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Measurement plan

TKI MUSA project

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About the MUSA project

Estuaries and tidal basins form the transition zones between land and sea. They contain important habitats for flora and fauna and are extensively used by people, like for navigation. For ecological and navigational purposes, it is important to understand and predict the evolution of channels and shoals, including sedimentation rates and the composition of the bed sediments. The bed material of large estuaries and tidal basins largely consists of mixtures of mud and sand, with predominantly sandy channels and mainly muddy intertidal areas. The interaction between sand and mud, in combination with currents and waves, leads to complex dynamics in these areas, with migrating channels and shoals.

Much is known about the behaviour of the individual sediment fractions, but the knowledge and understanding of sand-mud interaction remains limited, as do the available tools and models to accurately predict the bed evolution and sediment transport rates in sand-mud areas. Existing models, like the ones by Van Ledden (2003), Soulsby & Clarke (2005) or Van Rijn (2007) have only limitedly been verified with observations due to a lack of good quality observational data. Also, none of the available approaches cover the complete spectrum of sand-mud interaction, which includes settling, erosion processes, waves and currents, and the bed shear stress. Therefore, in practice, sand- and mud fractions are often treated separately. This decoupled approach limits the predictive capacity of numerical models, and therefore the impact of human intervention such as deepening of channels and port construction on maintenance dredging volumes and other morphological changes.

In the MUSA-research project, a consortium contractors, consultants and research organizations join forces to increase the understanding of sand-mud dynamics by means of fieldwork campaigns and lab experiments, and to implement this knowledge in engineering tools and advanced models for the prediction of mud and sand transport and associated morphology in tidal conditions with both currents and waves.

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1 Introduction

1.1 Background

Based on the results from the literature study and the input during the first consortium meeting (June 22, 2020), the basis of this Measurement Plan for the laboratory experiments and field measurements was setup (R2r0). The Measurement Plan has been updated after first experiments and results have become available in October 2020.

The measurement plan is a living document and will be continuously updated during the various phases of the project. In this way insights from the first experiments can be incorporated in the follow up measurements. Moreover, based on the first experiments we more accurately know the required manhours per experiment, which determine the total number of experiments possible.

1.2 Research objectives and proposed activities

Based on the results from the literature study and the input during the first consortium meeting, research questions have been defined and required laboratory experiments are proposed. A distinction has been made between 2 main areas of interest: erosion and settling/deposition. The bed density is important for both erosional and depositional processes, hence added as another area of interest. Since most earlier experimental work has been done for currents, the effect of waves on the erosion of mixed mud-sand beds is a focus point in the MUSA-project. Most experiments will be focussing on erosion rather than on deposition.
The basic philosophy is to design a series of laboratory and field experiments which can be used to derive fairly simple and partly empirical relationships describing the most relevant erosion and deposition processes in terms of the size distribution, the mineral composition and the bed density for a range of mixed mud-sand conditions.
It is realized that some detailed parameters and processes such as the stress conditions and stress history of the bed may also be important, but this will not be studied in great detail in the MUSA-project given the available budget. Furthermore, it may require a detailed geotechnical approach which is beyond the scope of the present Musa-Project.

The research objectives and experiments of interest for each area of interest are described below. Within the tables provided also the project phase is mentioned where the laboratory / field experiments are executed focusing on the research question considered.

1.2.1 Erosion

The following research questions are defined relating to erosion:

<u>Main research question:</u>
What is the critical bed shear stress and erosion rate of mud-sand beds exposed to 1) currents only and 2) exposed to both waves and currents?

Sub-questions:

Nr	Research question	Focus of Phase
1	What is the effect of varying percentages of clay, silt and sand and degree of consolidation on the erodibility?	1A/B (Flow) 1C/D (Flow-wave)
2	What is the role of bed irregularities (gravel, shells) on the erodibility?	1A/B (Flow)
3	How are the critical stresses and erosion rates of the sand and mud fractions related to bulk sediment properties (bed density) and basic hydrodynamic parameters?	1A/B (Flow) 1C/D (Flow-wave)
4	What is the effect of the easily erodible upper fluffy layer (as found in field conditions)?	1B 2

The following laboratory experiments and field measurements are proposed relating to erosion:

Nr.	Experiments	Phase
1	Characterization of samples (Particle Size Distribution - PSD, clay minerology, Total Organic Carbon - TOC, undrained shear strength, Atterberg limits)	1A-1F
2	Perform erosion tests: a. Use mud-sand samples from different field sites; vary percentage of sand, clay type (and with varying sand and mud type also the plasticity index), bed density/ strength and roughness (e.g. shells); with/without a fluffy layer; b. Do simultaneous tests in a small current flume and erosion tube with propeller (EROMES);	1A
3	Perform similar erosion tests in large wave-current flume with long bed of mud-sand; focus on detailed velocities and concentrations of sand and mud in lowest 20 cm above the bed.	1B / 1C / 1D
4	Perform erosion tests in field conditions with mud-sand beds under both tidal currents and waves; focus on detailed velocities and concentrations of sand and mud in lowest 50 cm above the bed.	2

1.2.2 Settling

The following research questions are defined relating to deposition:

Nr	Research question	Focus of Phase
1	What is the influence of the settling velocity and sediment concentration distribution on the deposition flux close to the bed, and how can this be related to hydrodynamic forcing and sediment properties?	1D
2	What is the role of sand on mud floc size, shape, density, and the resulting settling rates?	1E
3	How to obtain an accurate settling velocity distribution using settling tube and video-camera results? And, related to this, what is the effect of sample transfer to the laboratory on floc size and settling velocity?	1E / 2

The following laboratory experiments and field measurements are proposed relating to deposition:

Nr.	Experiments	Focus of Phase
1	Measure sediment concentrations and settling velocities close to the bed in laboratory and field conditions with currents and/or waves;	1D
2	Develop a simple settling tube instrument which can be used for in situ determination of mud settling velocities in laboratory and field conditions;	2
3	Determine the best way of measuring fall velocities (accurate but also practical) by performing comparative tests at field sites with mud concentrations > 200 mg/l using both settling tube and in situ camera	1E /2

1.2.3 Bed density

The following research questions are defined relating to bed density:

Nr	Research question	Focus of Phase
1	What is the best method to measure the density of the upper 50 cm of the bed, with a focus on the transition layer between water and seabed?	1B / 2
2	What is the dry bed density of the upper 50 cm of mud-sand beds in tidal conditions and how does this relate to sediment properties (e.g. composition, compaction, mud/clay content and minerology)?	1A / 1B / 2
3	What is a simple method for extraction and analysis of samples in shallow and in deep water?	2

The following field measurements are proposed relating to bed density:

Nr.	Experiments	Focus of Phase
1	Perform comparative field tests at sites with soft mud-sand beds using various sampling instruments (e.g. Sonidens, Graviprobe, dropcorer; depending on availability and logistics).	2
2	Measure the bed density and sediment composition of the upper 50 cm at various tidal field sites.	1A / 1B / 2

If feasible, a simple, but accurate sampling instrument for bed density and sediment composition in laboratory experiments and at field sites will be developed.

1.3 Approach

We have distributed the work in the following phases.

<u>Phase 1: Laboratory experiments</u>

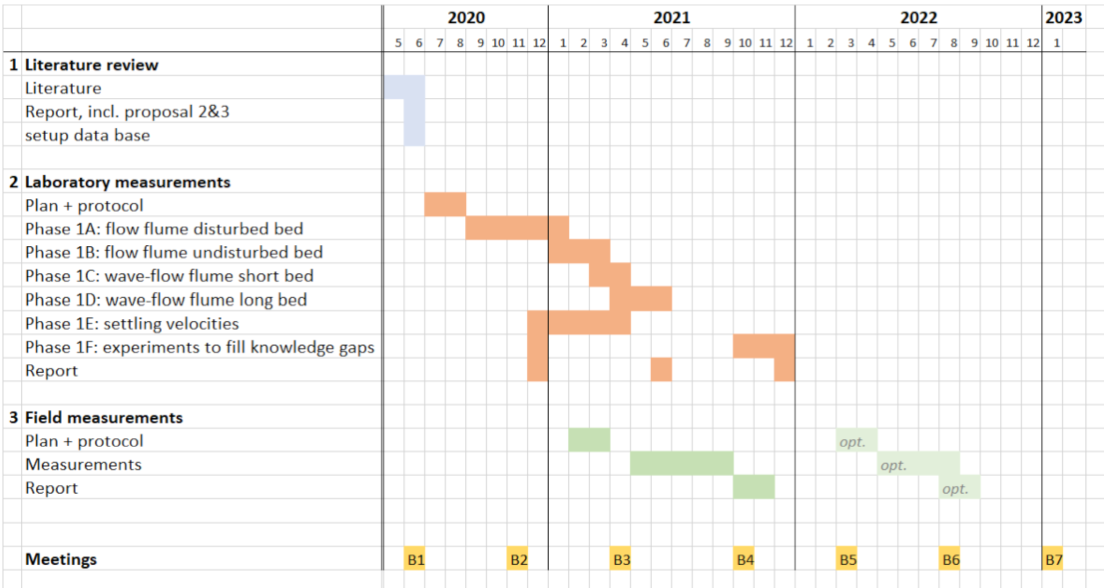
- 1A: Characterization of mud-sand sediments and erosion experiments (flow flume and Eromes) on remoulded beds
- 1B: Experiments on placed beds and in laboratory created beds (deposited beds).
- 1C: Experiments focusing on wave-flow flume experiments (short bed)
- 1D: Experiments focusing on wave-flow flume experiments (long bed) and deposition characteristics (settling velocities, concentrations)
- 1E: Settling velocity experiments in the laboratory (HRWallingford) and floc size
- 1F: Spare: Experiments which can still be executed at the end of the laboratory experiments period (end 2021) to fill in knowledge gaps identified during the project

<u>Phase 2: Field measurements</u>

To be further detailed in a next version of this document.

