

Introduction, aims and thesis structure

1. Introduction

1.1. Socio-economic relevance of fine-grained sediment dynamics

Because of (rapid) sedimentation of suspended particulate matter (SPM) and the presence of fluid mud (Verlaan and Spahnghof 2000, Winterwerp 2005, PIANC 2008, van Maren et al. 2009, Manning et al. 2011), shoaling of maritime access routes and harbour basins in coastal or estuarine turbidity maximum environments is detrimental for their accessibility. Deposition of mud in the dredging areas can be seen as a temporarily storage of (fluid) mud (Kineke et al. 1996, Le Hir 1997, Winterwerp and van Kesteren 2004, Schrottke et al. 2006, Uncles et al. 2006). Mud is here referred to as water-rich sediment typically with a considerable amount of clay-silt particles (also sand). The harbours of Zeebrugge (Fig.1.1), Ostend and the marinas of Blankenberge and Nieuwpoort, and their navigation channels need very regular maintenance dredging in order to guarantee accessibility. Maintenance dredging amounts up to about 10 million tons of dry matter per year for Zeebrugge and the major shipping lanes (Lauwaert et al. 2009).



Figure 1.1 Sediment transport in the vicinity of the harbour of Zeebrugge. Blue areas are masked areas

The dredged material, which consists of pure mud in the harbour or of sandy mud in the navigation channels, is disposed of at dedicated disposal grounds at sea. The OSPAR convention (1992; Convention for the Protection of the Marine Environment of the North-East Atlantic) aimed at preventing and eliminating pollution and at protecting the maritime area against the adverse effects of human activities. Although disposing of dredged material at sea is allowed, a risk remains that toxic substances (organic micro-pollutants and heavy metals) associated with the disposal of dredged material over large areas are present. Detailed knowledge of SPM dynamics, including its temporal and geographical variability, is therefore needed.

Several research programmes have been carried out or are ongoing that have investigated the human impact caused by dredging and disposal in the Belgian nearshore area: MOCHA (BelSPO) (Fettweis et al. 2007), MAREBASSE (BelSPO) (Van Lancker et al. 2007), QUEST4D (BelSPO) (Van Lancker et al. 2011), HCBS-Zeebrugge (IMDC 2010); and MOMO (Flemish Authorities) (Lauwaert et al. 2009, Fettweis et al. 2011a).

Several techniques have been proposed to minimize harbour siltation of which an overview is presented in PIANC (2008) and Kirby (2011). In Belgium the focus is on optimizing the disposal of dredged material (Fettweis et al. 2011b), on optimizing dredging methods (Berlamont et al. 1985, Berlamont 1989, Fettweis et al. 2011c) and

on decreasing the sedimentation in the dredging areas. The latter requires infrastructural adaptations (e.g. current-deflecting-wall) in order to decrease the water exchange and thus the mud input between the harbour basin and its environment (Fettweis and Sas 1998, Hofland et al. 2001, Kuijper et al. 2005, van Maren et al. 2009, 2011). The efficiency of disposal grounds is defined by physical, economical and ecological aspects. In other words, an efficient disposal ground implies a minimal recirculation of the disposed matter towards the dredged areas. As such, a minimal distance between the dredged area and disposal ground is preferred, however, under the assumption that the impact on the marine environment is negligible. Consequently, there is no disposal ground that covers all three aspects. Efficiently disposing of dredged material then requires a more dynamic strategy that allows choosing the best location, as a function of the (predicted) physical impacts or conditions. Potential disposal grounds may be chosen in the coastal turbidity maximum, when it can be argued that the disposal activities do not increase significantly the turbidity levels, compared to the natural background in turbidity (Fettweis and Van den Eynde 2003).

1.2. High-turbidity areas in the southern North Sea

The southern North Sea region is composed of the Southern Bight, the German Bight and also part of UK waters; 56° north latitude is the northward boundary. The overall distribution of salinity, and hence water masses determine the distribution of turbidity (e.g. Lee and Folkard 1969). Since 1997, measuring physical oceanographic characteristics from space (ocean colour remote sensors; MODIS-Aqua, SeaWiFs; MERIS) has become common practice to derive mean patterns of e.g. surface SPM in shelf seas such as the North Sea (Ruddick et al. 2000, van der Woerd and Pasterkamp 2004, Eleveld et al. 2004, Staneva et al. 2009, Neukermans et al. 2009, Nechad et al. 2010, Pietrzak et al. 2011). The southern North Sea SPM system is characterized by different spatial structures of turbidity (Fig. 1.2): (1) the 'classical' river plumes such as the Tees, Humber, Thames estuary, Wash, Meuse-Rhine, Elbe, Weser and Ems. In the northern hemisphere, the freshwater-turbidity plumes turn right due to Coriolis forcing. Exception is the Thames river plume that turns left due to residual circulation (e.g. Pietrzak et al. 2011). In the German Bight, the coastal waters are affected by mainly the Elbe, Weser and Ems. (2) The East Anglian Plume (Prandtl et al. 1993, Dyer and Moffat 1998) representing offshore deflecting buoyant coastal waters. It originates from the Thames river plume and crosses the southern North Sea (Holt and James 1999) towards the German Bight (Dyer and Moffat 1998). (3) The turbidity area in the Belgian-Dutch coastal waters which is best described as a coastal turbidity maximum zone.

