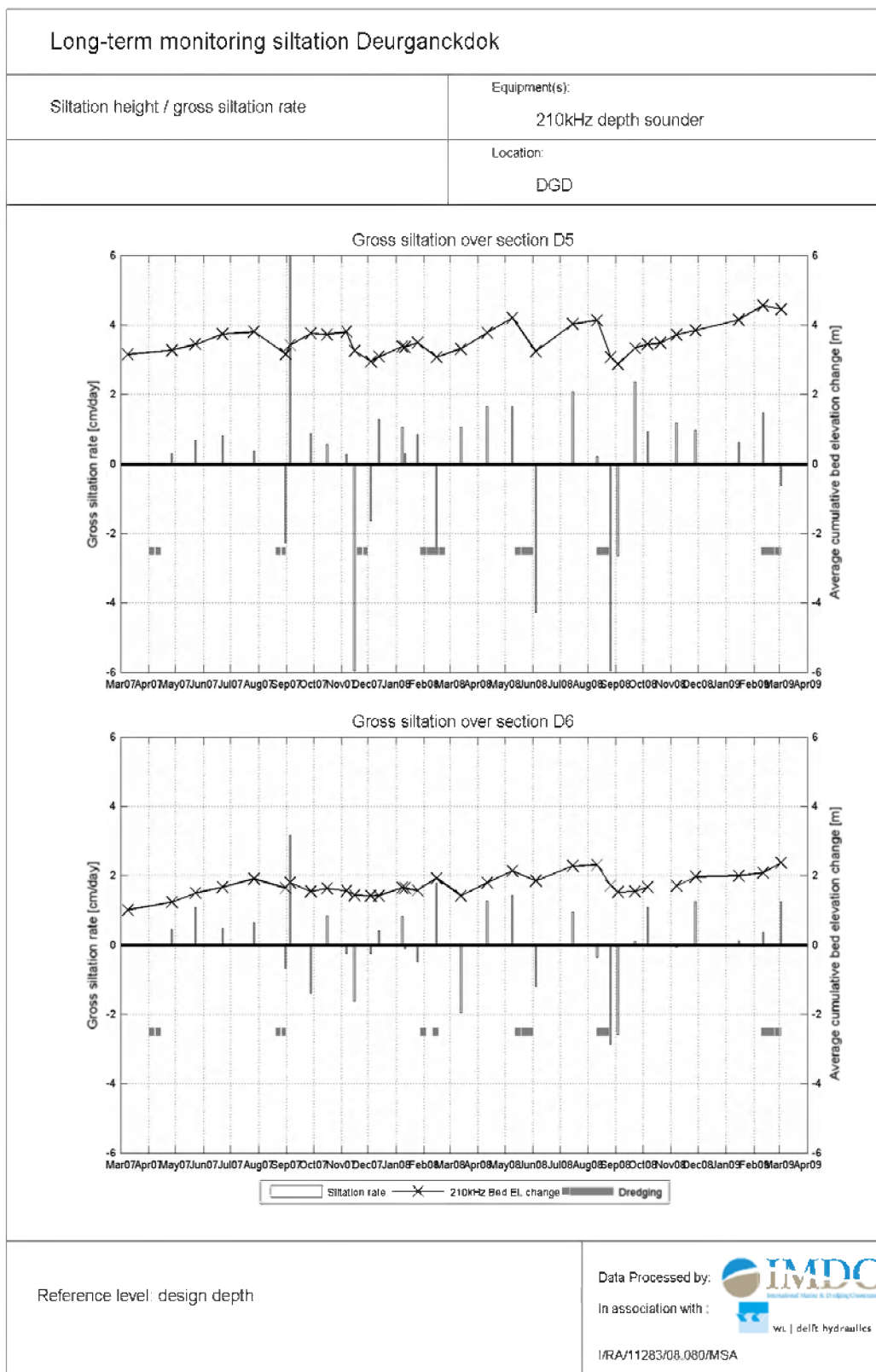


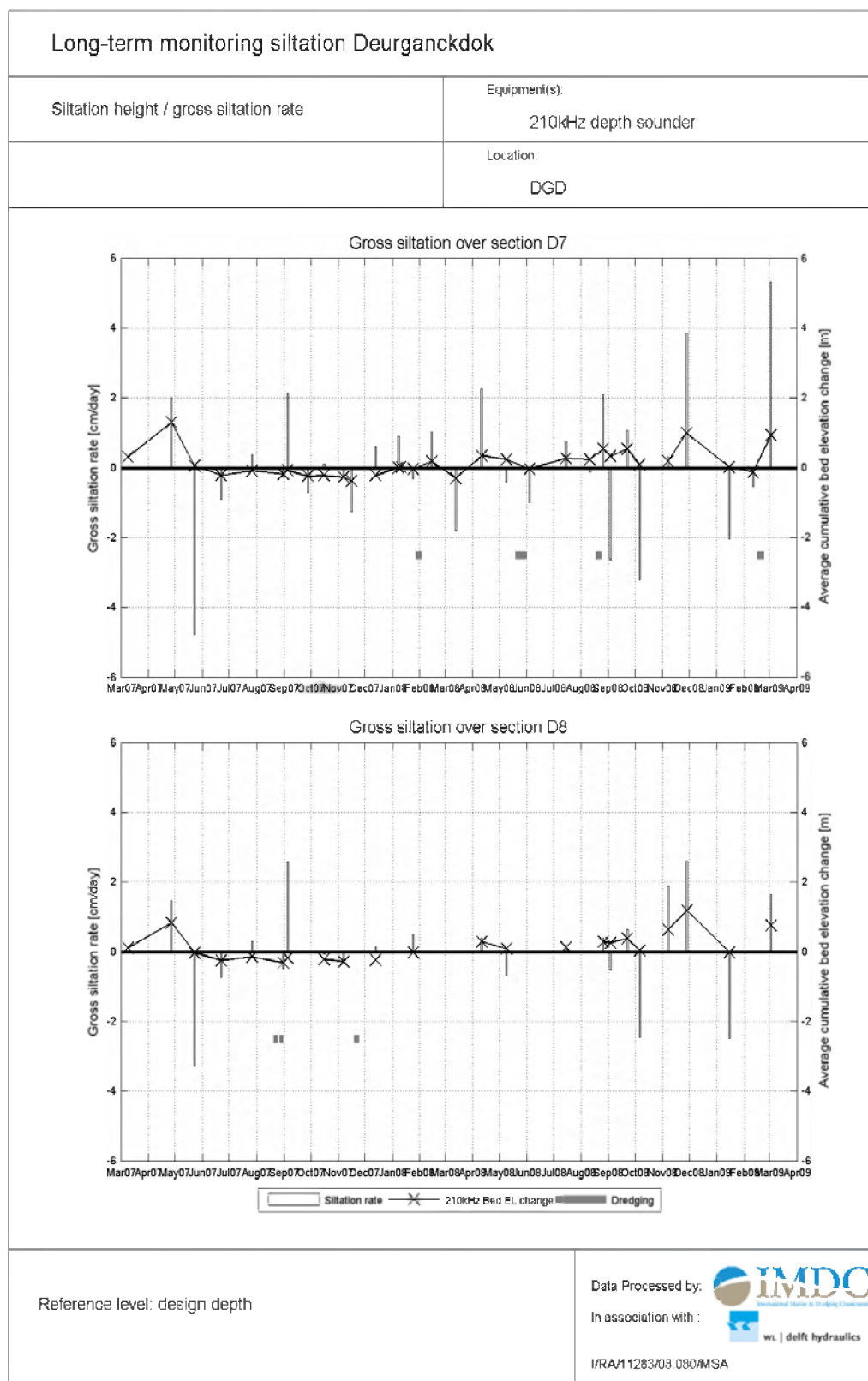


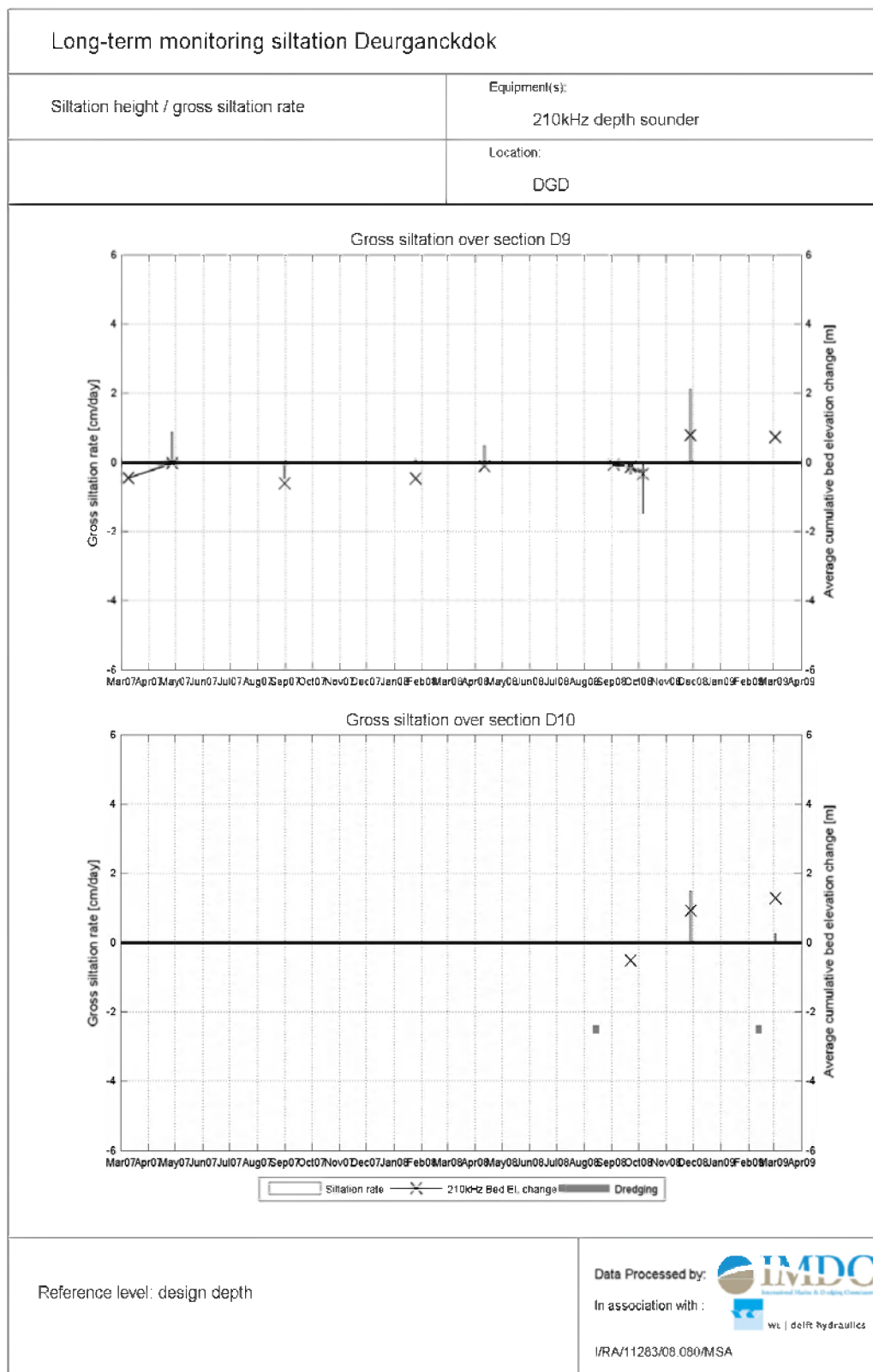
C.3 Water-bed interface evolution for all sections