1.4 Time schedule

The time schedule foreseen is presented below:



The following remarks are made:

- We prefer to have the laboratory experience on flow-wave flume experiments (Phase 1D) to be executed before the field measurements to enable to use the experience from the flume in the field.
- We have included Phase 1F in order to have the possibility to do some experiments at the end of the laboratory experiment period (end of 2021). When during the analysis of the measurements and experiments we notice some additional experiments can strengthen the results, they can be executed under this phase.
- The experiments on settling velocity and floc size performed by HRWallingford are planned to be executed between December 2020 and April 2021;
- Presently Phase 1A has been most extensively described while somewhat less detail is provided on later Phases 1B-1F for which more detail will be given in next versions of this document.

- Semi-annual consortium meetings are foreseen to present and discuss research findings and discuss the plans and the way forward towards the next (sub)phase.

1.5 Outline

Based on the research objectives and proposed activities as presented above we have detailed the measurement plan. In the measurement plan a distinction is made between the laboratory experiments and field measurements as described in the subsequent chapters.

The outline of the measurement report is as follows:

- Chapter 2 - laboratory experiments
- Chapter 3 - field measurements
- Chapter 4 - the laboratory facilities, survey vessel and equipment
- Chapter 5 - procedures for laboratory experiments and field measurements.
- Chapter 6 - description of the database

2 Laboratory experiments

2.1 Introduction

In this chapter the proposed laboratory experiments as defined during the first consortium meeting (22 June 2020), and further detailed based on input from the consortium and during the first phase of the laboratory experiments, have been detailed. The various activities as part of the lab experiments are described, complemented with estimates on required man-hours.

2.1.1 Covid and experiments

In general laboratory experiments on sand-mud mixtures are time consuming. At the start of the MUSA project we have foreseen to execute the experiments at WaterProof with significant assistance from LVRS, Deltares and in-kind contribution of other consortium partners. Due to Covid we have however limited the amount of personnel in our laboratory where possible to prevent the possibility to infect each other. Thereto only a limited number of WaterProof personnel and students are allowed within the laboratory and no assistance from the consortium partners can take place. Presently (1-11-2020) it is unknown how the Covid situation will evolve in future and how it will affect the efficiency of experiments / assistance by other partners. We hope that in the beginning of 2021 the Covid situation will allow the assistance of consortium partners as well.

2.1.2 Living document

For the laboratory experiments we follow a phased approach consisting of 5 sub-phases. During the first phases the required amount of time to execute the various foreseen experiments becomes known. Lessons learned from the first phases (both from a practical, logistical and scientific point of view) will then be used to further detail next phases and to quantify the exact number of experiments.

2.1.3 Number of experiments

The number of experiments provided in this document should be seen as an indication only and may change along the project. First assessment of the required man-hours to execute the measurement plan indicates that the proposed activities require a larger amount of time than we have available within the budget. As such, we distinguish between experiments that are expected to be feasible within the budget (“basic package”) and a larger number of experiments (more field locations) that enhance the reliability of the research findings and enable the gathering of more insights, but likely require more budget and for which students are needed (“extensive package”). Within both packages, the same tasks are performed, however, the number of samples differs.

Whether indeed all experiments can be executed depends on the ability to find enough students to assist during the experiments. Between August 2020 and December 2020, 2 students of Utrecht University have assisted during the laboratory experiments of Phase 1A. For the upcoming period between January and June 2021 we are currently searching for 1 or 2 more students. One of these students might come from Denmark for which we currently have contacts with DHI.

2.2 Phased approach

The laboratory experiments will be executed in 5 sub-phases:

- Phase 1A: Characterization of mud-sand sediments and erosion experiments (flow flume and Eromes) on disturbed beds;
- Phase 1B: Experiments on undisturbed beds and on beds created in the laboratory from deposition;
- Phase 1C: Experiments focussing on wave-flow flume experiments (short bed);
- Phase 1D: Experiments focussing on wave-flow flume experiments (long bed) and deposition characteristics (settling velocities, concentrations)
- Phase 1E: Experiments focusing on settling velocities
- Phase 1F: We have foreseen a period end 2021 in which experiments can be executed to fill in knowledge gaps

For each sub-phase a brief overview of the foreseen tasks, knowledge, methodology and timeframe is presented below. A more extensive description of the experiments foreseen is provided in Section 2.3 (Phase 1A), Section 2.4 (Phase 1B), Section 0 (Phase 1C), Section 2.6 (Phase 1D), Section 2.7 (Phase 1E) and Section 2.8 (Phase 1F).

2.2.1 Phase 1A: Flow flume experiments disturbed beds (currently under execution)

Under Phase 1A we have started the laboratory experiments by collecting samples from a number of locations from the Western Scheldt estuary(various sites) and WaddenSea (Noordpolderzijl). Also, sediment samples from the Tamar estuary are foreseen to be collected the coming months. For more details, see Section 2.3.

<u>Tasks</u>
Under this phase the following tasks will be executed:

- Sediment sampling:
    - at various locations (5 Western Scheldt, 2 Noordpolderzijl, 3-5 Tamar Estuary, 1 Scheldt River) where a range of sandy to fully clayey sediment is present
- General characterisation of sediment samples
    - Density, composition, mineralogy, etc.
- Erosion tests
    - Approx. 48 flow-flume experiments
    - Approx. 42 Eromes experiments
- Tests related to bed density
    - Approx 12x6 consolidation tests

<u>Knowledge</u>
This phase will provide knowledge on

- General characterization of all samples from the chosen sites (in case certain types of sediments are not included within the chosen set, Phase 1B provides possibilities to fill gaps with additional samples).
- Effect of (1) bed density, (2) composition, (3) bed roughness and irregularities on erosion behaviour by both flow-flume and Eromes experiments.
- Insight on effects of mineral composition, -organic matter content on erosion and consolidation.

<u>Insight in methodology</u>
This phase will provide insight in methodologies by:

- Comparison of erosion rates and critical shear stresses with
    - Eromes
    - Flow-flume experiments

- Comparison of the accuracy of grain size distribution of fine fraction executed with:
    - fall velocities test
    - hydrometer test

Timeframe
Phase 1A: September 2020 – January 2020 (5 months), October 2021 – December 2021 (3 months)

2.2.2 Phase 1B: Flow flume experiments undisturbed bed

Under this Phase 1B we foresee to perform additional erosion experiments with Eromes and flow-flume using placed (undisturbed) beds. For more details, see Section 2.4.

Tasks
The following tasks are foreseen:
- Sediment sampling:
    - Additional samples are taken for the undisturbed bed experiments, for comparison reasons, preferably taken from the same sites and locations as analysed under Phase 1A.
- General characterisation of sediment samples
    - Density, composition, mineralogy, etc.
- Erosion tests
    - Approx. 8 flow-flume experiments considering sediment beds formed by deposition of sediment within the (flume) water column instead of considering seabed samples
    - Approx. 3 flow-flume experiments considering effect of undisturbed bed instead of mixed bed
    - because we have seen the Eromes experiments deliver additional information to the flow-flume experiments we do the experiments both with Eromes and flow-flume
- Tests related to deposition and consolidation (during preparation of the beds)
    - Concentration profile distribution in upper 20 cm above the bed
    - Consolidation tests of the upper 5 cm of the seabed

Knowledge
This phase will provide knowledge on:
- Erosion of freshly deposited material (sediment bed is created by deposition of diluted sediment in the water column) using either Eromes or/and Flow-flume.
- Effect of consolidation time of the freshly deposited sediments on erosion rate. Consolidation time ranging between 1 day to 1 month.
- Erosion of undisturbed in-situ bed; sediment is taken out of mudflat, directly transported to flume and tested and compared with Eromes.
- Evolution of seabed density over time in upper 5 cm

Insight in methodology
This phase will provide insight in the methodologies by:
- Comparison between erosion of disturbed and undisturbed bed. Results give insight in sampling requirements for erodibility tests.
- Comparison between erosion tests in which density is reached by natural consolidation compared to density artificially created by diluting.