1.3. Coastal turbidity maximum along the Belgian-Dutch coast

The term coastal turbidity maximum (CTM) refers to the persistent high surface SPM concentrations (up to 100 mg l⁻¹) in the Belgian-Dutch coastal zone (Bastin et al. 1984, Ruddick et al. 2000, Eleveld et al. 2004, Fettweis et al. 2010), with a main spatial extension between about Ostend and the Westerscheldt estuary. Geographically, the mouth of the estuary is situated at Vlissingen, although geomorphologically the area between Zeebrugge and Walcheren is part of the mouth. The term 'coastal turbidity maximum' is not frequently used in literature (Lee and Folkard 1969, Fettweis et al. 2010), and corresponds roughly with an 'estuarine turbidity maximum' (ETM) in the sense that one or more trapping mechanisms for SPM occur. These are not due to salinity (ETM), but rather due to e.g. congestion in the residual SPM transport (Fettweis and Van den Eynde 2003). In the shallow Belgian-Dutch CTM zone, where water depths range between 0 and 16 m MLLWS (Mean Lower Low Water Springs), the main morphological entities are sandbanks and swales, as also navigational channels e.g. towards Zeebrugge and the Westerscheldt. These channels are maintained at a water depth of minimum 15 m MLLWS.

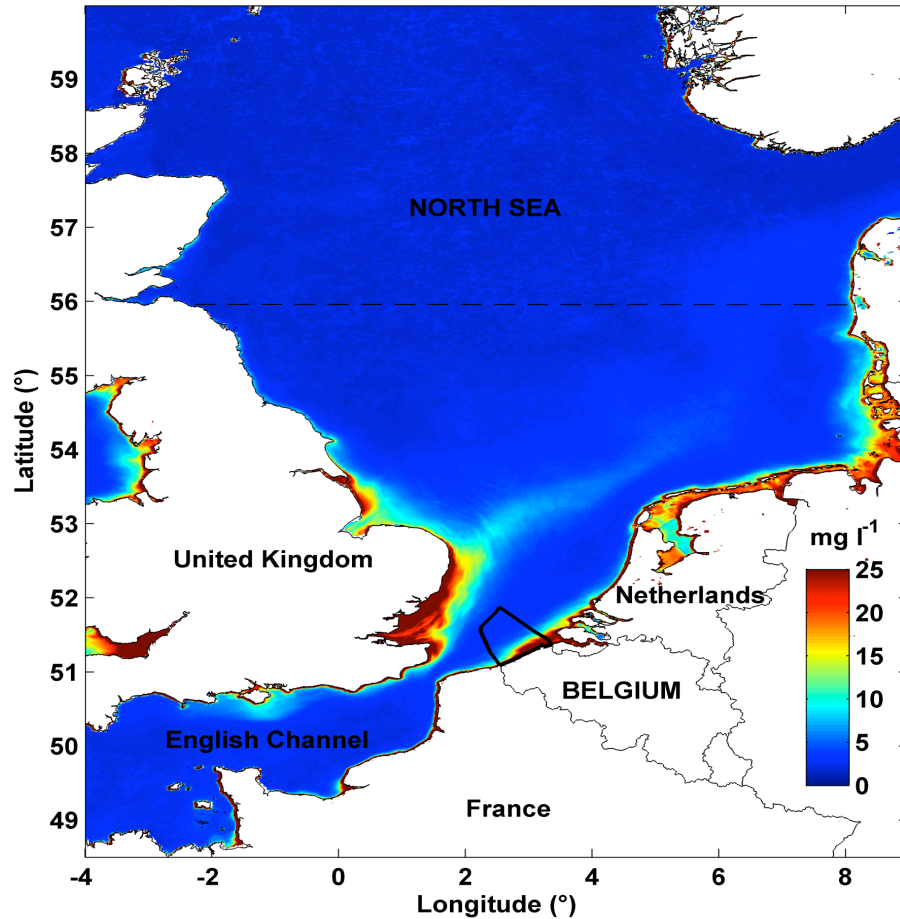


Figure 1.2 Emerging patterns of turbidity as observed (derived from MODIS-Aqua imagery) at the water surface in the southern North Sea

1.4. Coastal hydrodynamics

The macro-tidal regime is the main control of the hydrodynamics along the Belgian-Dutch coast. Tides are semi-diurnal and slightly asymmetric with a mean tidal range of 4.3 m at Zeebrugge during spring tide and 2.8 m during neap tide. Tidal current velocities are of the order of 0.6 to 1.2 m s⁻¹ in the coastal zone, with maximum velocities of 1.5 m s⁻¹ around the port of Zeebrugge. As a consequence, the bottom shear stresses (frictional force exerted by the flow per unit area of the seabed) are the largest there. The residual (subtidal) circulation is known to contribute to the long-term transport of fine sediments (mainly clay-silt particles and fine sands), and is governed by different forcings:

- wind forcing
- tides (through non-linear effects)
- vertical density gradients (temperature, salinity)

The wind climate may affect the residual current vectors resulting in significant flows in the surface layer diminishing with increasing water depth (Yang 1998, Lentz et al. 1999). Winds originate mainly from west-southwest, when Atlantic depressions are moving from west to east above the Belgian coast (Fig. 1.3).

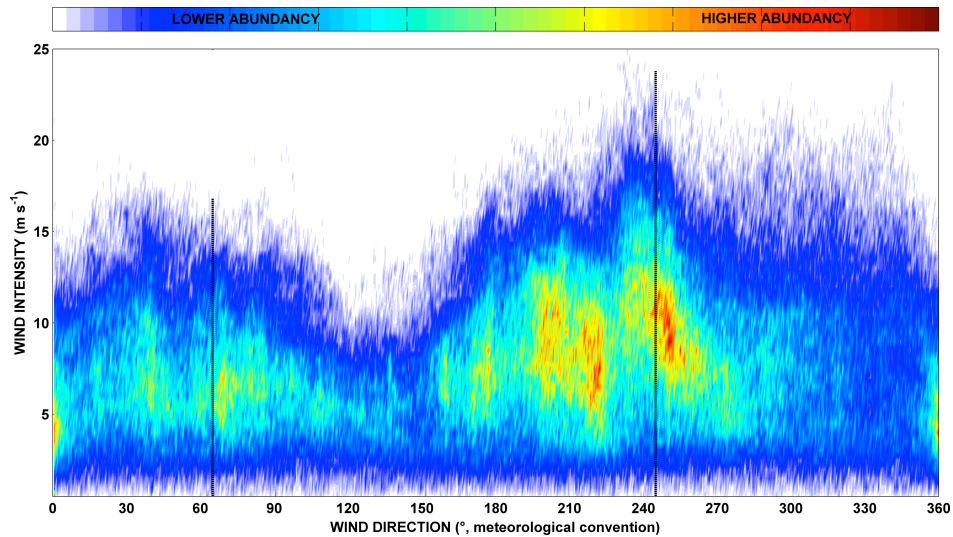


Figure 1.3 Wind climate along the Belgian coastal zone, based on measurements between 2000 and 2010 at Zeebrugge harbour station (data from Ministry of the Flemish Community, Maritime Services, Coastal Division/Hydrography)