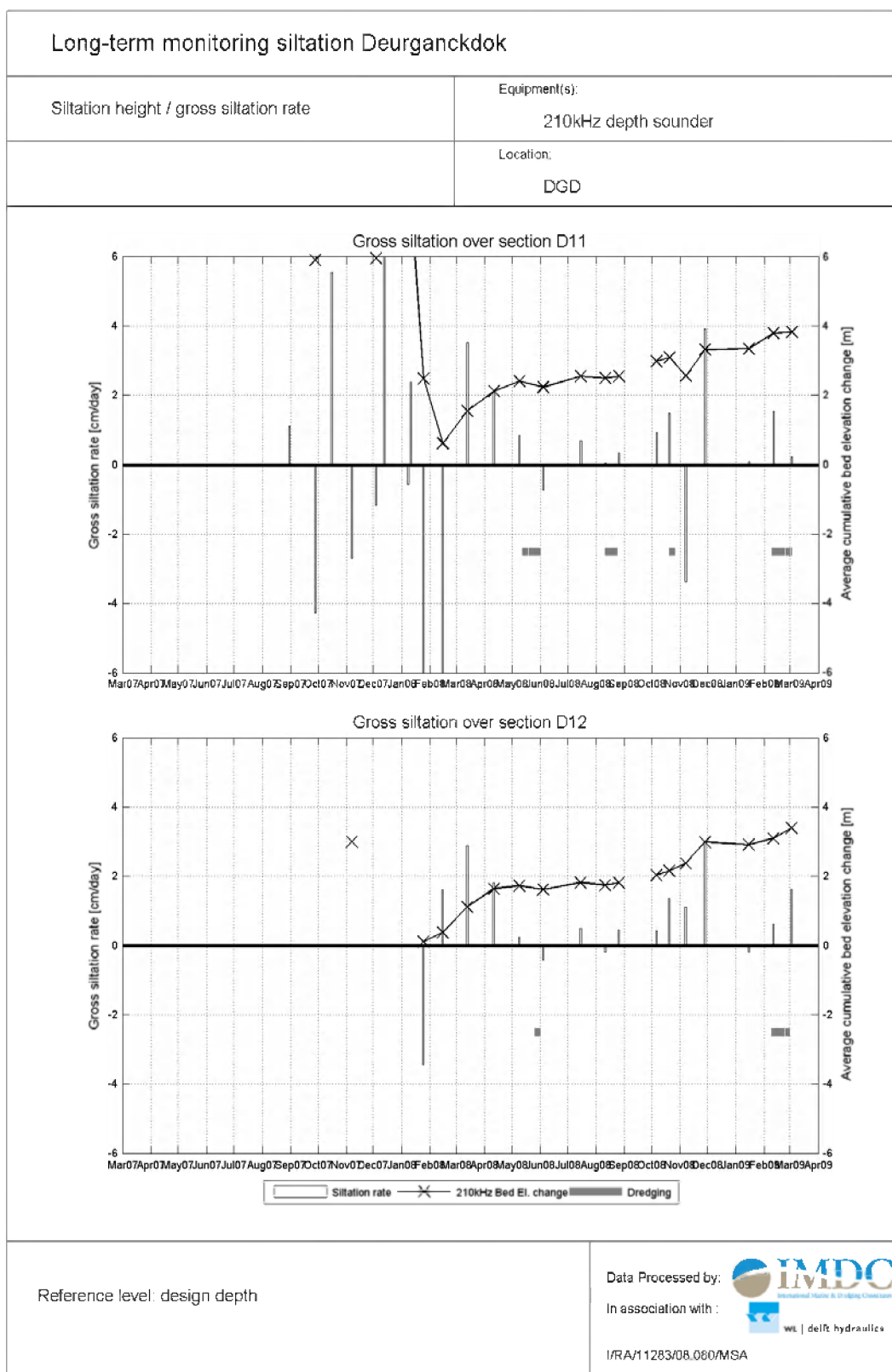


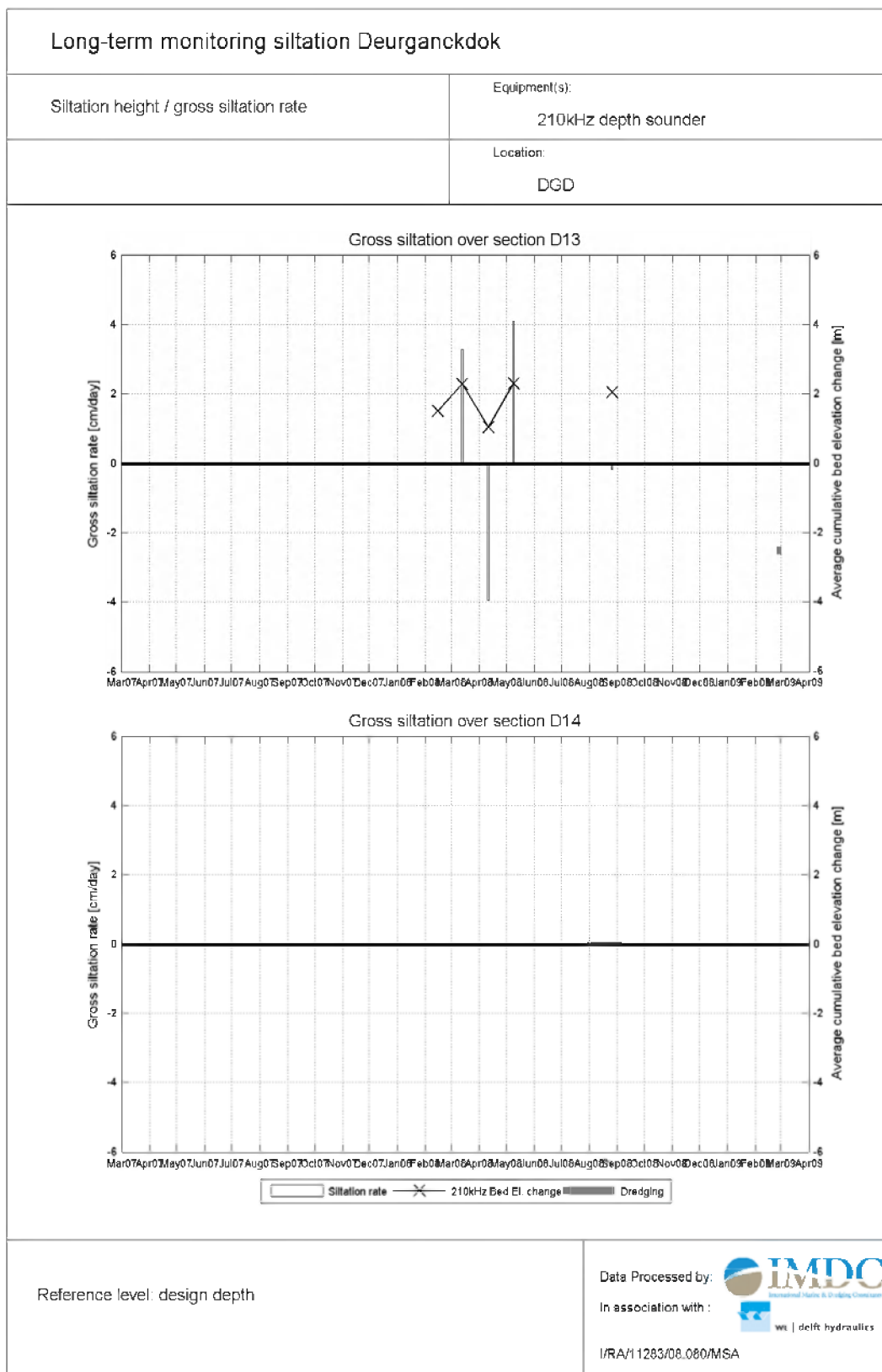


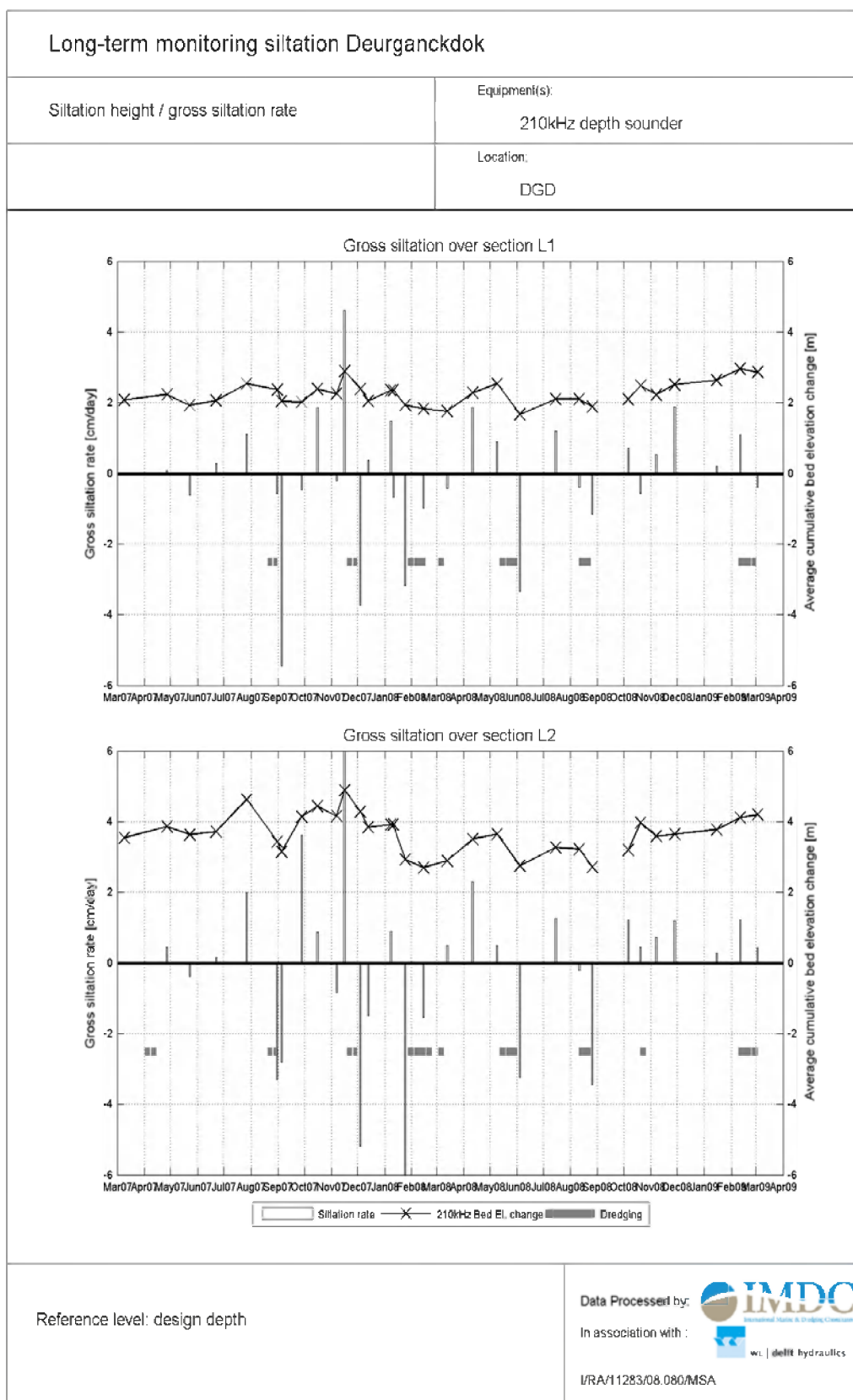


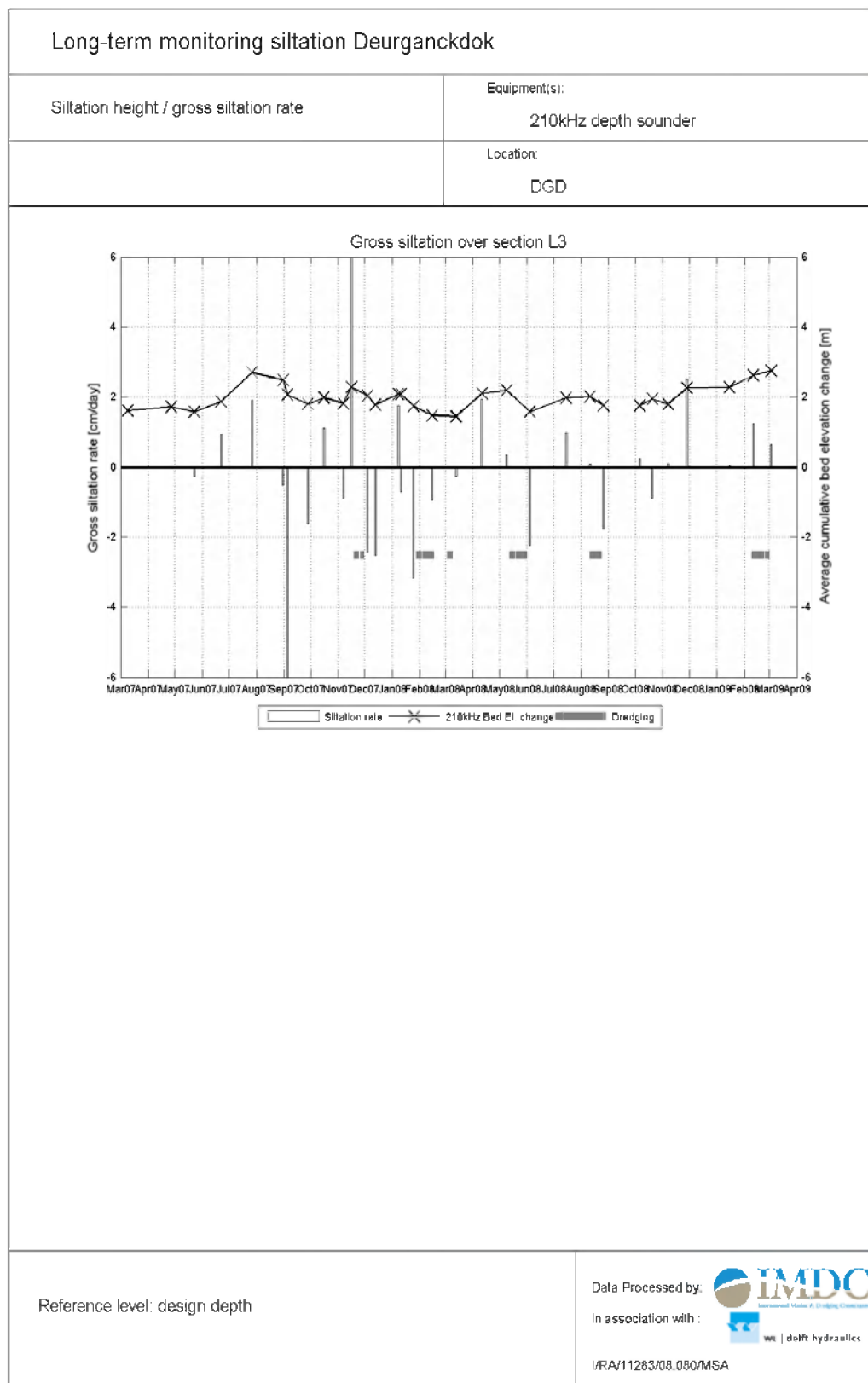




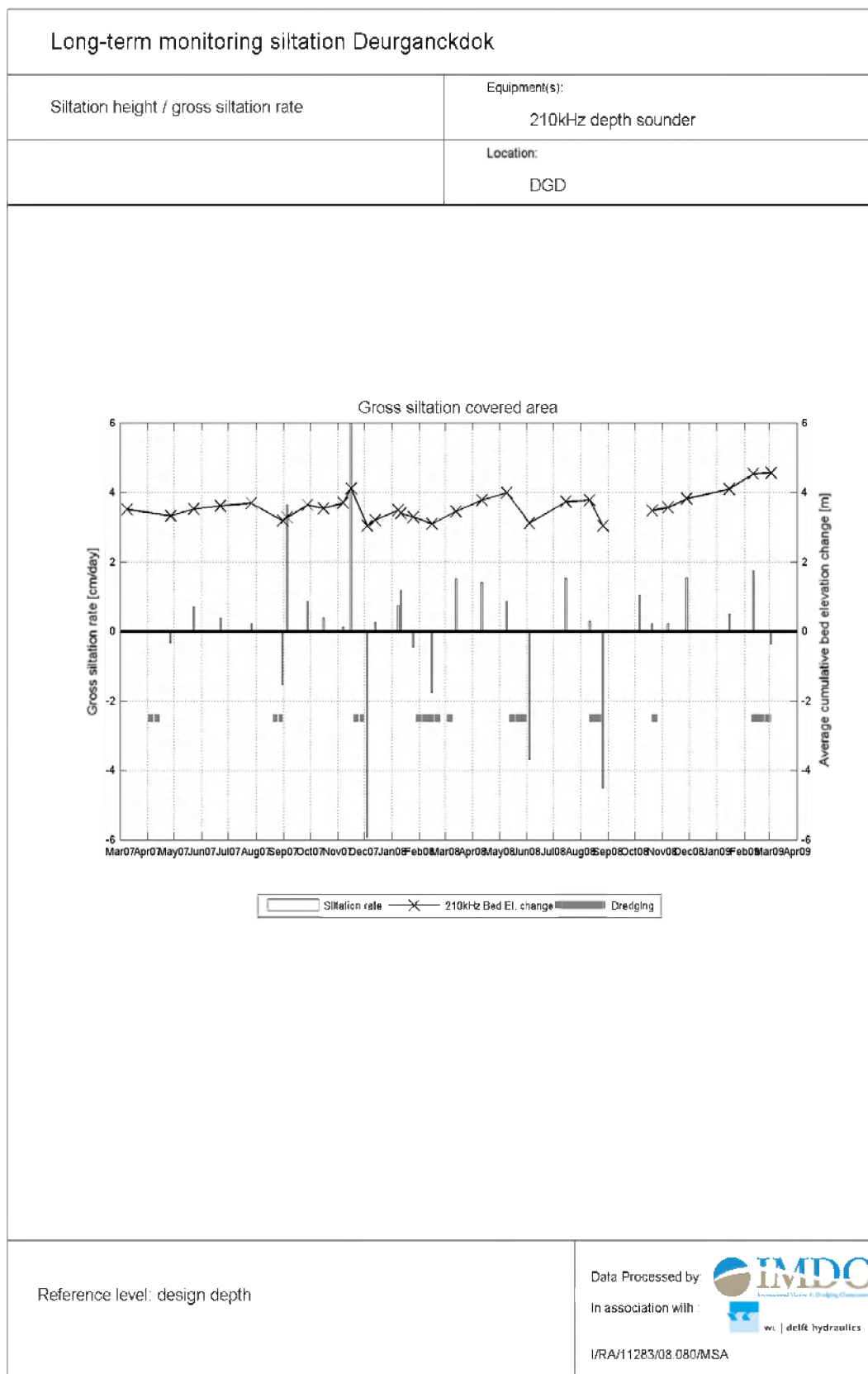








C.4 Siltation rate complete Deurganckdok



APPENDIX D.

AVERAGE MASS GROWTH AND GROWTH RATE

D.1 Difference maps

D.2 Tabular results

**Measured Mass (TDS/m²)

	05-Sep-07	16-Oct-07	16-Nov-07	05-Dec-07	24-Jan-08	22-Feb-08	28-Apr-08	05-Jun-08	11-Aug-08	26-Aug-08	11-Sep-08	20-Oct-08	06-Nov-08	30-Jan-09	12-Mar-09
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	0.52	0.58	-	-	-	-	-	-	-	-	-	-	-	-	-
3a	1.41	1.73	1.94	-	1.72	1.19	1.68	1.00	1.62	0.88	1.20	1.77	1.69	2.10	1.69
3b	1.13	1.34	1.50	1.29	1.32	0.91	1.31	0.87	1.24	0.83	1.07	1.40	1.37	1.60	1.33
3c	1.28	1.40	1.46	1.26	1.25	1.03	1.22	0.86	1.12	0.82	1.01	1.25	1.21	1.42	1.38
3d	-	-	-	-	-	0.92	0.90	0.85	0.86	0.82	0.93	1.05	0.89	1.27	1.19
3e	-	-	-	-	-	-	-	-	-	-	1.00	1.08	1.23	3.22	2.18
4Na	1.17	1.04	1.20	-	0.94	0.74	0.98	0.70	0.98	0.60	0.80	0.98	1.01	1.34	1.02
4Nb	0.95	0.86	0.94	-	0.82	0.58	0.81	0.50	0.74	0.59	0.69	0.95	0.89	1.09	0.89
4Nc	0.75	0.77	0.82	-	0.75	0.62	0.68	0.51	0.68	0.59	0.54	1.07	0.79	0.85	0.87
4Nd	-	-	-	-	-	0.88	0.48	0.39	0.55	0.60	0.43	0.79	0.63	0.86	0.80
4Ne	-	-	-	-	-	-	-	-	-	-	0.80	0.87	-	1.75	2.37
4Za	1.02	0.88	1.06	-	0.94	1.00	1.07	0.60	0.97	0.56	0.92	0.85	0.85	1.22	1.16
4Zb	0.93	0.77	0.91	-	0.75	0.68	0.79	0.53	0.69	0.52	0.74	0.87	0.75	0.96	0.98
4Zc	0.74	0.74	0.79	-	0.55	0.62	0.72	0.50	0.62	0.62	0.68	0.91	0.94	1.07	1.24
4Zd	-	-	-	-	-	0.82	0.54	0.42	0.54	0.52	0.57	0.78	0.81	1.13	1.22
4Ze	-	-	-	-	-	-	-	-	-	-	0.56	1.04	1.30	2.31	1.42
5Na	1.24	0.88	-	-	0.84	-	-	-	-	-	0.76	-	-	-	-
5Nb	1.14	0.90	-	-	0.70	-	0.82	0.52	0.81	-	0.79	0.76	0.70	0.90	1.08
5Nc	0.89	1.11	-	-	-	-	0.55	0.46	0.74	0.84	0.52	0.90	0.60	0.69	1.05
5Nd	-	-	-	-	-	-	0.32	0.24	0.51	-	0.20	-	0.38	0.67	0.91
5Ne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

****Measured Mass (TDS/m²)**

	05-Sep-07	16-Oct-07	16-Nov-07	05-Dec-07	24-Jan-08	22-Feb-08	28-Apr-08	05-Jun-08	11-Aug-08	26-Aug-08	11-Sep-08	20-Oct-08	06-Nov-08	30-Jan-09	12-Mar-09
5Za	0.82	-	0.84	-	0.68	-	-	-	-	-	-	-	-	-	-
5Zb	0.91	0.61	0.73	-	0.69	-	0.62	0.73	0.83	0.87	0.77	0.59	0.48	0.85	1.10
5Zc	-	0.59	-	-	-	-	0.59	0.44	0.68	0.73	0.71	0.71	0.74	0.70	1.08
5Zd	-	-	-	-	-	-	0.32	0.23	0.50	-	0.54	0.57	0.53	0.43	1.10
5Ze	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trench area mean	1.64	1.74	1.71	1.34	1.43	1.00	1.25	0.89	1.18	0.83	1.04	1.35	1.26	1.57	1.38

****Cumulative dredged mass in covered area (TDS)**

	05-Sep-07	16-Oct-07	16-Nov-07	05-Dec-07	24-Jan-08	22-Feb-08	28-Apr-08	05-Jun-08	11-Aug-08	26-Aug-08	11-Sep-08	20-Oct-08	06-Nov-08	30-Jan-09	12-Mar-09
1	168	168	168	196	196	196	196	196	196	236	236	236	236	236	264
2	1397	1397	1397	1427	1427	1767	1767	4025	4025	4854	4854	4854	4854	4854	6264
3a	100012	100012	100012	183532	183532	276927	276927	394510	394510	534785	534785	534785	534785	534785	592465
3b	101145	101145	101145	166723	166723	247239	247239	343264	343264	454137	454137	454137	454137	454137	493322
3c	69888	69888	69888	120397	120397	186486	207151	271242	271242	337665	337665	337665	363089	363089	392657
3d	2	2	2	567	567	1056	45001	60776	60776	78042	78042	78042	131936	131936	166799