Timeframe
Phase 1B: January 2020 – March 2021 (3 months)

2.2.3 Phase 1C: Wave-flow flume experiments short bed

Under this Phase 1C we foresee to perform additional erosion experiments in the wave-flow flume using a short bed (approx. 0.5 m long, 0.1 m thick). The type and focus of the experiments depend on the results from the preceding phases 1A and 1B. For more details, see Section 2.5

At this moment we have planned to execute wave-flow flume experiments for a number of sediment samples which have also been tested in the flow-flume. We foresee the following wave-flow flume tests:

- Sediment from 1 site with silt content ranging between 10 to 90%, in total max 5 samples.
- Erosion tests for 1 flow velocity (e.g. 0.2 m/s or 0.4 m/s) and a range of wave conditions (gradually increasing wave height during experiments while maintaining flow velocities constant).

Tasks

Under this phase the following tasks will be executed:

- Sediment sampling:
    - at 1 site where a range of sandy to clayey sediment is present, preferably from one of the sites sampled under Phase 1A or Phase 1B.
- General characterisation of sediment samples
    - Density, composition, etc.
- Erosion tests, 5 wave-flume experiments using a short bed:
    - 1 flow velocity (to be determined, e.g. 0.2 m/s and 0.4 m/s)
    - Increasing wave height in steps until erosion takes place
    - 5 samples with a range (of %silt / %sand) from 10-90%

Knowledge

This phase will provide knowledge on

- Effect of wave height on erosion rate under wave-flow conditions:
- Effect of flow velocity on erosion rate under wave-flow conditions (in case we do experiments for more than 1 flow velocity):
- Effect of %fines (clay+silt) / %sand on erosion rate under wave-flow conditions

Insight in methodology

This phase will provide insight in required methodology and sensitivity of tests:

- Comparison between erosion of
    - Flow flume experiments
    - Wave-flow flume experiments
    - Eromes

Timeframe

Phase 1C: March 2021 – April 2021 (2 months)

2.2.4 Phase 1D: Wave-flow flume experiments long bed

Under this Phase 1D we foresee to perform erosion experiments in the wave-flow flume using a long bed (3 to 5 m long). The type and focus points of the experiments to be executed under Phase 1D depends on the results from the preceding phases 1A-1C. For more details, see Section 2.6

At this moment we are planning to execute the following wave-flow flume tests:

- To reproduce 1 of the 10 wave-flow flume experiments as executed under Phase 1C using a long (4 to 5 m long bed) instead of a short bed.
- To extensively analyse the concentrations and fall velocities in the zone close to the bed.

Tasks

Under this phase the following tasks will be executed:

- Sediment sampling:
    - at 1 site where a range of sandy to clayey sediment is present, preferably from one of the sites sampled under Phase 1A
- General characterization of sediment samples
    - Density, composition, mineralogy, etc.
- Erosion tests standard,
    - wave-flow flume experiments using a long bed
    - wave-flow flume experiments using a long bed including roughness
    - wave-flow flume experiments using an placed (undisturbed) long bed
- Tests related to deposition (during 1 wave-flume experiment)
    - Measure concentrations close to the bed (at 4 heights in lower 30 cm) using 2 methods:
        - Pumping water + sieving (sand) + filtration (silt)
        - Acoustic sand transport meter ASTM (sand) + OBS (silt/ clay)
    - Measure settling velocities close to the bed (lower 30 cm) using 2 methods:
        - fall velocity test
        - underwater camera
- Execute experiments under decelerating flow

Knowledge

This phase will provide knowledge on:

- Distribution of sediment concentrations and grains size over the vertical but especially close to the bed
- Variability of sediment concentrations over time under steady flow conditions and waves
- Role of bed roughness for erosion of sand-mud mixtures

Methodology

This phase will provide insight in methodologies by:

- Applicability of short flumes for measuring erosion rates through a comparison of erosion rates in short and long flumes
- Testing the accuracy of acoustic sand transport meter (ASTM) compared to sieving/filtration.
- Comparison of 2 methods for measuring the settling velocity.

Timeframe

Phase 1D: April 2021 – June 2021 (3 months)

2.2.5 Phase 1E: Settling velocities of disturbed samples

Phase 1E will focus on the settling velocity of sediments with different mixtures of sand and mud executed by HR Wallingford. Under this phase tests are executed with mixed (disturbed) seabed samples. Experiments are executed where suspensions are created by suspending sediment in the water column to create varying sediment concentrations under different shear conditions. For more details, see Section 2.7

Tasks:

For more information on Phase 1A, see Section 2.7

Knowledge

This phase will provide knowledge on floc size, settling velocity, effective density, floc mass, floc shape, floc porosity and floc mass settling flux

Timeframe
Phase 1E: December 2020 – April 2021 (5 months)

2.3 Phase 1A; Flow flume experiments disturbed bed, Eromes and consolidation tests

In August 2020 we have started the laboratory experiments with Phase 1A in which we have collected a large number of samples from various locations along the Western Scheldt Estuary, Wadden Sea (Noordpolderzijl) and (not yet sampled) Tamar Estuary and Scheldt River.

Based on the literature analysis the effects of the following aspects on erosion rates are studied in the MUSA project:

1. Effect of bed density
2. Effect of % fines (%clay & %silt), %sand
3. Effect of bed roughness (e.g. shells)
4. Effect of mineral composition
5. Effect of % organic material

Within the MUSA project we focus on the first 3 aspects, by systematically performing erosion tests for varying density, sediment composition and roughness. By also determining the mineral composition and organic content of each sample, the effect of these aspects on erodibility is tested implicitly.

2.3.1 Sites foreseen

We plan to collect samples from the locations specified in tables below.

We make a distinction between 2 types of sites:

- Sites where a wide range in sandy/silty/clayey samples can be taken at relatively close distance from each other;
- Sites where predominantly silty/clayey sediment is available and where differences in mineralogy can be expected considering the 3 main groups of clay minerals (kaolinites, micas, and smectites).

In September 2020 samples have been collected from Noordpolderzijl and Western Scheldt estuary. We have requested HRWallingford to provide 5 samples from the Tamar estuary (not taken yet) and JDN from the Scheldt River (not taken yet).

For the extensive package, besides these sites (in grey), four additional field sites are included (green-colored). Two (light blue colored) field site mentioned in the table below is added as an option when it turns out that one of the field sites mentioned is not possible or when consortium partners are interested in information from a specific site and are willing to share the obtained information within the MUSA project.

	Sites where a range in sandy/silty/clayey samples can be taken:		
	Country	Location	Samples
1A-1E	NL	Noordpolderzijl	samples taken along 2 locations in the entrance to the port of Noordpolderzijl where transition between 95% sand and 95% mud takes place along 3 km long, 1 m deep channel
2A-2E	UK	Tamar Estuary	Samples taken from 5 locations along Tamar estuary (input HRWallingford)

3A-3E	NL	Holwerd	samples taken from 5 locations along the navigation channel towards Holwerd where transition between 95% sand and 95% mud takes place along approx. 5 km long, 4 m deep channel (input consortium partners)
4A-4E	NL	Western Scheldt	Samples taken from 6 locations between Terneuzen and Land van Saefthinge (north and south banks) where both sandy and silty locations are available
5A-5E	NL	Marker Wadden	Samples taken from 5 locations within Marker Wadden (input Boskalis)
6A-6E	DK	Rødsand lagoon	Samples taken from 5 locations along the Rødsand lagoon (input DHI)

	Sites where predominantly silty/clayey sediment is available with differences in clay minerals		
	Country	Location	Samples
101	BE	Scheldt River	1 sample taken from the bank of Scheldt river near Oosterweel (input JDN/ DEME)
102	IT	Adriatic Sea	1 sample taken from location Po delta (input HRWallingford)
103	NL	Terneuzen	1 sample taken from Terneuzen harbour (input JDN/DEME)
104	NL	To be discussed	1 sample taken by consortium partner (JDN / DEME / Boka / HRW / DHI)

Under Phase 1A it is foreseen to consider at least 11 samples (basic package) up to a maximum of 6x5 + 3x1 = 33 samples (extensive package). Below, we provide the numbers per task for the basic package only. The number of samples and all tests for the extensive package are summarised in Section 2.3.10.

2.3.2 Sample handling

At each site, samples of minimum 20 litres are taken. Moreover, for each sample approx. 5 litres of native seawater (to be specified at a later stage) should be collected and brought to the laboratory. This water enables to execute settling tests within the native seawater.