The second frequent wind sector is northeast, as a result of the development of a high pressure field (between two Atlantic depressions) that moves from the UK towards Central Europe or Scandinavia. Other wind directions are less abundant, since they are transitional directions between the two main wind regimes. Since the coastline (as indicated by the vertical lines in Fig. 1.3) is oriented about 65° true north, strong wind-forced flows are present alongshore (Verlaan and Groenendijk 1993, Yang 1998). Response time of the North Sea to changes in wind speed generally varies between 6 and 34 h (Ishiguro 1983). In literature, the existence of the CTM zone has been correlated with residual flow circulation. On a regional scale, the mechanism of SPM entering the North Sea through the Dover Strait open boundary and settling off the Belgian-Dutch coast has been widely discussed in literature (Eisma and Kalf 1987, Van Alphen 1990, Lafite et al. 1993, 2000, Gerritsen et al. 2000, Fettweis et al. 2007). However, the fate of fine-grained sediments in the coastal zone is still controversial. In some studies residual current patterns with large gyres (Nihoul 1975, Gullentops et al. 1976, Delhez and Carabin 2001) and flow convergences (Van Veen 1936) are hypothesized; these authors plead for a closed system to explain the presence of cohesive sediments (Fig. 1.4). In other studies, detailed hydrodynamic and sediment transport modelling (Fettweis and Van den Eynde 2003), ground-truthed with tracer tests (Van den Eynde 2004) have been used to argue against the existence of residual eddies, or the closed system concept. It was shown that most of the mud from the Dover Strait is actually leaving the study area towards the northeast, being controlled by tides and meteorological forcing. Because of the decreasing magnitude of the northeast-directed residual transport and the presence of the island of Walcheren (the Netherlands), a kind of congestion occurs in the sediment transport. In combination with the nature of seabed sediments (see 1.5), this would explain the presence of the turbidity zone.

Influence of vertical density gradients on the CTM formation, hence the potential of “thermo-haline circulation” is negligible. The water column is generally well mixed throughout the entire year (e.g. de Ruijter et al. 1987) due to the high tidal amplitudes, the strong tidal currents and the low freshwater discharge of the River Scheldt (yearly average is $100 \text{ m}^3 \text{ s}^{-1}$, with a minimum of $20 \text{ m}^3 \text{ s}^{-1}$ during summer and a maximum of $600 \text{ m}^3 \text{ s}^{-1}$ during winter). Horizontal density gradients occur in the coastal zone and are influenced by the freshwater outflow of the Westerscheldt estuary, mainly (Lacroix et al. 2004). They are caused by tidal- and wind-driven advection and are generally low (salinity difference during a tide is <1 ; salinity difference of 2 occurs in 10% of the tides).