3e	0	0	0	0	0	0	0	541	541	541	541	541	541	541	3311
4Na	13417	13417	13417	30401	30401	43770	43770	59267	59267	77087	77087	77087	77087	77087	93596
4Nb	11963	11963	11963	25875	25875	37656	37656	54643	54643	63023	63023	63023	63023	63023	80405
4Nc	5772	5772	5772	15231	15231	23121	25297	33070	33070	34740	34740	34740	34764	34764	47030
4Nd	0	0	0	14	14	14	8056	9494	9494	9570	9570	9570	9671	9671	18733
4Ne	0	0	0	0	0	0	0	64	64	64	64	64	64	64	155
4Za	505	505	505	11308	11308	18930	18930	33788	33788	44385	44385	44385	44385	44385	54230
4Zb	144	144	144	16474	16474	25109	25109	40083	40083	47269	47269	47269	47269	47269	58804
4Zc	28	28	28	6767	6767	10684	12990	17467	17467	18757	18757	18757	18758	18758	26802
4Zd	0	0	0	0	0	0	4048	4594	4594	4607	4607	4607	4635	4635	11653
4Ze	0	0	0	0	0	0	0	2	2	2	2	2	2	2	94
5Na	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7
5Nb	29	29	29	29	29	98	98	98	98	98	98	98	98	98	98
5Nc	19	19	19	19	19	26	26	26	26	26	26	26	26	26	30
5Nd	0	0	0	0	0	0	26	26	26	26	26	26	26	26	26

**Cumulative dredged mass in covered area (TDS)

	05-Sep-07	16-Oct-07	16-Nov-07	05-Dec-07	24-Jan-08	22-Feb-08	28-Apr-08	05-Jun-08	11-Aug-08	26-Aug-08	11-Sep-08	20-Oct-08	06-Nov-08	30-Jan-09	12-Mar-09
5Ne	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5Za	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5Zb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5Zc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5Zd	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2
5Ze	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	304494	304494	304494	578963	578963	873083	954291	1327186	1327186	1709924	1709924	1709924	1789394	1789394	2046744

**Total cumulative mass(TDS/m²)

	05-Sep-07	16-Oct-07	16-Nov-07	05-Dec-07	24-Jan-08	22-Feb-08	28-Apr-08	05-Jun-08	11-Aug-08	26-Aug-08	11-Sep-08	20-Oct-08	06-Nov-08	30-Jan-09	12-Mar-09
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	0.53	0.59	-	-	-	-	-	-	-	-	-	-	-	-	-
3a	2.42	2.74	2.95	-	3.58	3.99	4.48	5.00	5.61	6.29	6.62	7.19	7.11	7.51	7.69
3b	2.05	2.26	2.42	2.80	2.84	3.16	3.56	3.99	4.37	4.96	5.20	5.53	5.50	5.74	5.82
3c	1.99	2.10	2.17	2.48	2.47	2.91	3.31	3.60	3.86	4.23	4.41	4.66	4.87	5.08	5.35
3d	-	-	-	-	-	0.93	1.24	1.31	1.32	1.41	1.53	1.65	1.91	2.28	2.47
3e	-	-	-	-	-	-	-	-	-	-	1.00	1.08	1.24	3.22	2.21
4Na	1.54	1.41	1.56	-	1.78	1.95	2.18	2.33	2.61	2.72	2.92	3.10	3.13	3.46	3.59
4Nb	1.34	1.24	1.33	-	1.65	1.79	2.02	2.25	2.50	2.61	2.71	2.98	2.91	3.11	3.47
4Nc	0.97	0.99	1.04	-	1.34	1.52	1.66	1.79	1.97	1.94	1.89	2.42	2.14	2.20	2.70
4Nd	-	-	-	-	-	0.88	0.72	0.68	0.84	0.89	0.72	1.08	0.93	1.15	1.38
4Ne	-	-	-	-	-	-	-	-	-	-	0.81	0.88	-	1.75	2.37
4Za	1.04	0.90	1.08	-	1.41	1.78	1.85	1.99	2.37	2.40	2.76	2.68	2.68	3.05	3.40
4Zb	0.93	0.77	0.92	-	1.28	1.49	1.60	1.81	1.97	2.03	2.25	2.38	2.26	2.47	2.87
4Zc	0.74	0.74	0.79	-	0.81	1.04	1.22	1.17	1.30	1.35	1.40	1.64	1.66	1.80	2.27
4Zd	-	-	-	-	-	0.82	0.66	0.56	0.69	0.66	0.72	0.92	0.96	1.28	1.58
4Ze	-	-	-	-	-	-	-	-	-	-	0.56	1.04	1.30	2.31	1.42
5Na	1.24	0.88	-	-	0.84	-	-	-	-	-	0.76	-	-	-	-
5Nb	1.14	0.90	-	-	0.70	-	0.83	0.52	0.81	-	0.80	0.76	0.70	0.91	1.09
5Nc	0.89	1.12	-	-	-	-	0.55	0.46	0.74	0.84	0.52	0.91	0.61	0.70	1.05
5Nd	-	-	-	-	-	-	0.32	0.24	0.51	-	0.20	-	0.38	0.67	0.92