During or directly after sampling, the in-situ wet bulk density is determined using density rings (for hard sediments) or little pots (for soft sediments), see for more details Section 5.2. The wet density is determined from the:

- upper 50 centimeter (with 10 cm intervals)
- mixed sample in bucket

From each sample 0.5 liter of sample will be send to Andrew Manning (when required by Andrew also 500 ml of native water) for analysis on floc characteristics.

Each sample will have a unique identification number, see further details in Sections **Error! Reference source not found.**.

2.3.3 Analysis on mineralogy / general characteristics on all samples

All samples taken will be analyzed on mineralogy and the general characteristics will be determined. The methodology and procedures followed are described under Chapter 5.

The following characterization is foreseen (for all samples):

- Composition (%gravel/shell, %sand, %silt and %clay):
  - Dry sieving the fraction > 63 µm
  - hydrometer tests and / or settling test in distilled water incl dispergent for the fraction < 63 µm (settling tests only performed on limited number of samples)
- Clay mineralogy:
  - type, floc shape / size, settling behaviour (HR Wallingford/Andrew Manning)
  - mineral composition; e.g. illite, kaolinite (external laboratory, e.g. Wiertsema)
- % organic material by “loss on ignition” test
- Plasticity index and Atterberg limits (external laboratory, e.g. Wiertsema)
- Remoulded shear strength (Deltares laboratory), only for the samples with the highest clay/silt content (2 + 1 = 3 samples) and 3 different wet densities (by diluting the samples in native water). In total 3 x 3 = 9 tests are foreseen in the basic package.

2.3.4 Analysis on erodibility & consolidation on selection of sample locations

Based on the outcomes of the first analysis as described under Section 2.3.3, first step is to execute additional analysis on samples with a range varying between 95% sand and 95% silt.

Currently (1-11-2020) we have selected 2 samples both from Noordpolderzijl and 5 samples from Western Scheldt estuary in which this range is covered. Additional samples from the Tamar estuary (3x-5x) and Scheldt river (1x) will provide further information.

For each sample the following tests are executed for 12 samples (2x Noordpolderzijl, 6x Western Scheldt, 3x Tamar, 1x Scheldt river):

- Flow-flume erosion test
- Eromes test
- Consolidation test, for each test 6 different initial densities

In order to compare both methods with each other, in this plan the Eromes test will be performed in parallel with the Flow-flume tests for all tests. Based on the first results of both tests we see that both tests provide complementary information to each other and when both tests are performed in parallel the amount of extra work is limited. Moreover, because the Eromes can be applied in the field, we propose to perform all erosion tests both with flow-flume and Eromes.

Note: the effect of composition (%gravel/shell, %sand, %silt and %clay) will not be studied by artificially preparing samples to create the correct %sand, %mud, %clay, etc. Instead, only samples taken from the field are tested.

2.3.5 Analysis on erodibility on selection of wet densities

For all samples the effect of wet density on erodibility is investigated. Thereto each sample is diluted with (salt) water to obtain 2 additional wet densities. Including the original sample we have 3 wet densities per sample.

In total 12x2 = 24 additional erosion tests, both with Eromes and Flow-flume.

2.3.6 Analysis on erodibility on selection of consolidated wet densities

The different densities as described under Section 2.3.5 are created by adding water to a sample and mixing it, creating a vertically uniform sample. This results in overconsolidation near the surface and in underconsolidation at greater sediment depth. We therefore also select 2 samples with relatively low wet densities and small % of sand in which we investigate the effect of the vertical density variation on erosion. Thereto, each sample is split into 3 subsamples, equally diluted, but left consolidating for a different period. This leads to 6 additional tests.

2.3.7 Analysis on erodibility on selection of roughness

For 1 selected site and the 3 different silt percentage samples, we execute for each sample 2 additional flow-flume tests where roughness of the bed is increased from flat, to irregular to very irregular using shells. In total 1x3x2= 6 additional tests.

2.3.8 Analysis on erodibility on selection of %organic material

No additional tests are foreseen related to %organic material. It is expected that within the tests executed and described above also the percentage of organic material will differ.

2.3.9 Total type of tests (basic package)

	Standard test	Wet density	Consolidated wet density	Roughness	Total
Flow-flume	12	2x12=24	2x3 =6	1x3x2=6	48
Eromes	12	2x12=24	2x3 =6	0	42
Consolidation	12 x 6 = 72				72

2.3.10 Total number of tests and required time

In the table below the various tests, the required working hours and execution hours per test as well as the total man days are presented. The numbers for both the basic package (grey-colored columns) and the extensive package are shown (grey+green-colored columns). WaterProof and LVRS are responsible for all activities except mineralogy (Wiertsema), flocculation (HR Wallingford/Andrew Manning), %organic, Atterberg limits (Wiertsema) and remoulded shear strength (Deltares).

Test	**Nr.**	**Nr.**	**Working hours per test**	**Execution hours per test**	**Total man days**	**Total man days**
Sampling sites (3 sites)	3	9	16	8	6	18
Sample handling / waste	12	33	2	2	3	9
Grain size (> 63µm)	12	33	2	4 per day	3	9
Hydrometer (< 63µm)	12	33	4	6 per 2 days	6	17
Fall velocity (< 63µm)	12	33	4	3 per day	6	17
Mineralogy	3	9	1	Laboratory	1	2
Flocculation (most clay-rich)	3	9	2	4 per day	1	3
Density	12	33	0.2	40 per day	1	1
% organic	12	33	1.5	5 per day	2	6
Atterberg limits	12	33	1	Laboratory	2	5
Remoulded shear strength	9	27	2	Laboratory	2	7
Flow-flume	48	45	6	1.5 per day	36	46
Eromes	42	39	3	2 per day	16	20
Consolidation (per 6)	12	21	4	3 per week	4	11
				Total:	**87**	**165**

In total for Phase 1A approximately 87 working days are foreseen in the basic package and approximately 165 working days in the extensive package. These working days are all made by WaterProof personnel and/ or students which are assisting during the experiments. During the experiments LVRS and Deltares provide expert assistance and support. In case Covid allows, the consortium partners are welcomed to assist in the experiments as well for a number of days.

In the basic package, as the number of required man-days for WaterProof is much larger than the available number of man-days within the MUSA project available, students are recruited to assist *with the experiments and reduce the amount of man-days for WaterProof. For the Western Scheldt sites, we joined the MONEOS campaign by Rijkswaterstaat in September 2020 and collected the samples for our tests. Two students (UU) have joined this campaign, guided by the MUSA partners (Deltares, LVRS, WaterProof) and are assisting in the experiments until December 2020.*

*The basic package is limited to 4 field sites. Extending the number of sites enlarges the range of sites and therefore types of mixtures. The extensive package therefore offers more insight and enables a more generic application of the research findings. Furthermore, by using samples from more field sites (*the Rødsand Lagoon (input DHI), Marker Wadden (input Boskalis), and Italy (input HR Wallingford)*, the number of samples increases so that the findings become more reliable. To achieve this, the availability of extra students is a prerequisite. To this end, the consortium partners are requested to spend part of their in-kind contribution to the guidance and support of students who will be able to conduct experiments at the lab facilities of WaterProof. In this way, much more tests can be performed, hence enhancing the reliability of the results of this research program. The consortium partners themselves are of course more than welcome to join part of the experiments (when Covid regulations allow). Above will be explained during the consortium meeting of November 17, 2020.*

2.3.11 Required sample volume

The required sample volume depends on the amount and type of tests. In the table below we summarized the volume (in dm^3) required.

Test	Required volume (dm^3)
Density (in-situ)	<0.5
Grain size	0.5
Mineralogy	<0.5
Flocculation	0.5
Density	<0.5
% organic	<0.5
Atterberg limits	0.5
Remoulded shear strength	0.5
Flow-flume standard	2.0
Flow-flume extra density test (x2)	4.0
Flow-flume extra roughness test (x2)	4.0
Eromes standard	2.0
Eromes extra density test (x2)	4.0
Consolidation	2.0
Total (liters)	**>20**

2.4 Phase 1B; Flow flume experiments undisturbed bed, Eromes and consolidation tests

Under this Phase 1B we foresee to perform additional erosion experiments with Eromes and flow-flume. The type and focus points of the experiments to be executed under Phase 1B depend partly on the information that we achieved to gather under Phase 1A.

This phase will provide knowledge on:

- Erosion of freshly deposited material (sediment bed is created by deposition of dissolved sediment in the water column) using either Eromes or/and Flow-flume.
- Effect of consolidation time of the freshly deposited sediments on erosion rate. Consolidation time ranging between 1 day to 1 month.
- Erosion of undisturbed in-situ bed; sediment is taken out of mudflat, directly transported to flume and tested and compared with Eromes.
- Evolution of seabed density over time in upper 5 cm

Further detailing of this phase will be described during Phase 1B.