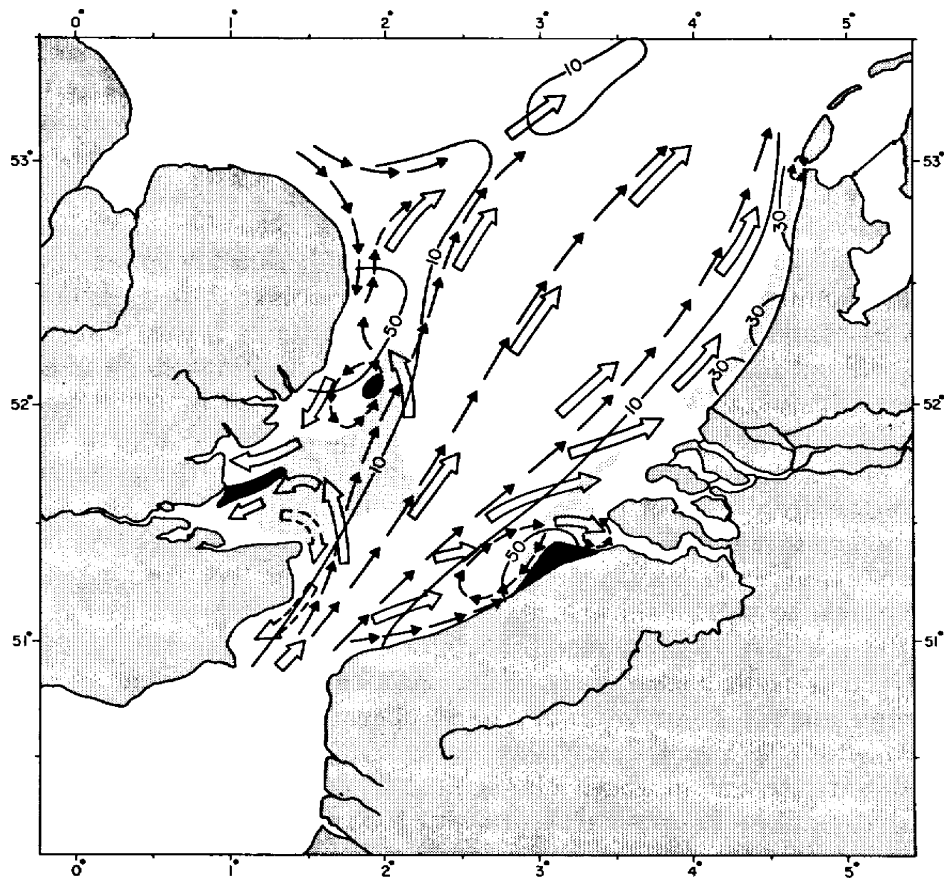


Figure 1.4 Overview of SPM transport in the southern Bight of the North Sea (adopted from Eisma and Kalf 1979); SPM concentration in mg l^{-1} ; small arrows are residual current patterns (Nihoul and Roday 1975, Prandle 1978 in Eisma and Kalf 1979); contour arrows indicate transport pathways of SPM; interrupted contour arrows (Ramster et al. 1976 in Eisma and Kalf 1979) are indicative of flow of water and SPM from the Thames estuary to the English Channel under strong northerly winds; black areas are mud deposits consisting of $>50\%$ of particles smaller than $50 \mu\text{m}$ (Bastin 1974, Jarke 1956 in Eisma and Kalf 1979); dotted areas are deposits consisting of $>2\%$ of particles smaller than $50 \mu\text{m}$ (Eisma 1966, McCave 1979 in Eisma and Kalf 1979)

1.5. Heterogeneous sedimentary environment

Both the geological and sedimentological situation in the Belgian-Dutch coastal zone is complex. The Palaeozoic basement was flooded during Late Cretaceous times (Le Bot et al. 2003), and the present Tertiary sequence coincides with slightly, northeast dipping deposits. These, from mid-Eocene to upper-Pliocene, deposits exhibit a varying sedimentology (sandy clay, clay, clayey sand, and sand) with thickness between 10 and 30 m (De Batist 1989, Ebbing et al. 1992). Further, Quaternary sediments mainly include the Pleistocene backfilled scour hollows in Palaeogene shelf strata (Mostaert et al. 1989, Liu 1990), and the Holocene tidal sandbanks. Thicknesses of the Quaternary deposits in the coastal zone vary between 0 and 10 m, mainly (besides the Ostend valley deposits). More resistant Tertiary layers, such as Boom clay and Asse clay, outcrop in the navigational channel towards the Westerscheldt where the Quaternary cover is absent. The Quaternary deposits are typically sands with sporadic strata of shells (or shell fragments); though near the Zeebrugge harbour and the Vlakte van de

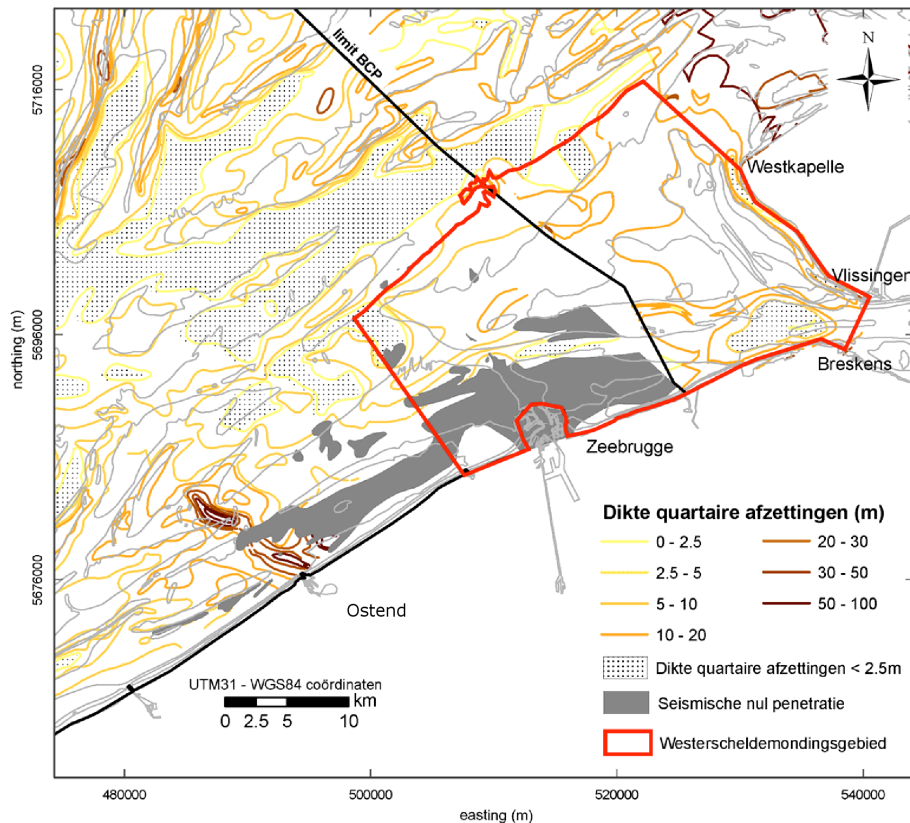


Figure 1.5 Thickness (m) of Quaternary sediments (Liu 1990, Ebbing et al. 1992); dotted areas are less than 2.5 m thick; the red polyline corresponds to the Westerscheldt estuary; very poor seismic penetration is found in the grey filled region (from Du Four et al. 2006)

Raan, clay, clay-sand alternations and peat layers are mostly present (Le Bot et al. 2003, 2005).

The Holocene (interglacial period beginning at the end of the Pleistocene, i.e. ~11700 years ago) is characterized with a sea level rise because of melting glaciers. The shallow parts of the inundated coastal area allowed the development of marshes and peat formation (Baeteman and Van Strijdonck 1989). In addition, the Pleistocene deposits are largely eroded (Baeteman and Van Strijdonck 1997) and reworked as tidally-induced mudflat deposits, estuarine sand plates and beach deposits. Finally, during the last period of the Holocene, a continuous displacement and reworking of sediments under tidal hydrodynamics resulted in the present-day seafloor morphology (planar, small and large bed forms) (Eisma and Kalf 1979, Mathys 2009).