**Total cumulative mass(TDS/m²)

	05-Sep-07	16-Oct-07	16-Nov-07	05-Dec-07	24-Jan-08	22-Feb-08	28-Apr-08	05-Jun-08	11-Aug-08	26-Aug-08	11-Sep-08	20-Oct-08	06-Nov-08	30-Jan-09	12-Mar-09
5Ne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5Za	0.82	-	0.84	-	0.68	-	-	-	-	-	-	-	-	-	-
5Zb	0.91	0.61	0.73	-	0.69	-	0.62	0.73	0.83	0.87	0.77	0.59	0.48	0.85	1.10
5Zc	-	0.59	-	-	-	-	0.59	0.44	0.68	0.73	0.71	0.71	0.74	0.70	1.08
5Zd	-	-	-	-	-	-	0.32	0.23	0.51	-	0.54	0.57	0.53	0.43	1.10
5Ze	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trench area mean	2.26	2.36	2.33	2.87	2.96	2.63	3.02	3.33	3.63	4.04	4.25	4.55	4.65	4.96	5.14

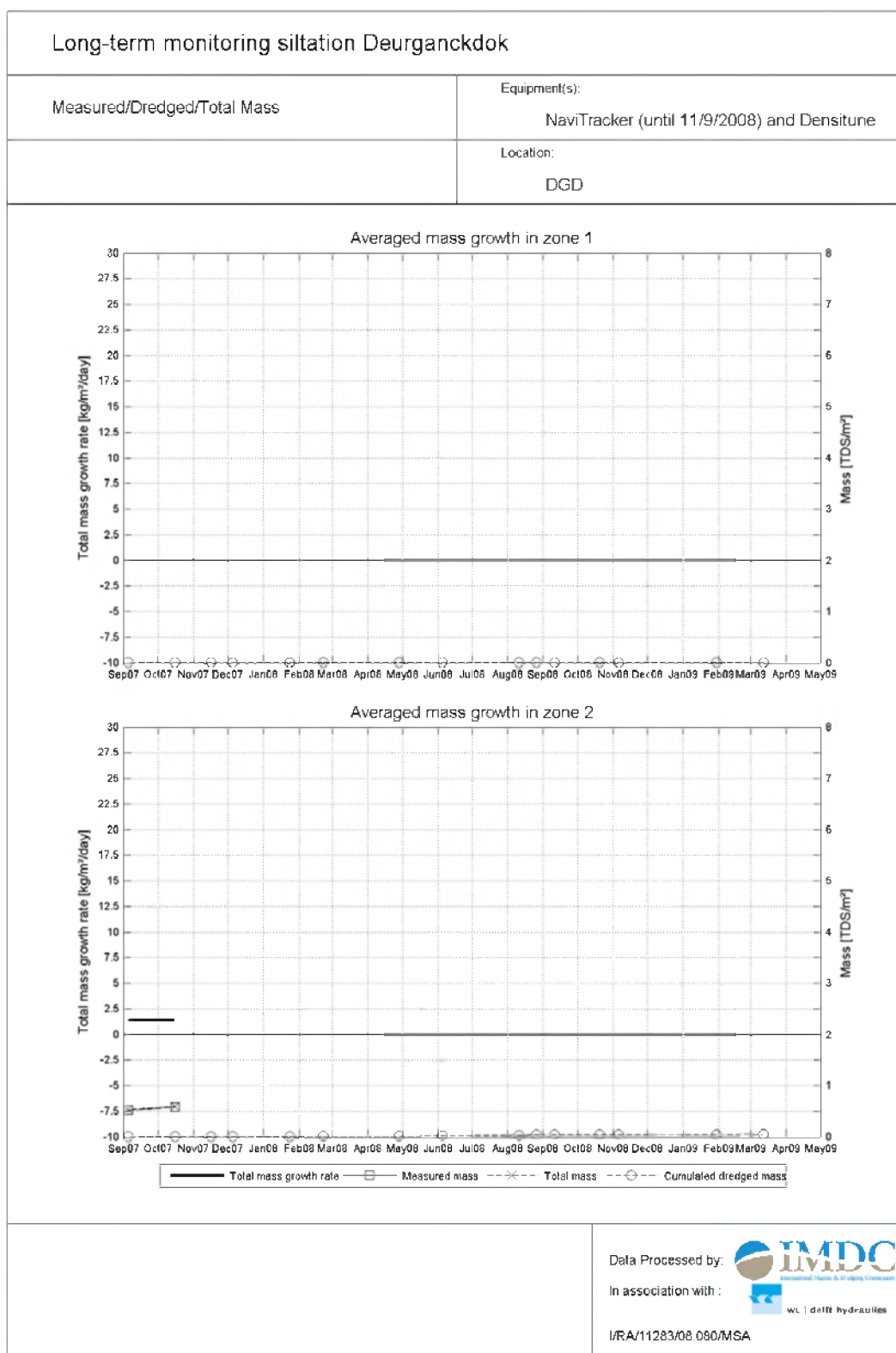
**Growth rate (kg/m²/day)

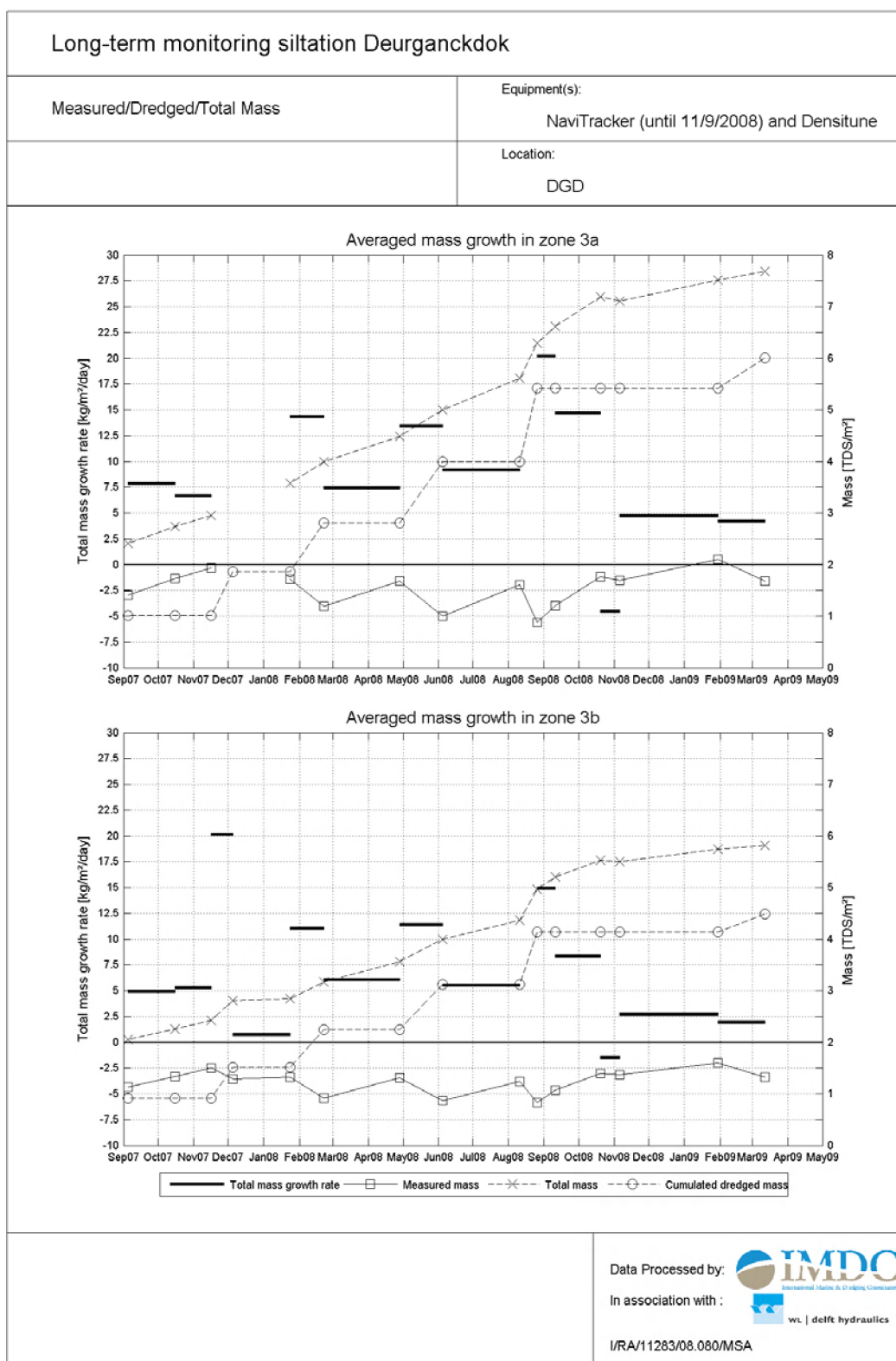
	05-Sep-07 16-Oct-07	16-Oct-07 16-Nov-07	16-Nov-07 05-Dec-07	05-Dec-07 24-Jan-08	24-Jan-08 22-Feb-08	22-Feb-08 28-Apr-08	28-Apr-08 05-Jun-08	05-Jun-08 11-Aug-08	11-Aug-08 26-Aug-08	26-Aug-08 11-Sep-08	11-Sep-08 20-Oct-08	20-Oct-08 06-Nov-08	06-Nov-08 30-Jan-09	30-Jan-09 12-Mar-09
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	1.41	-	-	-	-	-	-	-	-	-	-	-	-	-
3a	7.90	6.70	-	-	14.36	7.47	13.46	9.19	45.39	20.19	14.69	-4.51	4.74	4.24
3b	4.96	5.29	20.16	0.76	11.04	6.05	11.39	5.54	39.91	14.94	8.38	-1.48	2.75	1.92
3c	2.92	2.06	16.25	-0.24	15.35	6.00	7.72	3.83	24.64	11.77	6.34	12.32	2.51	6.45
3d	-	-	-	-	-	4.76	1.86	0.21	6.01	6.93	3.23	14.92	4.43	4.56
3e	-	-	-	-	-	-	-	-	-	-	2.09	9.13	23.34	-24.65
4Na	-3.19	5.11	-	-	5.86	3.54	3.86	4.22	7.17	12.43	4.71	1.54	3.87	3.35
4Nb	-2.22	2.65	-	-	4.67	3.58	6.07	3.63	7.53	6.42	6.76	-3.70	2.36	8.61
4Nc	0.50	1.65	-	-	6.09	2.15	3.48	2.67	-1.76	-3.44	13.73	-16.83	0.75	12.23
4Nd	-	-	-	-	-	-2.31	-1.06	2.36	3.52	-10.95	9.29	-8.95	2.63	5.49
4Ne	-	-	-	-	-	-	-	-	-	-	1.80	-	-	15.19
4Za	-3.48	5.74	-	-	12.90	1.12	3.69	5.57	2.01	22.54	-1.87	0.05	4.31	8.43
4Zb	-3.92	4.59	-	-	7.13	1.67	5.71	2.41	3.89	13.58	3.34	-6.87	2.46	9.56
4Zc	-0.03	1.49	-	-	7.88	2.82	-1.28	1.88	3.23	3.29	6.11	1.36	1.61	11.56
4Zd	-	-	-	-	-	-2.33	-2.61	1.82	-1.69	3.53	5.17	2.18	3.79	7.39
4Ze	-	-	-	-	-	-	-	-	-	-	12.30	15.08	11.88	-21.58
5Na	-8.70	-	-	-	-	-	-	-	-	-	-	-	-	-
5Nb	-5.69	-	-	-	-	-	-8.08	4.39	-	-	-0.85	-3.64	2.44	4.31
5Nc	5.39	-	-	-	-	-	-2.27	4.15	6.45	-19.80	9.83	-17.67	1.06	8.73