2.4.1 Sites foreseen

We plan to collect / use samples from the same locations as described under Phase 1A (Western Scheldt, Tamar estuary and/or Noordpolderzijl). By using the same type of sediment we make sure that experiments under Phase 1A and 1B are comparable. The undisturbed samples are taken from the field by taking a slice of the upper 10 cm of the seabed. The procedure is described under Section 5.2.

2.4.2 Analysis of mineralogy / general characteristics on all samples

To reduce the amount of effort, when possible, only the basic general characteristics of the samples will be determined (wet density and composition of both sand and silt fractions). The methodology and procedures to be followed are described under Chapter 5.

2.4.3 Analysis of erodibility & consolidation of freshly deposited beds

Under Phase 1A tests are executed with mixed (disturbed) seabed samples. Under this Phase experiments are executed where the beds are created by dissolving sediment in the water column, creating a suspension with high sediment concentrations and resulting formation of a freshly deposited bed. in which the sediment is dissolved. The best method to create these beds is subject of further investigation upfront the experiments.
The following experiments are foreseen:

- 2 samples from 1 site, each with a different silt content (approx. 50% and 90%), are used to create 1 x 5 beds per site (10 in total).
- From each sample the 4 created beds are tested in the flow-flume or Eromes for varying consolidation periods (e.g. 1 day, 3 days, 10 days, 30 days). The 5th created bed is used only to be able to follow (and measure) the development of wet density over time
- In total 8 flow-flume or Eromes experiments are performed
- The development of the density of the beds is monitored using e.g. RheoTune and/or by taking subsequent wet density samples from the 5th created bed.

2.4.4 Analysis of erodibility & consolidation of undisturbed in-situ bed

Under this task we execute experiments on erosion of undisturbed in-situ bed (placed beds); sediment is taken from the mudflat (procedure, see Section 5.2), directly transported to the laboratory and tested with Eromes and Flow-flume. The experiments with undisturbed beds are compared to the experiments using disturbed beds as executed under Phase 1A. To facilitate comparison, preferably the sample locations of both (disturbed and undisturbed) should be the same.

- It is foreseen to execute experiments with 3 sediment compositions, e.g. 10%/50%/90% from 1 site
- In total 3 experiments using Flow-flume and Eromes are performed

2.4.5 Total type of tests (basic package)

	Created bed by deposition test	Undisturbed bed from the field	Total
Flow-flume	2 x 4 = 8	1 x 3 = 3	11
Eromes	2 x 4 = 8	1 x 3 = 3	11
Consolidation	2 x 4 = 8		8

2.4.6 Total number of tests and required time

In the table below the various tests, the required working hours and execution hours per test as well as the total man days are presented. The numbers for both the basic package (grey-colored columns) and the extensive package are shown (green-colored columns). WaterProof and LVRS are ultimately responsible for these activities, partners are responsible for providing the necessary input.

Test	Nr.	Nr.	Working hours per test	Execution hours per test	Total man days	Total man days
Sampling sites (2 sites)	1	2	16	8	2	4
Sample handling / waste	2	4	2	2	1	2
Grain size (> 63µm)	2	4	2	4 per day	1	2
Hydrometer (< 63µm)	2	4	4	6 per 2 days	1	2
Density	2	4	2	2	1	2
Flow-flume (or Eromes)	11	22	6	1.5 per day	8	16
Eromes (or Flow-flume)	11	22	3	2 per day	4	8
Consolidation (settling tube)	8	16	4	3 per week	4	8
				Total:	**22**	**44**

In total for Phase 1B approximately 22 working days are foreseen in the basic package and approximately 44 working days in the extensive package. These working days are all made by WaterProof personnel and/ or students which are assisting during the experiments. During the experiments LVRS and Deltares provide expert assistance and support. In case Covid allows, the consortium partners are welcomed to assist in the experiments as well for a number of days.

* In the extensive package, WaterProof will undertake additional field campaigns in Holwerd and Delfzijl, rendering it possible to analyse much more samples in the lab, for which student hours are needed to enable the testing of all samples.
** In the extensive package, the total number of estimated man-hours is larger in this table then follows from the previous table listing all activities, because it requires some time for students to get acquantained with the subject and the lab.
*** In the extensive package, the total number of estimated man-hours is larger in this table then follows from the previous table listing all activities, because it requires some time for students to get acquainted with the subject and the lab.

2.4.7 Required sample volume

The required sample volume depends on the amount and type of tests. In below table we summarized the volume (in dm^3) required

Test	Required volume (dm^3)
Density (in-situ)	<0.5
Grain size	0.5
Mineralogy	<0.5
Flocculation	0.5
Density	<0.5
% organic	<0.5
Atterberg limits	0.5
Remoulded shear strength	0.5
Flow-flume standard	2.0
Flow-flume extra density test (x2)	4.0
Flow-flume extra roughness test (x2)	4.0
Eromes standard	2.0
Eromes extra density test (x2)	4.0
Consolidation	2.0
Total (liters)	**>20**

2.5 Phase 1C; Wave-flow flume experiments selected samples short bed

Under this Phase 1C we foresee to perform additional erosion experiments in the wave-flow flume using a short bed (approx. 0.5 m long). The type and focus of the experiments depend on the results from the preceding phases 1A and 1B.

At this moment we have planned to execute wave-flow flume experiments for a number of sediment samples which have also been tested in the flow-flume. We foresee the following wave-flow flume tests:

- Sediment from 1 site with silt content ranging between 10 to 90%, in total max 5 samples.
- Erosion tests for 1 flow velocity (e.g. 0.2 m/s or 0.4 m/s) and a range of wave conditions (gradually increasing wave height during experiments while maintaining flow velocities constant).

2.5.1 Sites foreseen

We plan to collect / use samples from the same locations as described under Phase 1B. By using the same type of sediment we make sure that experiments under Phase 1B and 1C are comparable. A point of attention are possible seasonal variations with respect to Phase 1A and 1B. The undisturbed samples are taken from the field by taking a slice of the upper 10 cm of the seabed. Procedure is described under Section 5.2.

2.5.2 Analysis on mineralogy / general characteristics on all samples

To reduce the amount of effort, when possible, only the basic general characteristics of the samples will be determined (wet density and composition of both sand and silt fractions). The methodology and procedures followed are described under Chapter 5.

2.5.3 Analysis on erodibility wave-flow flume for sediments with varying %fines/sand

5 wave-flow flume experiments are executed for sediment from 1 site (for which also experiments are executed under Phase 1A and 1B).
The following experiments are considered:

- 5 wave-flume experiments using a short bed:
  - 1 flow velocity (to be determined, e.g. 0.2 m/s and 0.4 m/s)
  - Increasing wave height in steps until erosion takes place
  - 5 samples with a range (of %silt / %sand) from 10-90%

2.5.4 Analysis on erodibility wave-flow flume for different roughness

For 3 sediments (the 10%, 50% and 90% silt percentage samples) additional wave-flow flume experiments are executed in which the roughness of the bed is increased. For each sample, 2 additional wave flow-flume tests are executed where roughness of the bed is increased from flat, to irregular to very irregular using shells. In total 3x2= 6 additional tests (flat beds have been tested already under 2.5.3.

2.5.5 Total type of tests (basic package and extensive package)

	Standard tests	Roughness tests	Total
Wave-Flow flume	1 x 5 = 5	3 x 2 = 6	11

2.5.6 Total number of tests and required time

In the table below the various tests the required working hours and execution hours per test as well as the total man days are presented. The numbers for the basic package (grey-colored columns) and the extensive package (green-colored columns) are identical, but shown together for consistency with the presentation of the tables for Phase 1A and Phase 1B. WaterProof and LVRS are ultimately responsible for these activities, partners are responsible for providing the necessary input.

Test	Nr.	Nr.	Working hours per test	Execution hours per test	Total man days	Total man days
Sampling sites (1 site)	1	1	16	8	2	2
Sample handling / waste	5	5	2	2	2	2
Grain size (> 63µm)	5	5	2	4 per day	2	2
Hydrometer (< 63µm)	5	5	4	6 per 2 days	3	3
Density	5	5	2	2	1	1
Wave – Flow flume (short bed)	11	11	11	1.5 per day	22	22
				Total:	**35**	**35**

In total for Phase 1C approximately 35 working days are foreseen in the basic package and in the extensive package. These working days are all made by WaterProof personnel and/ or students which are assisting during the experiments. During the experiments LVRS and Deltares provide expert assistance and support. In case Covid allows, the consortium partners are welcomed to assist in the experiments as well for a number of days.