The composition of bottom sediments in the Belgian-Dutch coastal zone is not uniform; it varies from pure clays to very coarse sands (Verfaillie et al. 2006). The heterogeneous character of the seabed is natural, but also partly because of human impact, such as dredging-disposal activities (see 1.1). The sand fraction is partly relict and partly in transport, dependent on the prevalent bottom shear stresses. Grain-sizes become typically coarser in the offshore direction (Lanckneus et al. 2001). Clay and silt size bottom sediments are also abundant between Ostend and the River Scheldt mouth (Van Lancker et al. 2007 a, b). In the last years, several techniques have been used to characterize the nature of the muddy seabed in the CTM zone: seismic surveys (Missiaen et al. 2002, Mathys 2009), seabed mapping (Van Lancker et al. 2004) and intensive seabed box coring (Van Lancker et al. 2004, Fettweis et al. 2010).

The bed structure, wet bulk density and consolidation of the cohesive sediments have been investigated with erosion behaviour measurements (Fettweis et al. 2005,

Fettweis et al. 2010), and allowed establishing the presence of the following bed layers: fluffy / fluid mud layers ($0.5\text{--}1\text{ Pa}$; $1100\text{--}1200\text{ kg m}^{-3}$); freshly (recently) deposited mud ($1\text{--}4\text{ Pa}$; $1300\text{--}1500\text{ kg m}^{-3}$); soft to medium consolidated Holocene mud (up to 13 Pa ; $1500\text{--}1800\text{ kg m}^{-3}$) with intercalations of thin sand layers ($\sim 1\text{ Pa}$). From the geophysical surveys in the CTM zone, a mud plate has been identified as a distinct unit of Holocene age partly covered by sands (Mathys 2009). The presence of the mud plate confirmed earlier observations (Stessels 1866, Van Mierlo 1899, Gilson 1900, Bastin 1974, Gullentops 1976); for Mathys (2009) it is a deposit formed within the last 450 years. This deposit is basically seen as a reworked (Holocene) back barrier deposit. The very poor seismic penetration of the unit is because of methane gas formation in shallow peat layers (Missiaen et al. 2002). The thickness is on average less than 1 m , but may reach 5 m in the eastern part. It forms the largest reservoir of fine-grained sediments in the nearshore area (Fettweis et al. 2009); it contributes as a source of SPM, mainly during storm events (Fettweis et al. 2010). However, the physical behaviour of the outcropping consolidated mud (swelling, mass erosion, resuspension, weakening) in the area is quantitatively not known yet.

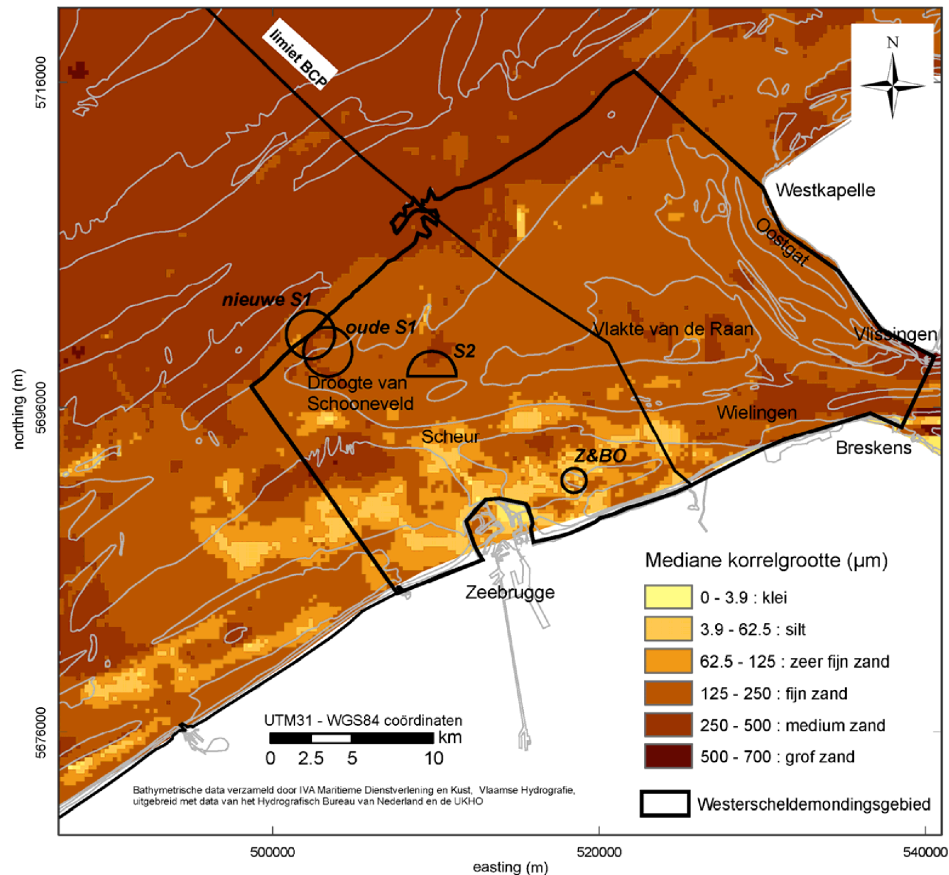


Figure 1.6 Map of median grain size (based on *sedisurf@database* (Van Lancker et al. 2007 a), and sediment data from TNO (NL); black (semi-) circles are disposal grounds of dredged material (from Du Four et al. 2006)