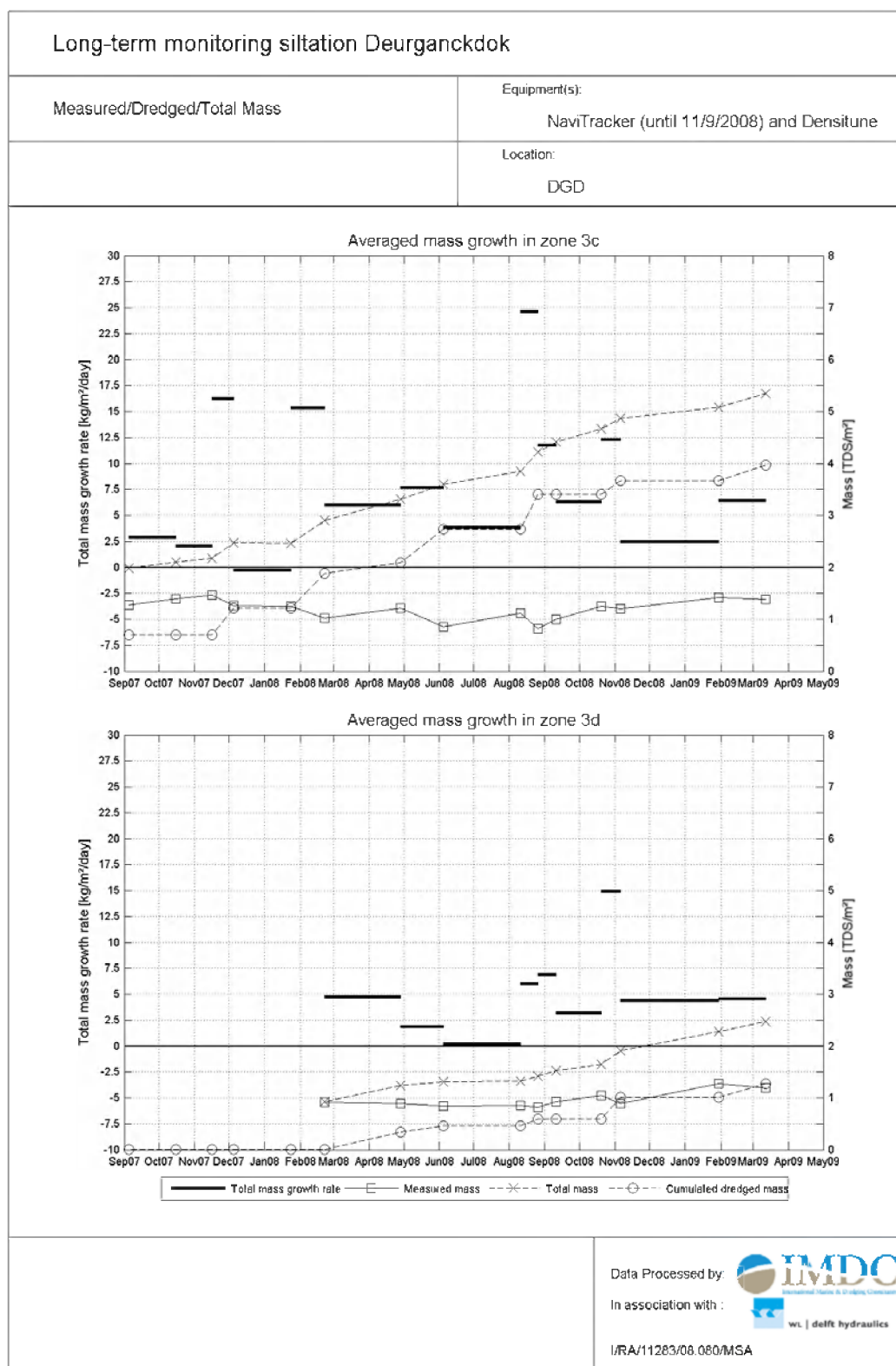
****Growth rate (kg/m²/day)**

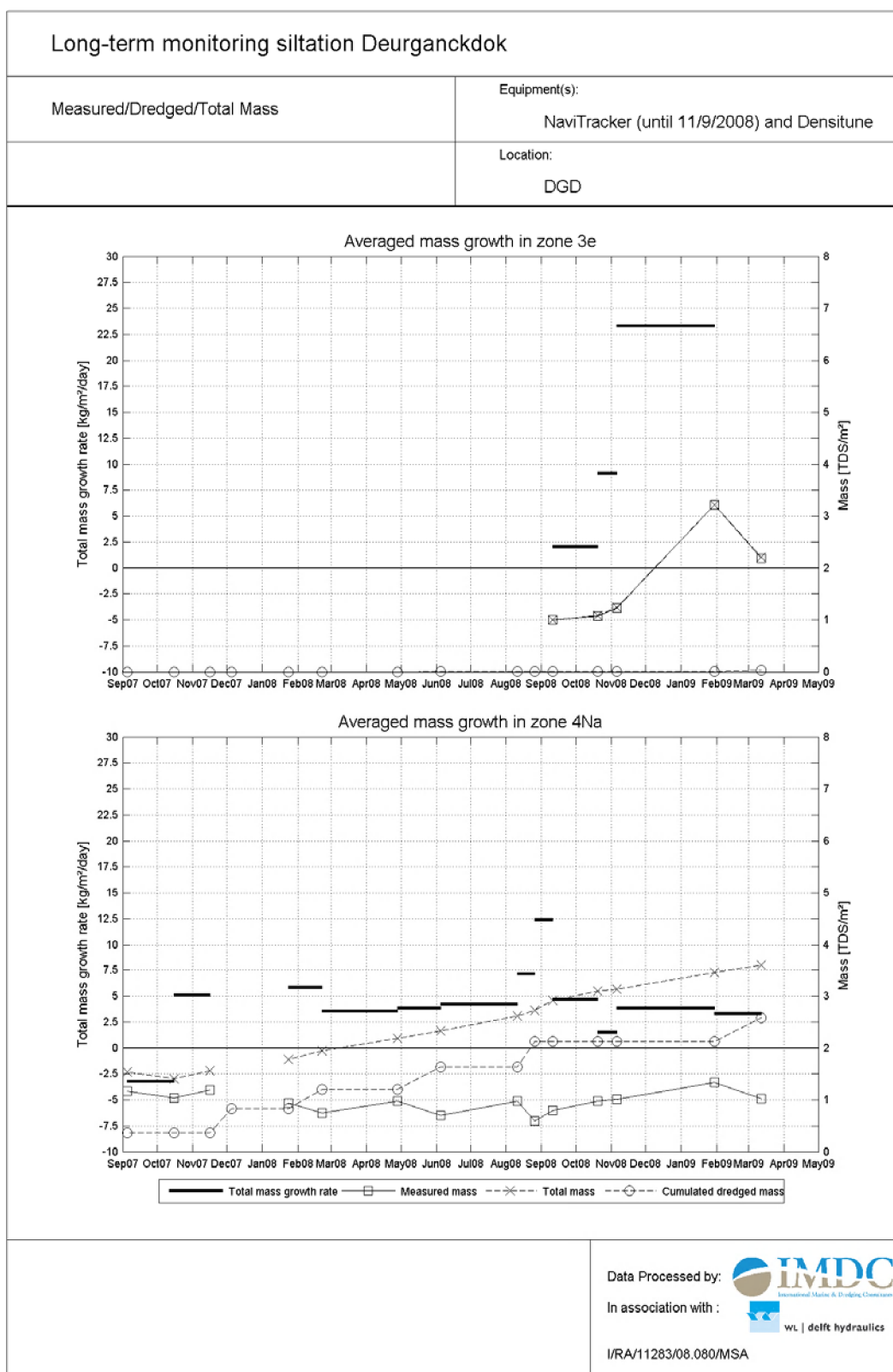
	05-Sep-07 16-Oct-07	16-Oct-07 16-Nov-07	16-Nov-07 05-Dec-07	05-Dec-07 24-Jan-08	24-Jan-08 22-Feb-08	22-Feb-08 28-Apr-08	28-Apr-08 05-Jun-08	05-Jun-08 11-Aug-08	11-Aug-08 26-Aug-08	26-Aug-08 11-Sep-08	11-Sep-08 20-Oct-08	20-Oct-08 06-Nov-08	06-Nov-08 30-Jan-09	30-Jan-09 12-Mar-09
5Nd	-	-	-	-	-	-	-2.21	4.12	-	-	-	-	3.34	6.05
5Ne	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5Za	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5Zb	-7.24	3.76	-	-	-	-	2.85	1.54	2.36	-6.00	-4.59	-6.33	4.29	6.13
5Zc	-	-	-	-	-	-	-3.91	3.56	3.56	-1.03	-0.08	1.60	-0.43	9.18
5Zd	-	-	-	-	-	-	-2.36	4.13	-	-	0.76	-2.34	-1.22	16.48
5Ze	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trench area mean	2.55	-0.94	28.06	1.80	-11.38	5.97	8.19	4.39	27.59	13.02	7.80	5.84	3.64	4.25