2.5.7 Required sample volume

The required sample volume depends on the amount and type of tests. We make sure enough material is collected such that the Flow-wave flume experiments can be executed.

2.6 Phase 1D; Wave-flow flume experiments selected samples long bed

Under this Phase 1D we foresee to perform erosion experiments in the wave-flow flume using a long bed (3 to 5 m long). The type and focus points of the experiments to be executed under Phase 1D depends on the results from the preceding phases 1A-1C.

At this moment we are planning to execute the following wave-flow flume tests:

- To reproduce 1 of the 5 standard wave-flow flume experiments as executed under Phase 1C using a long (4 to 5 m long bed) instead of a short bed.
- To reproduce 1 of the 6 roughness focussed wave-flow flume experiments as executed under Phase 1C using a long (4 to 5 m long bed) instead of a short bed.
- To reproduce 1 of the above standard wave-flow flume experiments using a placed (undisturbed) bed instead of a remoulded bed.
- To extensively analyse the concentrations and fall velocities in the zone close to the bed.

2.6.1 Sites foreseen

We plan to collect / use samples from the same locations as described under Phase 1C. By using the same type of sediment we make sure that experiments under Phase 1D and 1C are comparable. The undisturbed samples are taken from the field by taking a slice of the upper 10 cm of the seabed. Procedure is described under Section 5.2.

2.6.2 Analysis on mineralogy / general characteristics on all samples

To reduce the amount of effort, when possible, only the basic general characteristics of the samples will be determined (wet density and composition of both sand and silt fractions). The methodology and procedures followed are described under Chapter 5.

2.6.3 Analysis on erodibility wave-flow flume for sediments with varying %silt/sand

1 wave-flow flume experiment is executed for sediment from 1 site (for which also experiments are executed under Phase 1A and 1B).
The following experiments are considered:

- 1 wave-flow flume experiment using a long bed:
  - 1 flow velocity (to be determined, e.g. 0.2 m/s or 0.4 m/s)
  - Increasing wave height in steps until erosion takes place
  - 1 sample with a given (%silt / %sand) content, e.g.30/70% or 70/30%
- In total 1 experiment

2.6.4 Analysis on erodibility wave-flow flume for sediments with varying roughness

1 wave-flow flume experiment is executed for sediment from 1 site (for which also experiments are executed under Phase 1A and 1B).
The following experiments are considered:

- 1 wave-flow flume experiment using a long bed:
  - 1 flow velocity (to be determined, e.g. 0.2 m/s or 0.4 m/s)
  - Increasing wave height in steps until erosion takes place
  - 1 sample, preferably silty, (e.g. %silt / %sand is 70/30%)
  - 1 roughness
- In total 1 experiment

2.6.5 Analysis on erodibility wave-flow flume for sediments using placed (undisturbed) bed

1 wave-flow flume experiment is executed for sediment from 1 site (for which also experiments are executed under Phase 1A and 1B).
The following experiments are considered:

- 1 wave-flow flume experiments using a long bed:
  - 1 flow velocity (to be determined, e.g. 0.2 m/s or 0.4 m/s)
  - Increasing wave height in steps until erosion takes place
  - 1 sample with a given (%silt / %sand) content, e.g.30/70% and 70/30%
- In total 1 experiment

2.6.6 Analysis related to settling and deposition

During 1 wave-flow flume experiment tests related to settling and deposition are executed. The following tests are foreseen:

- Measure concentrations close to the bed (at 4 heights in lower 30 cm) using 2 methods:
  - Pumping water + sieving (sand) + filtration (silt)
  - Acoustic sand transport meter ASTM (sand) + OBS (silt/ clay)
- Measure settling velocities close to the bed (lower 30 cm) using 3 methods:
  - settling velocity test at 2 heights (2 tests)
  - video camera

2.6.7 Total number of tests and required time

	Standard test	Roughness test	Placed bed test	Total
Wave-Flow flume	1	1	1	3
Settling test			2	2
Hydrometer test			4	4
Video camera			2	2
Concentration monitoring			2	2

2.6.8 Total number of tests and required time

In the table below the various tests the required working hours and execution hours per test as well as the total man days are presented. The numbers for the basic package (grey-colored columns) and the extensive package (green-colored columns) are identical, but shown together for consistency with the presentation of the tables for Phase 1A and Phase 1B. WaterProof and LVRS are ultimately responsible for these activities, partners are responsible for providing the necessary input.

Test	Nr.	Nr.	Working hours per test	Execution hours per test	Total man days	Total man days
Sampling sites (1 site)	3	3	8	8	3	3
Sample handling / waste	3	3	4	4	2	2
Grain size (> 63µm)	3	3	2	4 per day	1	1
Hydrometer (< 63µm)	3	3	4	6 per 2 days	2	2
Fall velocity (< 63µm)	3	3	4	3 per day	2	2
Density	3	3	2	2	1	1
Wave – Flow flume (long bed)	6	6	32	1 per 3 days	24	24
Underwater camera	2	2	32	1 per 3 days	8	8
Concentration monitoring	2	2	32	1 per 3 days	8	8
				Total:	**51**	**51**

In total for Phase 1D approximately 51 working days are foreseen in the basic package and in the extensive package. These working days are all made by WaterProof personnel and/ or students which are assisting during the experiments. During the experiments LVRS and Deltares provide expert assistance and support. In case Covid allows, the consortium partners are welcomed to assist in the experiments as well for a number of days.

2.6.9 Required sample volume

The required sample volume depends on the amount and type of tests. In below table we summarized the volume (in dm^3) required

Test	Required volume (dm^3)
Density (in-situ)	<0.5
Grain size	0.5
Mineralogy	<0.5
Flocculation	0.5
Density	<0.5
% organic	<0.5
Atterberg limits	0.5
Remoulded shear	0.5
Flow-flume standard	2.0
Flow-flume extra density test (x2)	4.0
Flow-flume extra roughness test (x2)	4.0
Eromes standard	2.0
Eromes extra density test (x2)	4.0
Consolidation	2.0
Total (liters)	**>20**

2.7 Phase 1E Settling velocity tests

Phase 1E will focus on the settling velocity of sediments with different mixtures of sand and mud executed by HR Wallingford. Under this phase tests are executed with remoulded (disturbed) seabed samples. Experiments are executed where suspensions are created by suspending sediment in the water column to create varying sediment concentrations under different shear conditions.

Measurements of settling spectra will then be conducted using LabSFLOC-2 video system. The following experiments are foreseen:

- Number of sites to be examined is anticipated to be approx. 5-7, with an expected number of 5 samples from each site (total 25-35 samples). As an alternative, individual samples from other locations can be included as long as the amount of samples do not exceed 35.
- Baseline samples of pure clay, pure sand and some mixtures with EPS (X-gum) will be undertaken for comparison.
- Measurements are performed for a range of sediment concentrations (approx.. 4) at 3 shear rates, using jar-tests.
- Selection of a number of high resolution 'wet' mixed sediment floc image stills for additional analysis using digital trinocular microscope

2.7.1 Site foreseen

The sites to be investigated are still to be confirmed but are expected to include between 5 and 7 of the following sites: Noordpolderzijl, Tamar Estuary, Holwerd, Western Scheldt, Marker Wadden, RØdsand Lagoon and a site of choice.

2.7.2 Sample Handling

From each grab sample obtained, 0.5 litre of the grab sample will be used (alongside 500 ml of native water) used for the flocculation measurements.

2.7.3 Analysis of floc characteristics

Measurements of settling spectra will then be conducted using the LabSFLOC-2 video system. Data outputs will comprise mass-balanced spectra of individual:

- floc size
- settling velocity
- effective density
- floc mass
- floc shape
- floc porosity
- floc mass settling flux.

Data will be plotted and floc parameters are summarised in tables. All protocols, data processing, results, etc will be collated in a MUSA data report, created by HRW.

2.7.4 Total numbers of tests and required time.

It is envisaged that 15 tests per sample will be undertaken and that 5 samples will be tested from 5-7 sites. This gives around 400-500 tests in total. The number of days required to complete these tests is yet to be confirmed.

2.8 Phase 1F: Experiments to fill unforeseen knowledge gaps

Under this phase we can do experiments which could provide us more insight in aspects for which additional information is required / lack of knowledge still exists.

To be detailed in next version of this document.

2.9 Totals Phase 1A – 1F

2.9.1 Indication of total manhours required for phase 1A to 1D

The table below summarizes the foreseen experiments as well as the estimated total days per phase, for both the basic package (grey) and the extensive package (green).