1.6. SPM characteristics

Ocean colour satellite sensors derive SPM concentration for the near-surface layer from optical properties of the sea (e.g. Doerffer et al. 1994). The degree of turbidity (water clarity) is an optical property of the water and is influenced by (1) coloured dissolved organic matter (CDOM; e.g. humic substances) and (2) suspended

particulate matter (SPM). The latter consists of fine-grained materials (clay, silt and sand) and is composed of minerals (clay minerals, quartz, carbonates), organic matter (OM) and water (Eisma 1986, Berlamont et al. 1993). OM consists of micro-organisms, their metabolic products, residuals from dead organisms and faecal pellets (Hamm 2002, Bhaskar et al. 2005). OM content in the water column will determine the flocculation dynamics (Fettweis et al. 2006, see 1.7), as with higher OM content the SPM flocs become larger. Flocculation is caused mainly by the clay minerals interacting with each other, with other minerals and with the organic matter resulting in increased cohesiveness of the SPM (Kranenburg 1994, Dyer and Manning 1999, Son and Hsu 2009). Regarding the Belgian coastal zone, the SPM consists of a clay to silt ratio of ~1:4, median grain size of the primary particles (building stones of flocs) of $<3\mu\text{m}$, 7.5% organic matter, and 40% CaCO_3 (Fettweis et al. 2007 b). These figures must be regarded with caution since measurements were realised at different sample stations and under different hydrodynamical conditions. Density of primary particles takes into account the different fractions (OM, CaCO_3 and clays and non-clay minerals) and the corresponding densities, and was found to be 2580 kg m^{-3} for the Belgian coastal zone. From a mineralogical point of view (Zeelmaekers 2011), the consolidated mud deposits, as well as the freshly deposited mud, share the same clay-composition as the SPM found in the CTM. Therefore, he suggested that constant reworking of the older mudplate deposits contributes significantly more towards the SPM than previously thought. More distant sources of SPM considered in literature are the erosion of the coastal cliffs in the English Channel (Eisma and Kalf 1987, Lafite et al. 1993, Irion and Zöllmer 1999, Velegrakis et al. 1999, Gerritsen et al. 2000, Fettweis and Van den Eynde 2003), the erosion of outcropping Tertiary (Paleogene) clay (Fettweis et al. 2009) and the River Scheldt (Gullentops et al. 1976, Nechad et al. 2003).

1.7. SPM dynamics

Generally, SPM particles undergo various cycles of re-suspension, settling and advection before being deposited more offshore and forming fine-grained sediment deposits (e.g. Gerritsen et al. 2000). SPM dynamics are controlled by several forcings: tides, wind, mean sea level, ocean currents, sources of sediment, thermohaline fields, freshwater flux (Stanev et al. 2009); as well as by biological processes (e.g. Nowell et al. 1981, Arndt et al. 2007, März 2009) and human impact (dredging-disposal cycles), typically for the study area.

The most significant time-scale for SPM dynamics are the tides; the alteration of high current velocities and slack water inducing a continuous change in re-suspension, mixing, settling and deposition. Tidal ellipses are more elongated towards the shore and thus the difference between maximum and minimum currents increases. During the periods with minimum currents, the so-called slack waters (or slack tides), SPM aggregates into larger flocs with higher settling velocities and thus an enhanced settling and sedimentation occurs (e.g. Dyer 1989, van Leusen 1994). The cohesive sediments (predominantly clayey particulate matter) are re-suspended when current velocities increase again. A schematic overview is given by Maggi (2005, Fig. 1.7) showing the complexity and coupling between aforementioned processes.

From cohesive sediment transport (modelling) studies, and chemical engineering applications (i.e. water purification), flocculation is very well known to be controlled by turbulent shear and time (Toorman 2001). SPM flocs will start breaking up during increased turbulence. In the subtidal time-domain, neap tidal phases are characterized by higher accumulation rate, deposition of thicker (fluid) mud layers, consolidation of these layers and a decrease of SPM concentrations (Fettweis and Van den Eynde 2003). The subsequent spring tide conditions will re-suspend these temporal mud deposits.

Floc size (distribution) and hence settling velocity may considerably vary over the tidal cycle, as well as for spring and neap tide (Winterwerp et al. 2002, Fettweis et al. 2006). Also, seasons have an influence on SPM concentration, which are mainly explained by the higher frequency of storms during winter (Visser 1969, Cacchione and Drake 1982, Williams et al. 1999, Ferré et al. 2005, Guillen et al. 2006). Higher river discharges in spring, and hence high plankton growth are expected (Terwindt 1967, Lancelot and Mathot 1987, Lacroix et al. 2007) implying change in SPM composition and floc characteristics (van der Lee 2001, März et al. 2010).

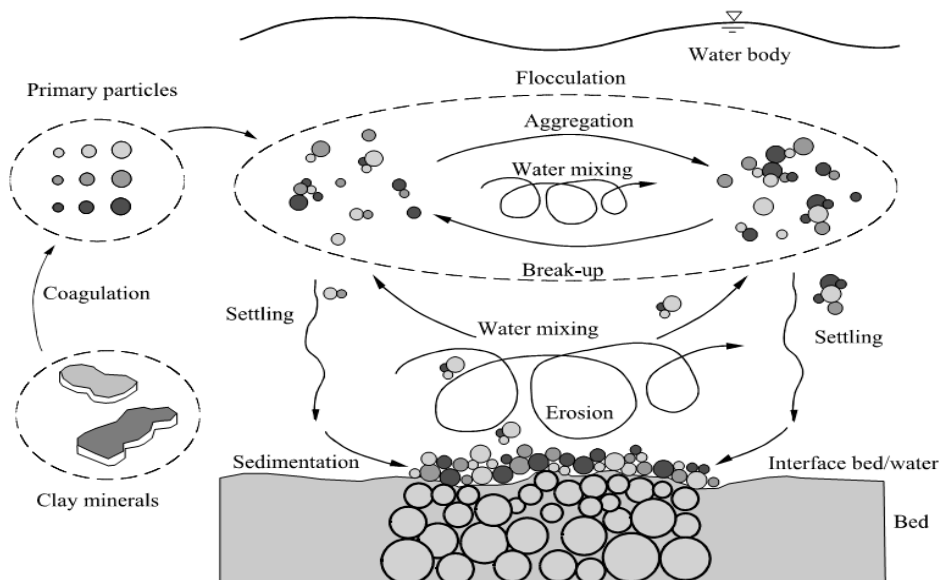


Figure 1.7 Cycle of deposition and resuspension of cohesive sediment (from Maggi 2005)