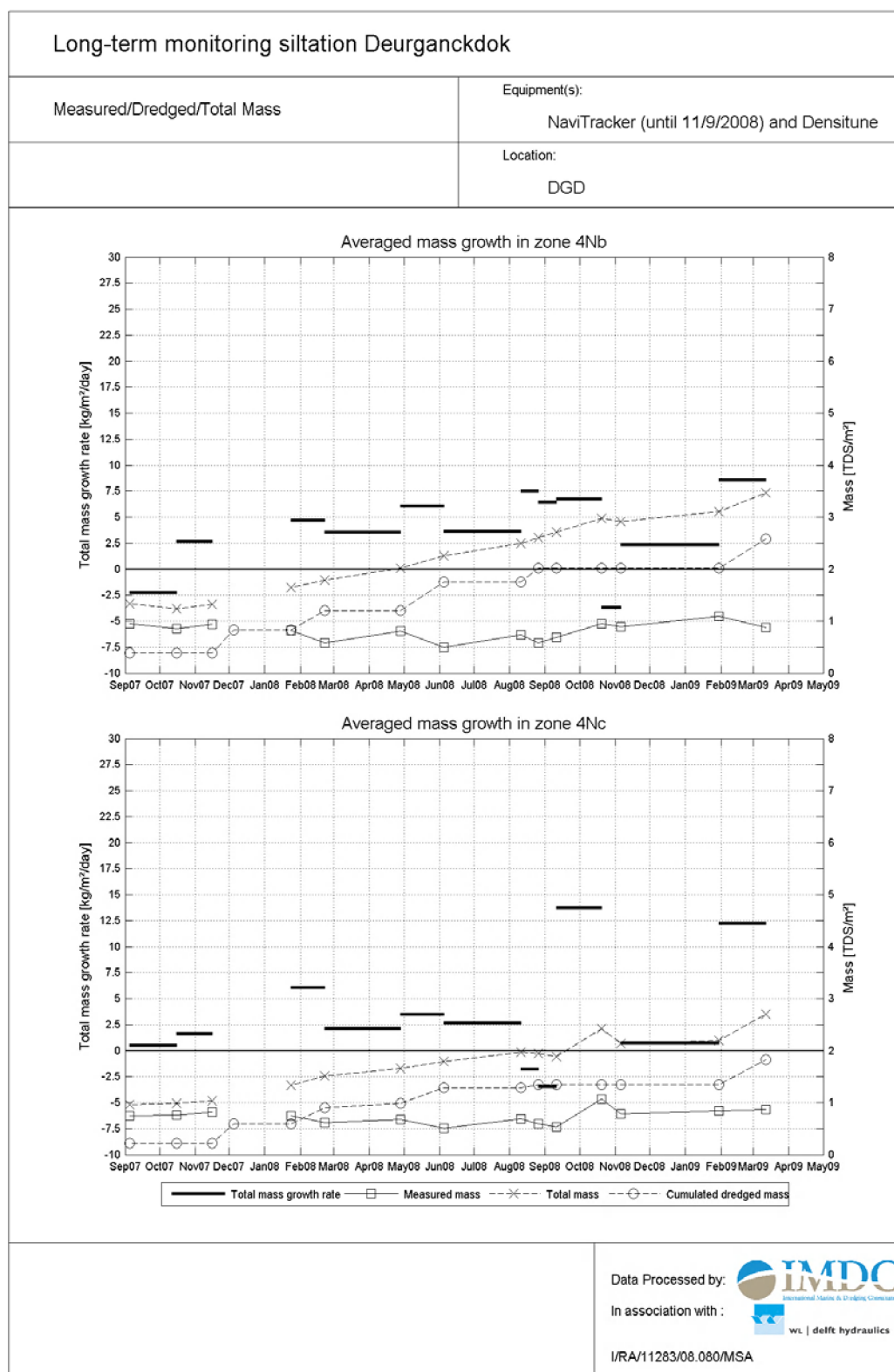
D.3 For each zone

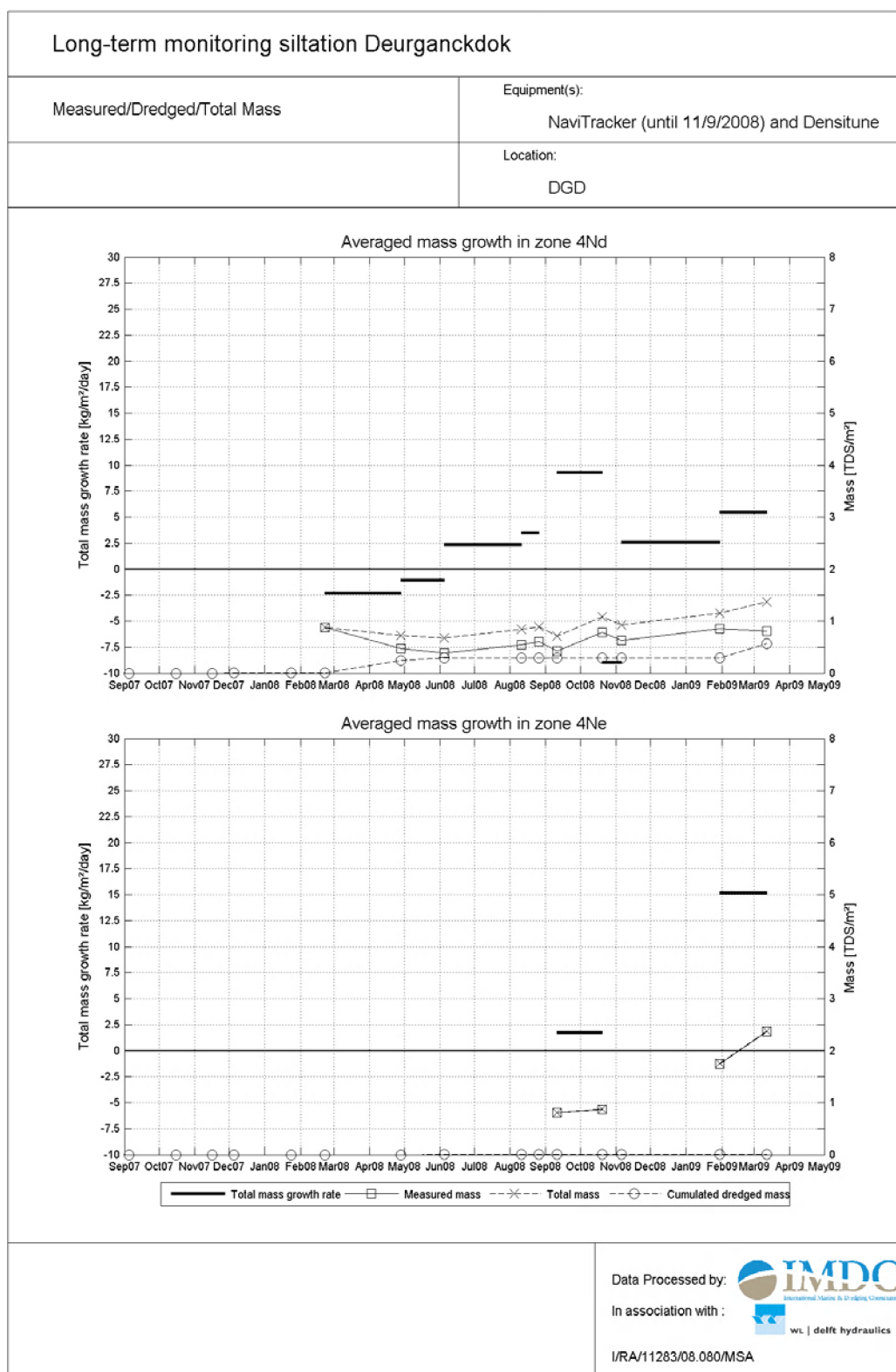


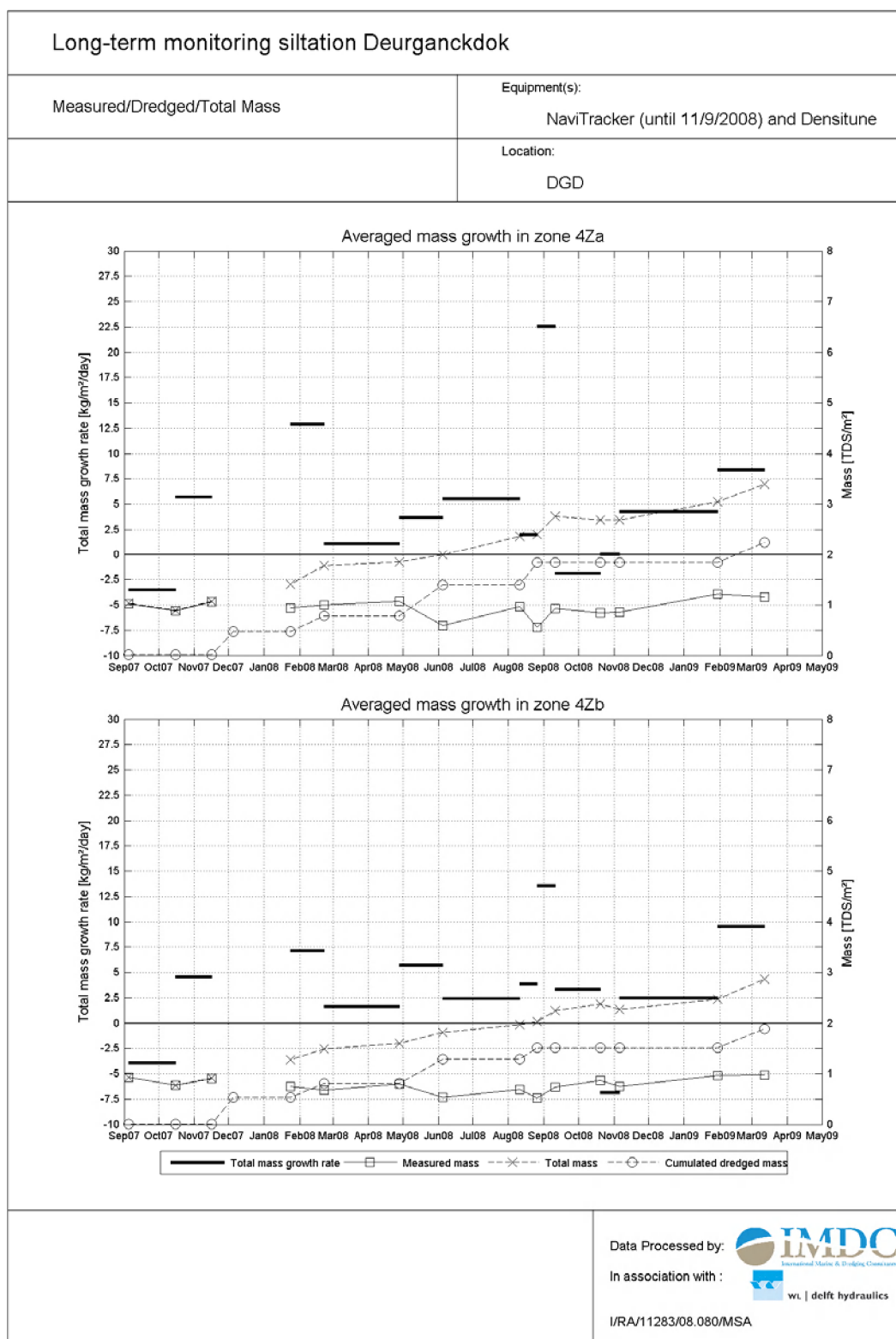


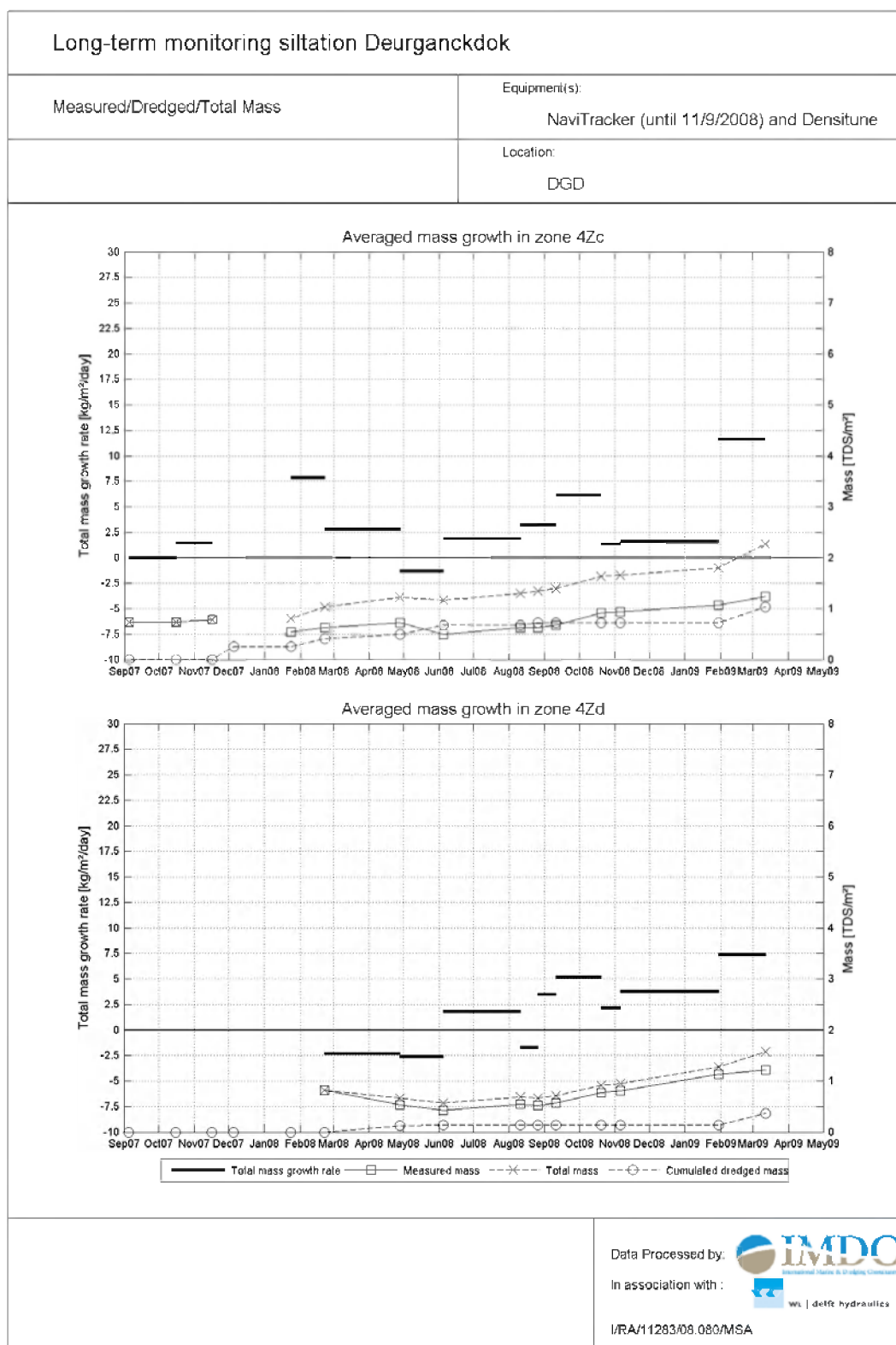


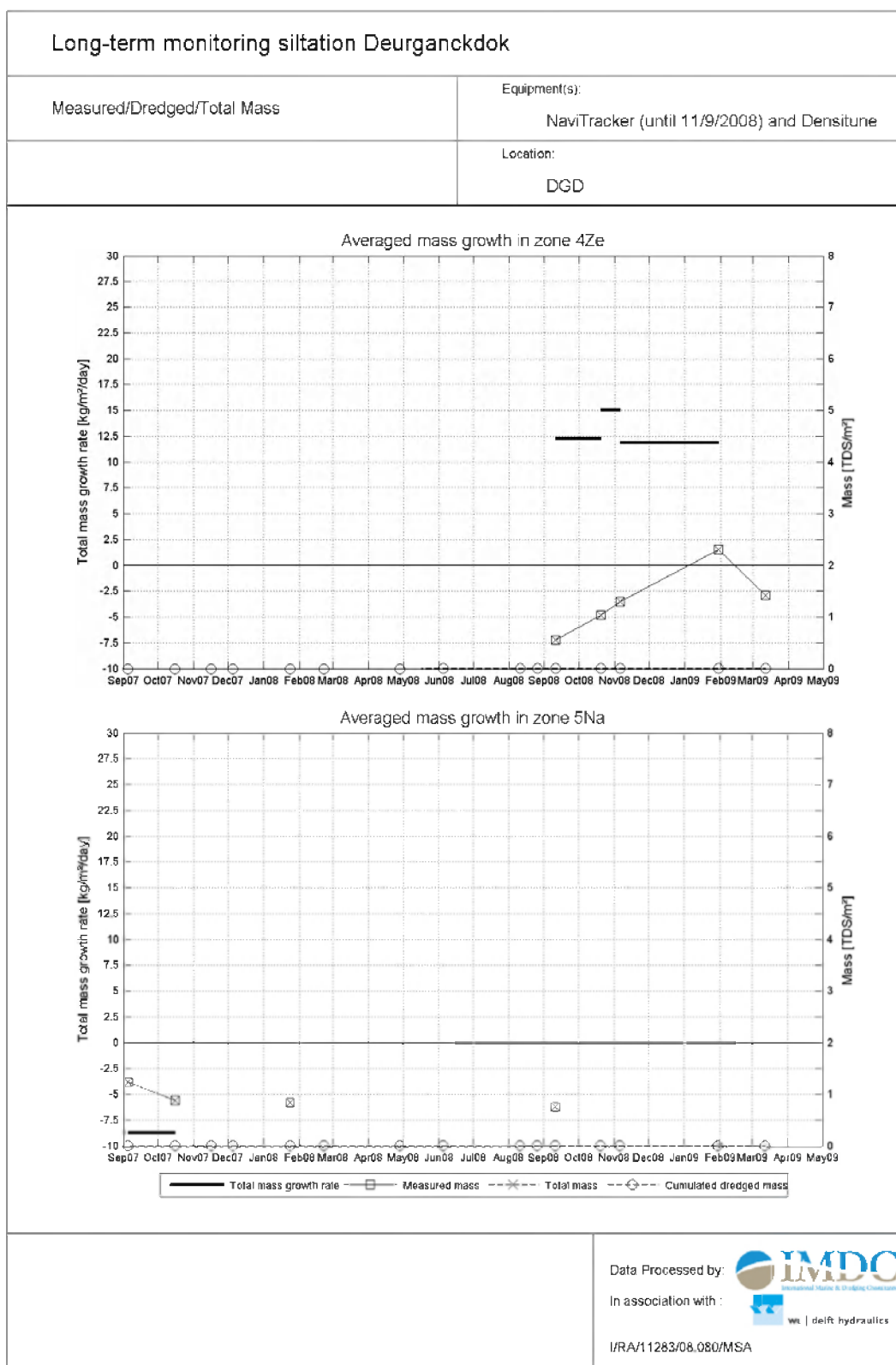


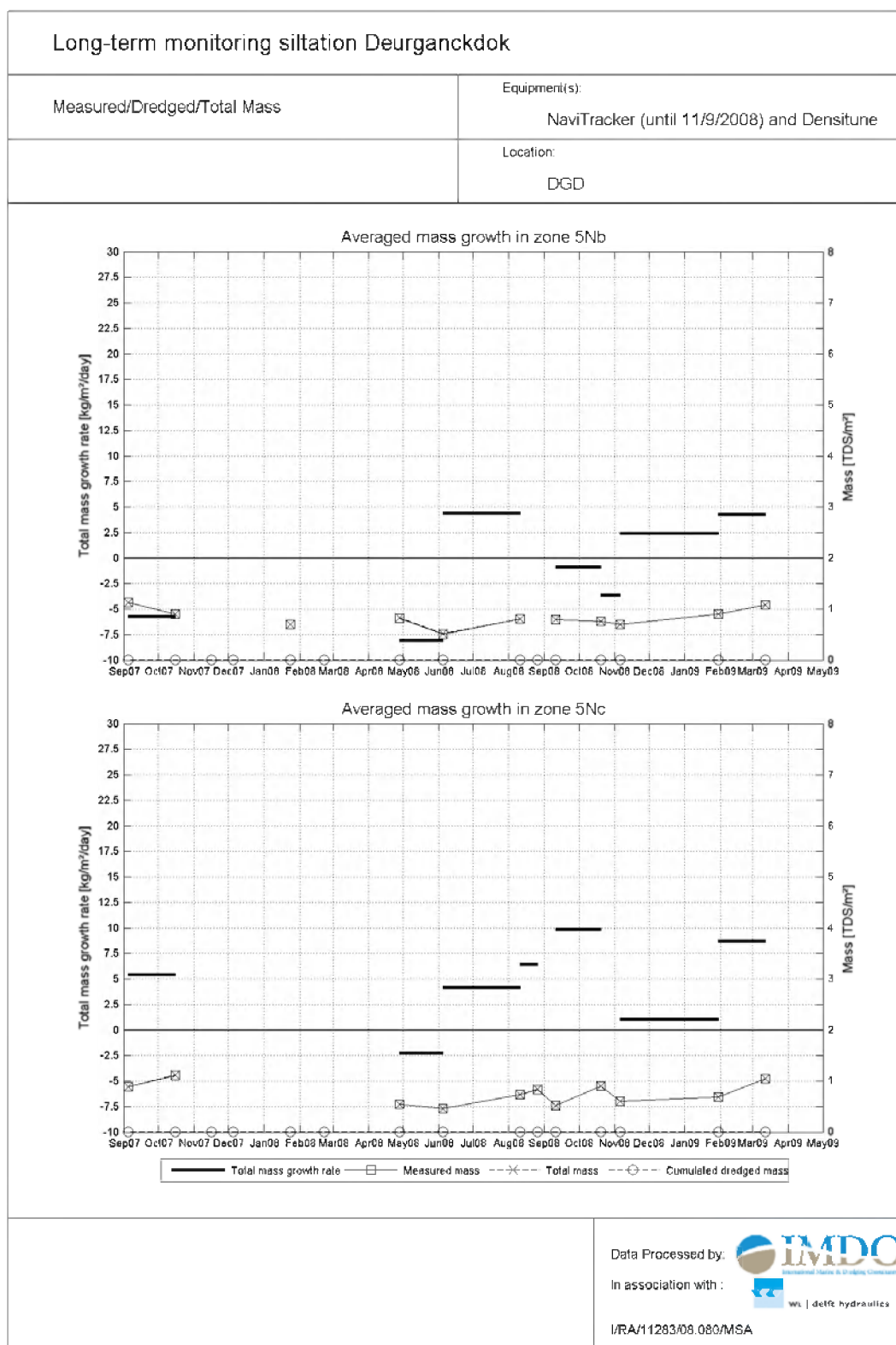


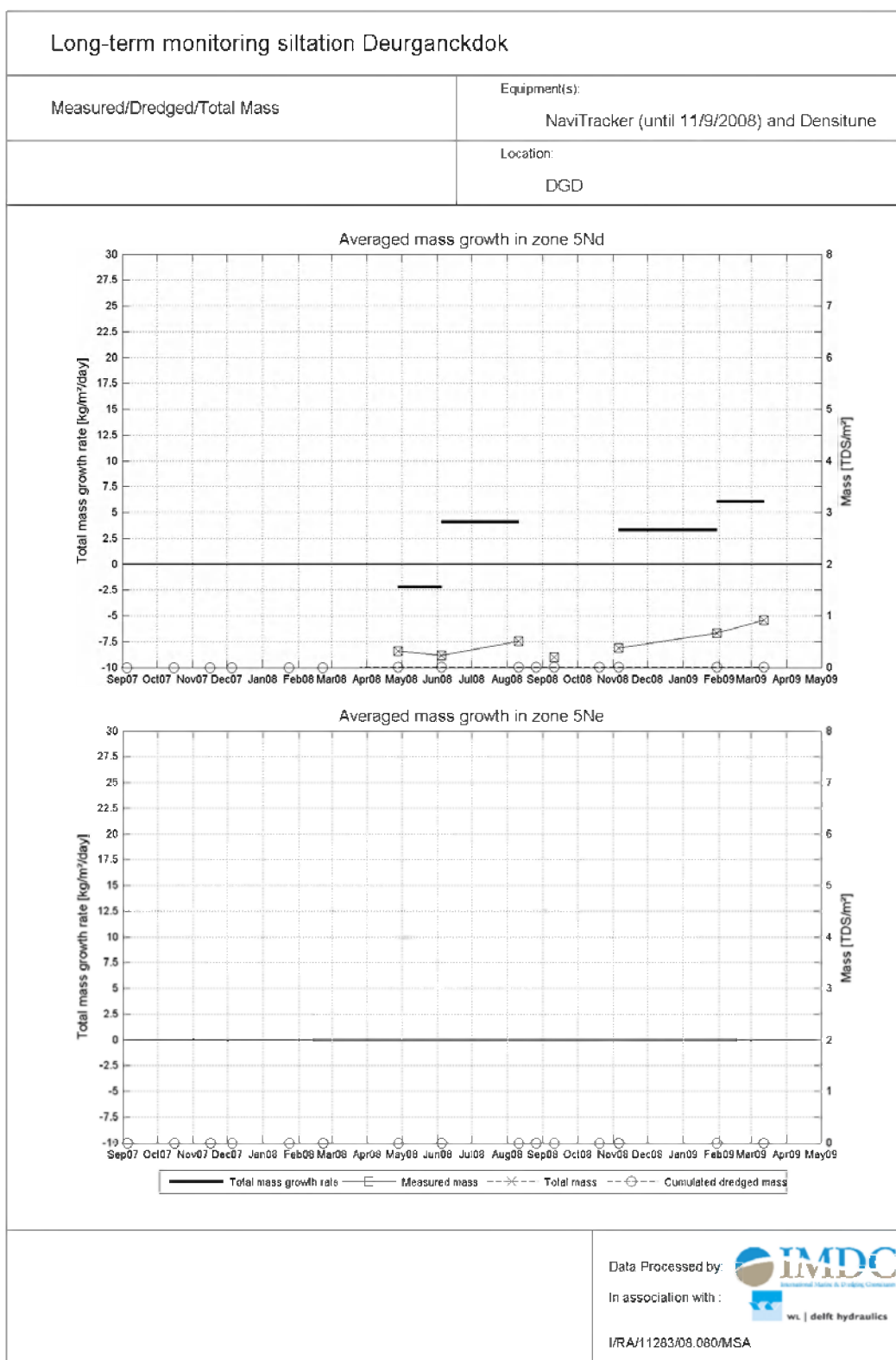


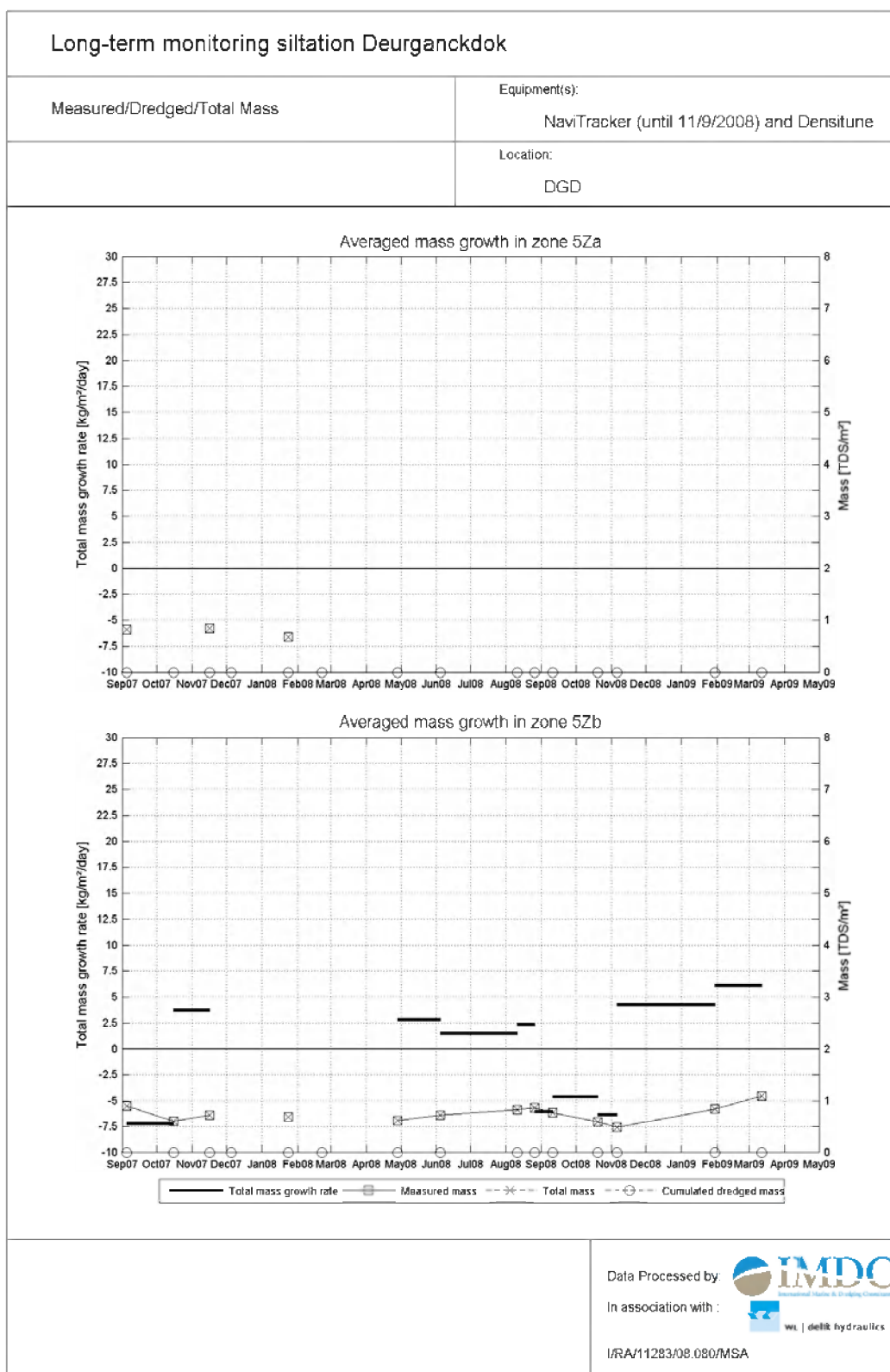


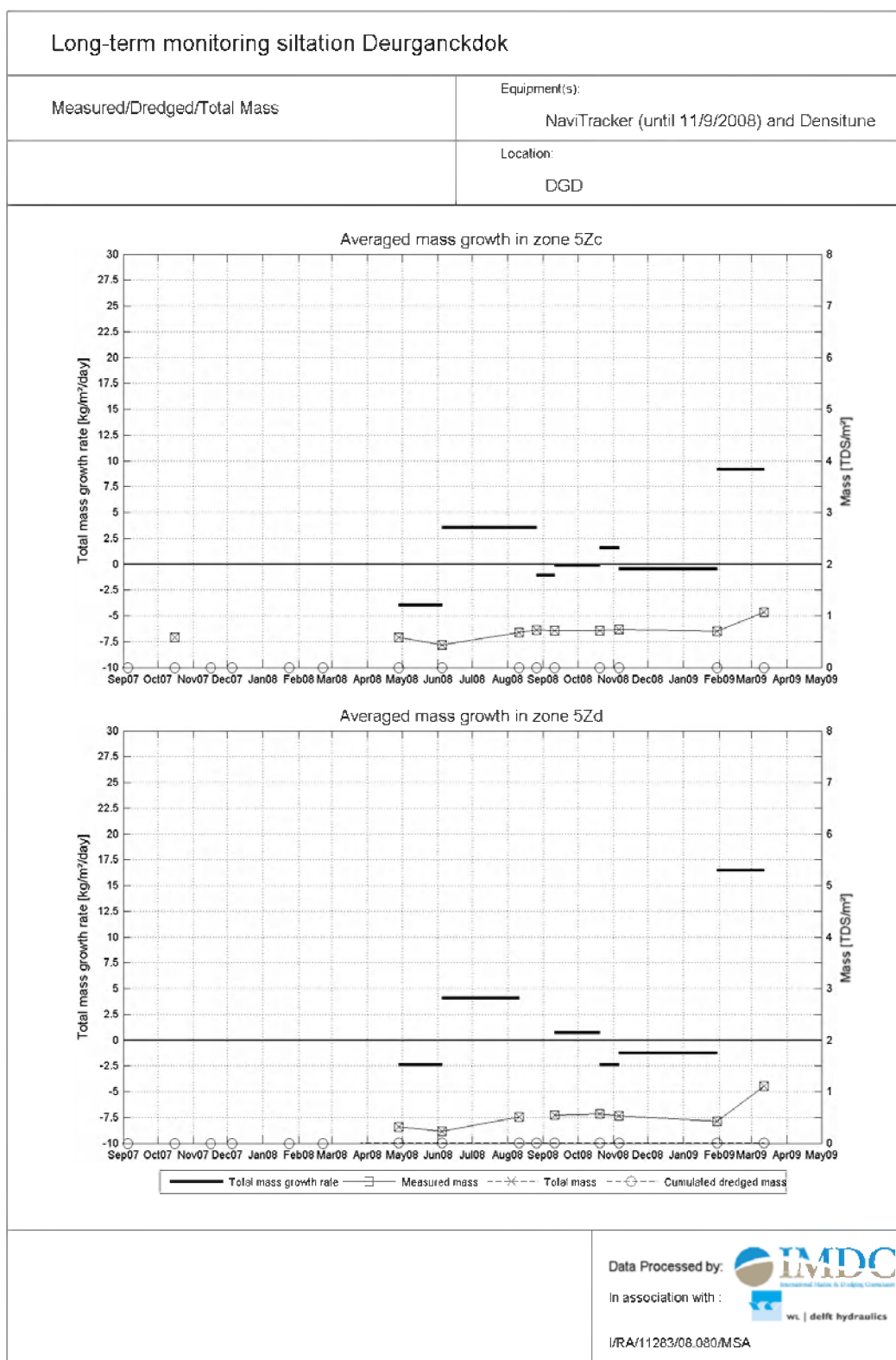


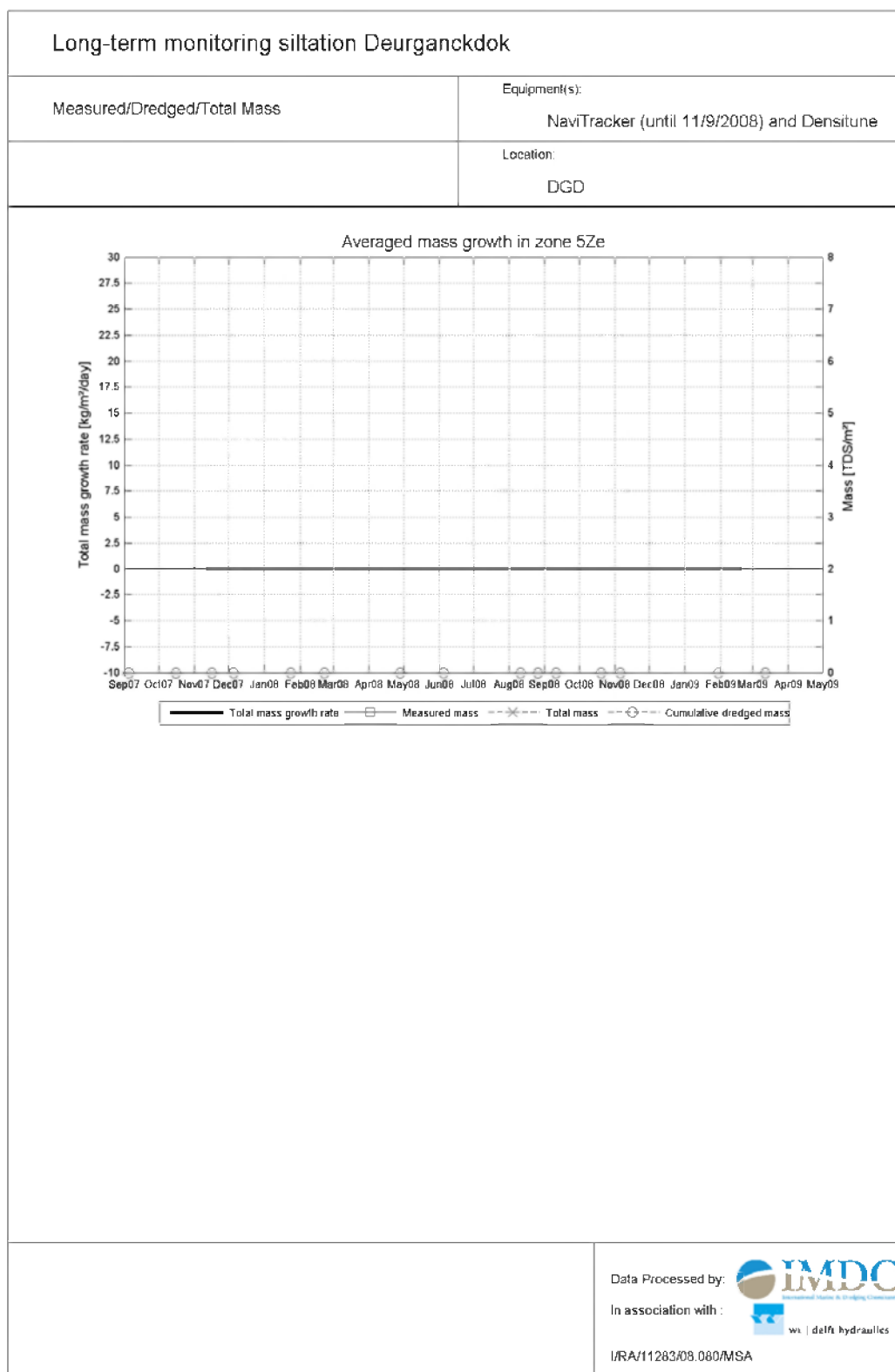




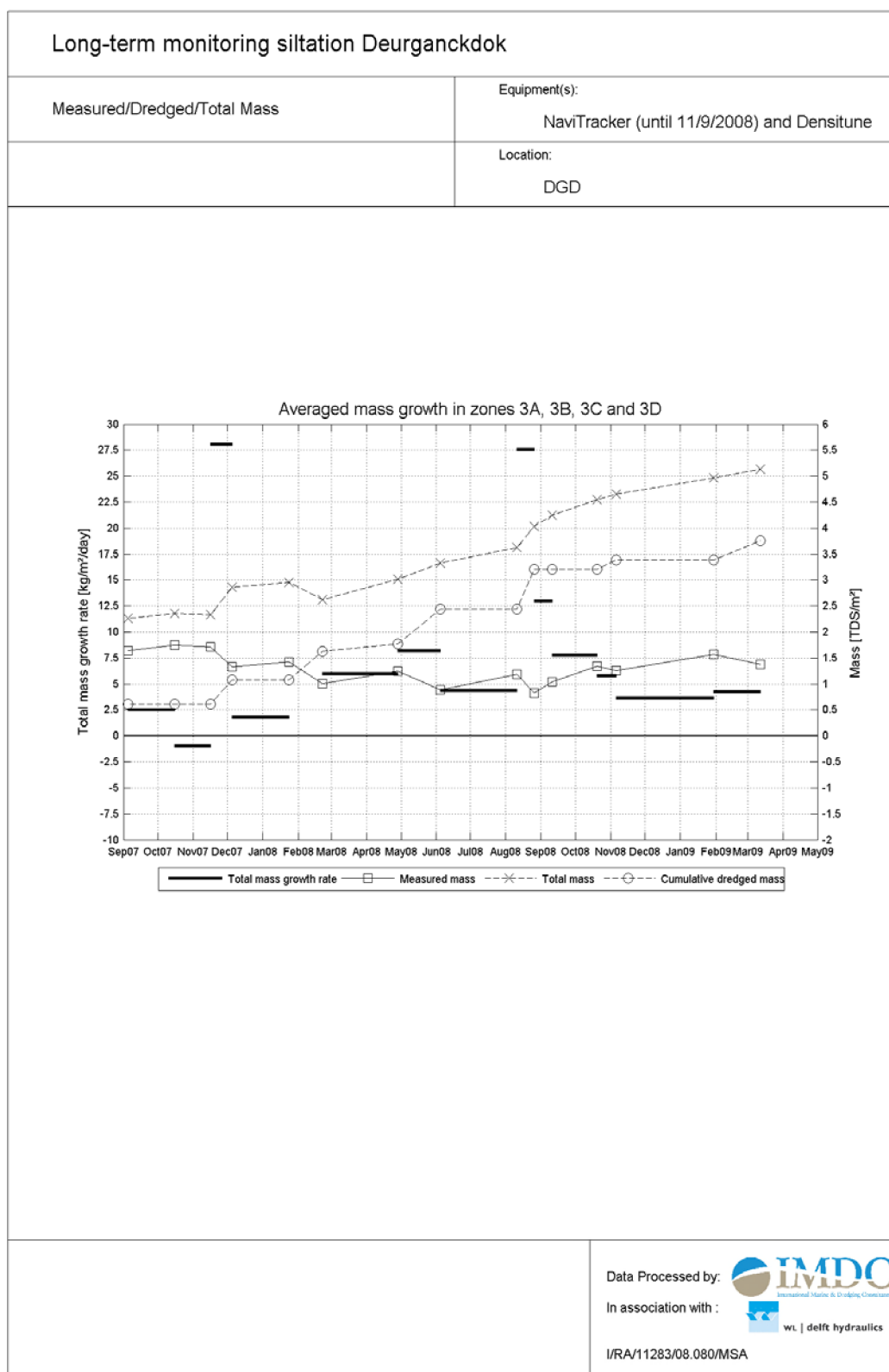








D.4 For complete Deurganckdok



APPENDIX E.

DREDGING DATA

Total dredged mass in covered area (TDS)																								
	02-Apr-07	09-Apr-07	20-Aug-07	27-Aug-07	19-Nov-07	26-Nov-07	28-Jan-08	04-Feb-08	11-Feb-08	18-Feb-08	03-Mar-08	12-May-08	19-May-08	26-May-08	11-Aug-08	18-Aug-08	20-Oct-08	09-Feb-09	16-Feb-09	24-Feb-09	02-Mar-09			
ZONE	07-Apr-07	14-Apr-07	25-Aug-07	31-Aug-07	24-Nov-07	30-Nov-07	03-Feb-08	10-Feb-08	17-Feb-08	24-Feb-08	09-Mar-08	18-May-08	25-May-08	01-Jun-08	17-Aug-08	24-Aug-08	26-Oct-08	15-Feb-09	23-Feb-09	01-Mar-09	02-Mar-09	Total (TDS)	%	
1	0	0	141	28	28	0	0	0	0	0	0	0	0	0	39	0	0	28	0	0	0	264	0.0	
2	57	23	1140	177	30	0	72	0	268	0	0	523	989	746	483	346	0	115	673	623	0	6264	0.3	