Phase	Type of experiments	Number of experiments	Total days WaterProof	Total days HRW
1-A	Flow flume (short bed) Eromes Consolidation	**48** **42** **12**	**87**	
1-B	Flow flume (short bed) Eromes Consolidation	**11** **11** **8**	**22**	
1-C	Wave-Flow flume (short bed)	**11**	**35**	
1-D	Wave-Flow flume (long bed)	**6**	**51**	
1-E	Settling velocity tests	**400-500**		**To be confirmed**
1-F	Unforeseen experiments	**To be determined**		
Total			**195**	

The working days for 1A – 1D are all made by WaterProof personnel and/ or students which are assisting during the experiments. During the experiments LVRS and Deltares provide expert assistance and support. In case Covid allows, the consortium partners are welcomed to assist in the experiments as well for a number of days.

The tests executed under 1E are performed by HR Wallingford.

3 Field measurement campaigns

3.1 Introduction

Presently field measurements are foreseen between May and September 2021. The Covid situation might change the planning of the field measurements as it is impossible to maintain enough distance on board of the foreseen survey vessel and to execute field measurements.

It is foreseen to detail the measurement campaign in February and March 2021 and to discuss the approach during the consortium meeting in April 2021. The exact planning of the measurements will be known in March 2021, the exact experiments to be performed after the consortium meeting in April 2021.

3.2 Measurements foreseen (to be updated)

At least the following measurements are foreseen:

- Measuring concentration profiles and grain size distribution of suspended sediment focusing on the lowest 50 cm above the bed preferably under various tidal and wave conditions
- Measuring settling velocities at a number of locations in the vertical using various methods and based on the results determine best approach:
  - Fipiwitu
  - Settling tube
  - Laser In Situ Scattering and Transmissiometry; Settling Tube (LISST-ST)
  - LabsFLOC2 video system (HRWallingford)
  - Deltares camera (if relevant)
- Measure bed density in the upper part of the bed and perform comparative field tests at sites with soft mud-sand beds using various sampling instruments (e.g. Sonidens, Graviprobe, dropcorer)

Due to the weather conditions, the field measurements will be carried out in summer as much as possible. Due to the possible Influence of biological activity (e.g. a biofilm on the muddy bed), which have a seasonal variation, it may also be relevant to perform field experiments in winter. Whether it is feasible and desirable to do so will be determined in the course of the project.

To allow enough time for the analysis and the implementation of results, the field measurements will be carried out as much as possible in 2021. If it turns out to be either necessary or relevant, some additional measurements can be carried out in spring or summer of 2022 (i.e. an optional measurement campaign).

3.3 Foreseen measurement campaigns

Given the available budget, 6 measurement campaigns of 2 to 3 days are foreseen. These field campaigns are going to be carried out at 2 to 3 different field sites. The exact number of measurements depends on the type of measurements that will be carried out and the location (further away is more costly). Possible locations for field experiments are the Dutch Wadden Sea, in the Western Scheldt and in the Lake IJssel / Marker Wadden, where there is a strong variation in sand-mud composition within a relatively short distance. The decision on what measurements will be carried out at what location will be made in consultation with the consortium.

4 Laboratory facilities, survey vessel and instruments

4.1 Introduction

This section describes the available equipment and facilities that are available for the research and their characteristics.

4.2 Laboratory facilities

The presence of sand and mud affects erosion rates, settling velocities and consolidation. Since a better understanding of all these processes is relevant for improved modelling of sand-mud dynamics, no choice has yet been made on what will be the strongest focus. This will be done based on the literature study and most relevant knowledge gaps. To give an overview of the possibilities, below an overview of the available facilities and the type and number of tests is given.

Available facilities
For this Project the following facilities are available:

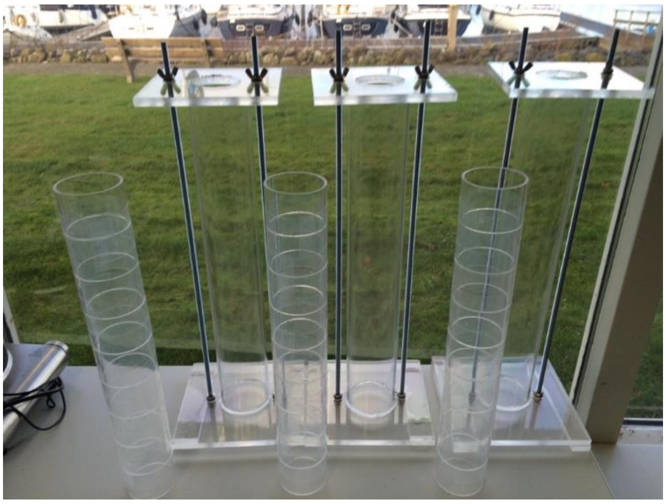
- Current flume, WaterProof
  In this flume, illustrated in the figure below, the erosion of sand-mud mixtures under various flow conditions can be tested. The flume is 5 m long, 30 cm wide and 30 cm high, but the width can be varied based on the sample size or the required current velocities. Current velocities can be increased in steps up to a maximum current velocity of approximately 1.5 m/s, depending on the chosen width and water depth. The water depth is chosen as such that the Froude number of the maximum velocity will always be < 1, to ensure subcritical flow. Flume tests can be performed with both fresh and salt water. The flume floor contains a removable compartment that contains the sediment sample, which allows for e.g. erosion tests for sediment samples of various degrees of consolidation.

- Wave-current flume, WaterProof
  This flume is illustrated in the figure below. It has a length of 14 m, a width of 0.5 m and a height of 0.6 m. Current velocities can be increased up to 1.0 m/s and waves can be generated as high as 0.4 m.

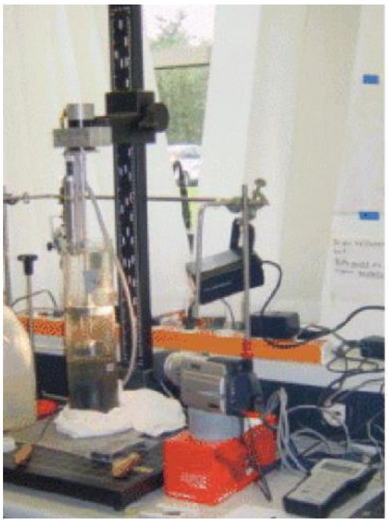
- Settling tubes, WaterProof
  There are settling tubes available to test the settling of sand (column height up to 1.5 m) and mud particles/flocs (column height 0.5 m).

- Grain size analysis, WaterProof
  The grain size distribution of both dry and wet material can be analyzed using the sieve that is illustrated in the figure to the right. In addition, the distribution of fine particles can be determined by settling tests. Concentrations can be determined by filtration.

- Consolidation analysis, WaterProof
  By using consolidation tubes, the distribution of the wet density in the upper 0.5 m of the sediment bed can be measured. Also, the time development of the wet density can be monitored. The consolidation tubes are illustrated in the figure below.

- Eromes, WaterProof
  The resistance of a sediment mixture against erosion can be determined by using the Eromes instrument. This instrument can be used in the laboratory and in the field. It is illustrated in the figures below.




- Gustprobe, Deltares
  The Gustprobe is a small measuring device for carrying out erosion tests. It consists of a cylinder with a diameter of 10 cm and a water column of 10 to 15 cm. A sediment sample can be placed at the bottom of the instrument. A rotating disk at the top of the instrument can bring the water in motion. The resulting shear stress imposed on the sediment sample ranges between 0.03 and 0.6 Pa. Water flows out of the cylinder through an Oslim (i.e. a measuring device for sediment concentrations) and back to the cylinder. In this way the sediment concentration in the water column is measured. The Gustprobe provides the opportunity to test the erodibility of dozens of samples, either directly from the field or prepared in the lab. For example, a wide spectrum of properties can be tested, such as the influence of sand-silt-clay ratios, the degree of consolidation and the influence of the presence of organic material.

- Density measurements (Deltares)
  There are several options available for measuring the density of the top layer (~50 cm) of the sediment bed:

- RheoTune. The RheoTune is a newer version of the Densitune. With this device it is possible to measure vertical density profiles in the subtidal. The RheoTune also provides rheology (yield stress) profiles that could also be useful for estimating erosion.
- SILAS. With the SILAS the 3D spatial variation of the density can be measured. It is a geophysical sub-bottom profiler that is mounted on a boat, like an echosounder.
- DAS fibro-optical measurements (Distributed Acoustic Sensing). The range of this instrument for measurements is 70 km with a sensing distance of every 1 m. You can install several fibro-optical cables in subtidal in order to get a spatial variation. The cable is cheap, but the logging device is relatively expensive.

- Flocculation cameras (HRW and Deltares)
Both at HRW and Deltares flocculation cameras are available for measuring settling velocities. The intention is to carry out flocculation measurements with the camera of HRW and compare those to the settling tube measurements (see also Section **Error! Reference source not found.**). If relevant, also the Deltares camera may be involved.