1.8. High-concentration mud suspensions (HCMS) and fluid mud

During periods of decreased turbulent kinetic energy (neap and slack tides), SPM flocs settle out of the water column resulting in high near-bed SPM concentrations. Suspensions with concentrations of a few 100 mg l^{-1} to a few g l^{-1} are defined as high-concentration mud suspensions (Winterwerp 1999). They interact with the turbulent flow field, behave Newtonian (with some increased viscosity), and are in transport with the main flow. A strong vertical, sediment-induced, density gradient (lutocline) in the water column (near-bed) is often associated with HCMS. Related to ETMs, HCMS have been described extensively (Inglis and Allen 1957, Allen et al. 1980, Faas and Wartel 1985, Odd 1988, van Leussen 1994). HCMS occurrences are also associated with current-driven sediment gravity flows off high-load rivers (Friedrichs and Wright 2006); however high-load river discharges in the Belgian coastal area are not expected (Fettweis et al. 2007). Fluid mud is a suspension of cohesive sediment above the gelling point (between 10 to 100 g l^{-1}); the gelling point refers to the concentration that is favourable for flocs to structure a network (Winterwerp and van Kesteren 2004). The rheology of fluid mud exhibits non-Newtonian behaviour, and can be either stationary or mobile. Both HCMS and fluid mud give rise to large siltation rates, as found in harbour basins and navigational channels (Winterwerp 2002). Another mechanism, responsible for the occurrence of HCMS in the marine environment, is due to wave action (de Wit and Kranenburg 1997, Li and Mehta 2000, Winterwerp et al. 2001, Fettweis et al. 2010).

1.9. Influence of SPM on the structure and function of eco-systems

The ecological functioning of the coastal system is amongst other controlled by the water clarity and thus by the amount of fine-grained material in the water column. In addition, SPM may control the transport, re-activity and biological impacts of substances in the marine environment (Turner and Millward 2002). For example, SPM has a crucial impact on the underwater light field by reducing the available light for primary production (Behrenfeld and Falkowski 1997, Arndt et al. 2011). Additionally, SPM controls the development of phytoplankton biomass and hence the dissolved nutrients in the water column (Cloern 1987, Monbet 1992). Further, SPM dynamics control the functioning of benthic communities (Murray et al. 2002) since SPM carries a major part of the food resources for the benthos. Frequent HCMS and fluid mud

formation may affect bioturbation or bio-irrigation modes, both important ecosystem functions of soft substrata macrobenthos. Bioturbation and bio-irrigation are of paramount importance for ecosystem functioning in fine sandy sediments receiving high loadings of organic matter (OM). A decrease in density of bioturbators entails a decrease in OM burial, whereas a decline in bio-irrigators implies less oxygenation of the sediment and denitrification, an important nitrogen-eutrophication counteracting process in shallow coastal seas. Bioturbation and bio-irrigation are therefore key transport mechanisms in carbon and nitrogen cycling in shallow seas (Braeckman 2011).

1.10. Aims

The overall aim of this PhD dissertation was to increase knowledge on the dynamics of suspended particulate matter (SPM) in the Belgian coastal zone. High amounts of SPM are associated with the occurrence of a coastal turbidity maximum (CTM), present within the Belgian-Dutch coastal zone. The seabed is composed of a mixture of sand and mud; both are re-suspended under various hydro-meteorological conditions. Within the CTM, the formation of high-concentrated mud suspensions (HCMS) is a particular phenomenon, though its dynamics and occurrence has up to now, only occasionally been investigated. Further the dissertation aimed at increasing the understanding of human impacts on SPM dynamics. This requires dedicated instrumentation, preferably measuring on a quasi-continuous basis. The choice of instrumentation is critical in determining the processes occurring in the water column, as well as near-bed.

Main questions posed were:

- (1) What drives the temporal variability of SPM within the CTM zone?
- (2) How does (1) influence the spatial variability of the extent of the CTM zone?
- (3) What is the dynamic behaviour of HCMS, and their influence on near-bed processes?
- (4) How will mixed sediments within the CTM zone influence optical and acoustic sensor measurements?
- (5) Can anthropogenic contributions to SPM concentration be distinguished from the natural variability through time?

1.11. Thesis structure

Research results are divided over the following “paper chapters”:

In Chapter 2 in-situ measurements are described at a single-point location in the Belgian nearshore area. The effect of wind on the advection of the fine-grained sediments and the dynamics of high-concentrated mud suspensions are investigated aiming at obtaining new insights into fine-grained sediment transport. Different techniques have been used, including acoustic methods for sediment transport and ensemble-averaging of data. In a next chapter, general findings from the single-point location described in Chapter 2 are tested against the SPM concentration field results in the Belgian-Dutch coastal zone as measured from space (Chapter 3). Satellite images are used to study the geographical variability of the turbidity maximum, based on meteorology- and climate-based classification schemes. In Chapter 4, the near-surface satellite and near-bed tripod findings are combined to study the behaviour of sediment suspensions, aiming at determining the full-water column characteristics (sediment re-suspension, advection, fluxes and vertical mixing degree) by means of acoustic Doppler profiler datasets. Implications towards used instrumentation for measuring SPM concentration result from particle size differentiation over time. Chapter 5 deals with multi-modal suspended particle size distributions under different hydro-meteorological influences, based on several statistical techniques (Chapter 2

treats only the median value of the particle size spectrum). Chapters 6 and 7 are combined since both represent applied research. They deal with the formation and erosion of high-concentrated mud suspensions in the coastal turbidity maximum zone with relevance to mine burial, and to disposal (of dredged mud) activities, respectively. The synthesis (with discussion) chapter (8) is followed by conclusions and future research perspectives (Chapter 9).