3a	3111	23207	46059	27635	40406	43114	29277	24258	35827	4033	0	59931	36320	21332	59941	80335	0	7478	12311	35768	2122	592465	28.9	
3b	7854	36043	28619	28630	45720	19857	24791	32056	22571	1099	0	34338	36401	25286	33300	77573	0	2268	9991	25328	1597	493322	24.1	
3c	7213	16162	25493	21020	38674	11835	22477	17659	24994	959	20665	17708	25536	20847	11229	55195	25424	2341	7773	18303	1151	392657	19.2	
3d	0	0	2	0	470	95	162	52	274	0	43945	946	5952	8877	3508	13759	53894	3608	12843	17634	779	166799	8.1	
3e	0	0	0	0	0	0	0	0	0	0	0	0	0	541	0	0	0	283	499	1987	0	3311	0.2	
4Na	25	435	8759	4198	5662	11322	4564	5226	3524	54	0	8337	4706	2455	11052	6768	0	5137	9582	1789	0	93596	4.6	
4Nb	60	427	7704	3772	6984	6928	5206	4737	1838	0	0	5739	5745	5503	5866	2514	0	4629	12123	629	0	80405	3.9	
4Nc	127	141	3396	2108	5861	3598	2659	3765	1440	27	2176	2594	2216	2962	1249	421	23	3763	7966	537	0	47030	2.3	
4Nd	0	0	0	0	14	0	0	0	0	0	8042	39	157	1242	0	75	101	2700	6081	281	0	18733	0.9	
4Ne	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0	0	0	65	9	16	0	155	0.0	
4Za	0	143	359	3	7480	3323	4483	1118	2008	13	0	7668	6137	1054	8679	1918	0	1930	6477	1438	0	54230	2.6	
4Zb	0	69	14	61	12214	4116	5141	2847	646	0	0	5496	8591	887	5103	2083	0	3055	7731	749	0	58804	2.9	
4Zc	0	0	0	28	4699	2040	1947	1525	445	0	2305	949	3290	239	487	803	1	2500	5327	217	0	26802	1.3	
4Zd	0	0	0	0	0	0	0	0	0	0	4048	302	230	15	13	0	27	1514	5288	217	0	11653	0.6	
4Ze	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	56	22	15	0	94	0.0	
5Na	0	0	3	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	7	0.0	
5Nb	0	0	29	0	0	0	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98	0.0	
5Nc	0	0	19	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	4	0	0	30	0.0	
5Nd	0	0	0	0	0	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0	26	0.0	
5Ne	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	
5Za	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	
5Zb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	
5Zc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	
5Zd	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0.0	
5Ze	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	
Total	18447	76649	121738	87660	168243	106227	100846	93251	93837	6185	81209	144573	136270	92053	140949	241789	79470	41468	104701	105533	5649	2046744		
%	0.9	3.7	5.9	4.3	8.2	5.2	4.9	4.6	4.6	0.3	4.0	7.1	6.7	4.5	6.9	11.8	3.9	2.0	5.1	5.2	0.3			