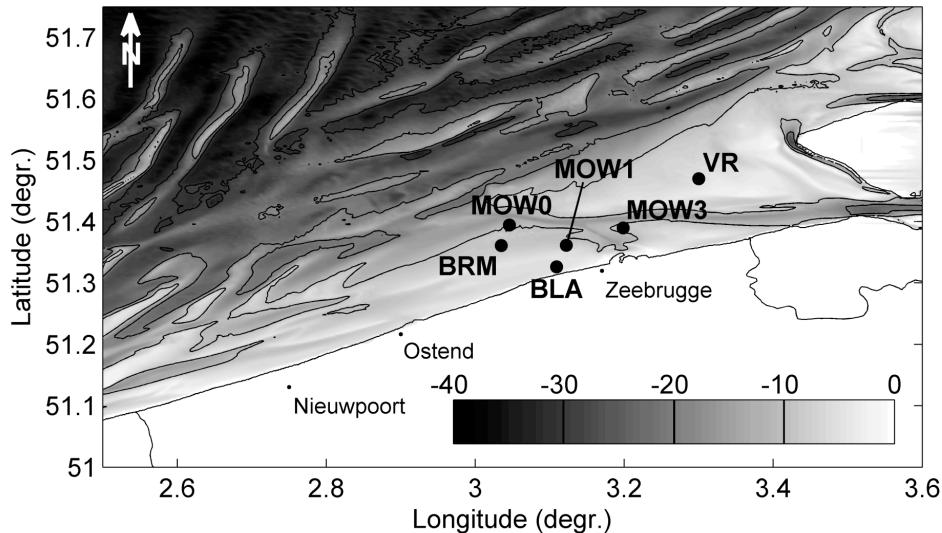


Figure 1.8 Overview of observatory and study locations used in the study area. Extent map coincides with MODIS-Aqua SPM concentration maps (Chapter 3). Bathymetry (in meters) with MLLWS as reference

Fig. 1.8 shows all measurement locations (MOW1, MOW0, BRM, BLA, VR, and MOW3) used in this study; all of them are shallow (< 10 m). All chapters are published or accepted/submitted for publication, resulting in inevitable overlap regarding introductions and study area descriptions; though, each chapter can be consulted independently from the others.

For the dissertation, in-situ data and research results were made available from the following research projects:

- **MOMO (Flemish Authorities, Maritime Access):** *Monitoring and modelling of cohesive sediment transport and evaluation of the effects of dredging and dumping operations on the marine ecosystem (Management Unit of the North Sea Mathematical Models-MUMM)*

The "MOMO" project is part of the general and permanent duties of monitoring and evaluation of the effects of all human activities on the marine ecosystem to which Belgium is committed following the OSPAR convention (1992). The goal of the project is to study the cohesive sediments on the Belgian Continental Shelf (BCS) using numerical models as well as by carrying out measurements. Through this, data will be provided on the transport processes, which are essential in order to answer questions on the composition, origin and residence of these sediments on the BCS, the alterations of sediment characteristics due to dredging and disposal operations, natural variability, the impact on the marine ecosystem, the estimation of the net input of hazardous substances and the possibilities to decrease this impact as well as this input.

Fettweis M, Baeye M, Lee BJ, Van den Eynde D, Van Lancker VRM (2011). Monitoring en modellering van het cohesieve sedimenttransport en evaluatie van de effecten op

het mariene ecosysteem ten gevolge van bagger- en stortoperatie (MOMO): activiteitsrapport (1 juli 2010 - 31 december 2010). BMM/MUMM: Brussel. 44 pp. + appendices.

- **QUEST4D (Belgian Science Policy):** *QUantification of Erosion/Sedimentation patterns to Trace natural versus anthropogenically-induced sediment dynamics (Ugent, MUMM, KUL, WL)*

Quest4D targets the Belgian part of the North Sea to investigate the seabed ecosystem over the past 100 years. Main objectives include: (1) Increase in knowledge on natural variability of seabed nature and processes; (2) Establish historic baselines, as reference situations for impact studies; (3) Quantification of ecosystem changes, on the medium- to long-term; (4) Demonstration of human impact, with case studies relating seabed changes to both naturally and anthropogenically induced sediment dynamics; (5) Assessing climate change scenarios and their effect on seabed management; and (6) Development of more sustainable exploitation strategies of non-living seabed resources.

Van Lancker V, Baeye M, Du Four I, Janssens R, Degraer S, Fettweis M, Francken F, Houziaux JS, Luyten P, Van den Eynde D, Devolder M, De Cauwer K, Monbaliu J, Toorman E, Portilla J, Ullman A, Liste Muñoz M, Fernandez L, Komijani H, Verwaest T, Delgado R, De Schutter J, Janssens J, Levy Y, Vanlede J, Vincx M, Rabaut M, Vandenberghe H, Zeelmaekers E, Goffin A (2011). QUantification of Erosion/Sedimentation patterns to Trace the natural versus anthropogenic sediment dynamics (QUEST4D). Final Report. Science for Sustainable Development. Brussels: Belgian Science Policy, 97 pp. + Annexes.

- **MINE BURIAL** (*Mine Warfare Data Centre group*): *Belgian Naval Defence, Direction Générale Material Resources (DGMR) Mine Counter Measure, and in co-operation with Bundesamt für Wehrtechnik und Beschaffung - Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik (BWB - FWG, Germany) and Ghent University (Renard Centre of Marine Geology RCMG)*

The "Mine Burial" project aims to evaluate the time necessary for partial or total burial of objects in shallow water (<40m depth) by studying the sand dynamics on the Belgian Continental Shelf in both time and space domain. Several techniques are used to reach this goal: time-series of side scan sonar measurements, box-cores for validation of acoustic images, and instrumented mines at strategic locations to investigate small-scale variability of sand dynamics for over several months. The areas of analysis are chosen following scientific, economical and societal criteria. The research is used for military and civil applications regarding the safety at sea.

1.12. References

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