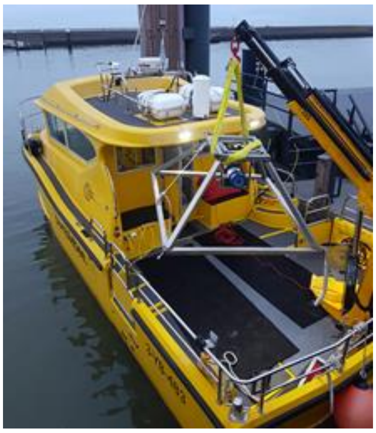
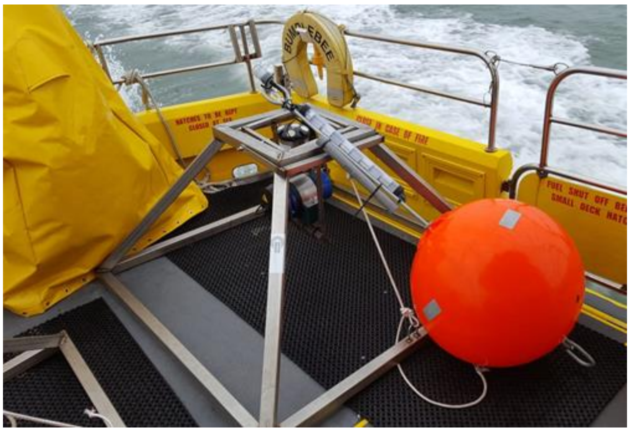
- Additional facilities, Deltares
A few large wave-current flumes are present at Deltares. Although tests at a larger scale have advantages with respect to e.g. the scalability of results, it is not expected that these facilities will be used within the current TKI Project. There is a focus on exploring many different conditions and sediment compositions within this Project, which is feasible in smaller wave-current flumes. It may be relevant to test certain conditions on a larger scale in a potential follow-up project.

4.3 Survey vessel and field instruments

4.3.1 Survey vessel

For carrying out field measurements the measuring vessel Bumblebee is available. This catamaran can sail up to 20 knots, it can beach on shallow areas and has a crane for placing measuring instruments and frames. The vessel is equipped with a frame to carry out ADCP measurements while sailing. There are also various measuring frames available on which instruments can be mounted.

4.3.2 Field instruments

At WaterProof, a number of measuring devices have been developed that can accurately measure the water depth, current speed, sand- and mud concentrations (separately), temperature and salinity. The measurements can be done close to the seabed. The instrument is illustrated in the figures below.


For sediment sampling a Van Veen grab, core sampler and drop core are available. In addition several instruments are available for measuring bed densities (see Section 4.2). For measuring settling velocities, HRW has a flocculation camera available (see Section 4.2), which will be used during several field campaigns. This brings the opportunity to do comparative measurements with both the settling tube and the flocculation camera.

5 Procedures

5.1 Introduction

This section describes the procedures for each experiment.

5.2 Sampling in the field

5.2.1 Procedure remoulded (disturbed) samples:

At each site the samples are taken as follows

- Take samples from the upper 10 cm of the bed as follows
  - Dry flat: using shovel/ scoop
  - Underwater: use Van Veen grab. Remove water (and minimal fines) from samples by slowly draining the water
- Directly during/ after sampling, determine in-situ wet bulk density using density rings (rings with a known volume enabling to determine density):
  - From upper 1 centimeter
  - From upper 2-5 centimeter
  - From mixed sample in bucket
- Fill 25 liter buckets with sediment
- Fill 50 liter jerrycan with water
- Bring sample in water tight bucket to laboratory
- Send 500ml of sample to Andrew Manning. When required by Andrew also 500 ml of native water
- Store samples in a cool dark room protected from sunlight

5.2.2 Procedure placed beds (undisturbed samples):

For the laboratory experiments for which we need placed beds, we take out slices of sediment with a thickness of approx. 10 cm. We use thin stainless steel plates which have the same width as the flow-wave flume and a length of approx. 50 cm. By placing the plates behind each other a bed with length of 3-5 m can be created.

Exact method of execution is further detailed during project execution

5.2.3 Instruments used:

If dry: shovel / scoop
If underwater: Van Veen grab

5.3 In-situ wet density

5.3.1 Procedure:

- Determine volume and weight of empty jar / density ring (V_1, M_1)
  - Weigh 5 times, weight = average weight (to limit scale variations)
- Fill 5 pots / rings to the brim with sediment from in-situ sample and determine average weight (M_2)
  - Weigh 5 times, weight = average weight (to limit scale variations)
- Determine wet bulk density: $\rho_{wet} = (M_2 - M_1) / V_1$
- Determine dry bulk density using formula: $\rho_{dry} = (\rho_{wet} - \rho_w) / (1- \rho_w / \rho_s)$

Here is: ρ_w sea water density (~ 1022 kg / m3), ρ_s sediment density (~ 2650 kg / m3)

5.3.2 Instruments used:

- 60 – 80 ml jars or density rings
- Scientific scale

5.4 Grain size analysis, > 63 µm

5.4.1 Procedure:

- Determine and record the dry weight of the sample (e.g. aluminum dish with dried sediment) with an accurate scale (Kern brand).
- Determine which sieves will be used and check the permeability of these sieves. If the permeability is not sufficient, clean using the ultrasonic water bath.
- Unscrew the lid from the top sieve. Sprinkle the sample (tray of dried sediment) over the top sieve (coarsest mesh).
- Tighten the screws so that they do not come loose when the sieve is vibrating.
- Plug the strainer into the wall socket and switch the strainer on with the “Run stop” button.
- Use the settings: Amplitude = 3mm, time = 10 min, interval = 0
- For each sieve (10 in total, e.g. with meshes 4mm, 2mm, 1mm, 500µm, 250µm, 125µm, 63µm, 45µm and <45µm) take a separate aluminum dish and number it with any sieve size. Of these meshes, meshes of 2mm, 63µm and <45µm always have to be used.
- After 10 minutes the sieving process is finished and the lid can be removed.
- Take the top sieve and turn it over a white A3 or A4 sheet. Place the sieve upright next to the paper. The sediment that has fallen on the paper can now be poured from the paper into the numbered aluminum tray (bend the paper and make a slot).
- When the paper is empty, turn the sieve over the paper again and let the entire edge of the sieve touch the paper at the same time (harder blow than in previous step) to release any remaining sediment. Then use a small brush and wipe it over the back of the sieve to get the last part of the sediment out. Empty the paper back into the aluminum tray. If any sediment remains after this step, leave it in! This is a small measurement error that is passed on every test and has no significant influence on the results.
- Weigh the aluminum tray and record the weight (3 times). Use grain size curve excel to determine the D50.
- Repeat steps 8 through 13, but now for the sieves with finer meshes around the given D50. Record all weights and make a figure where the weight is plotted against the grain size.
- After approximately 10 tests, or when the permeability of the sieves after the test has been greatly reduced, clean the sieves in the ultrasonic bath

5.4.2 Instruments used:

- Sieve machine (Haver & Boecker)
- Scientific scale
- Ear protection

5.5 Grain size analysis, < 63 µm

5.5.1 Procedure

Via Hydrometer test, based on ASTM D4221 – 18, D7928

- dry sediment sample of about 100-300 gr on tray in oven (temperature of 150 °C); use larger sample mass for very sandy samples
- weigh dry sample of:
  - 30 g (mass Mtotal) when % sand is 0-30%;
  - 50 g (mass Mtotal) when % sand is 30-70%;
  - 150 g (mass Mtotal) when % sand is 70-100%;

- put dry sample in measuring glass with 125 ml-deflocculant + 400 ml distilled water; wait minimal 16 hours for complete deflocculation (use ultra-sonic vibration of 20 minutes in water bath if flocs are still present in suspension); The dispersing agent (deflocculant) is a mixture of sodium hexametaphosphate (S) and Natriumcarbonate (N), known as CALGON. We use the reference standard solution of 4.2% (35 g S+ 7 g N in 1 liter of distilled water).
- wash sample over 63-μm sieve using distilled water (with minimum distilled water, maximum 400 ml);
- wash sand fraction in glass; dry and weigh sample (M_{sand})
- put mud-residue into measuring glass and add distilled water until volume of 1 liter;
- mass mud fraction is M_{total}-M_{sand}; initial mud concentration is c=(M_{total}-M_{sand})/liter (range of 10 to 25 g/l)
- prepare the basin with water, place the water pump; this brings the basin to a constant temperature of 21.4 C.
- make a blank suspension of 1 liter of distilled water, place it in the basin and perform a reading when the temperature is 21.4 C; This measurement is for the hydrometer calibration.
- make a blank suspension of 1 liter of distilled water with 4.2% solution, place it in the basin and perform a reading when the temperature is 21.4 C; This measurement is for the hydrometer calibration.
- shake/stir mud fraction in glass cylinder for 15 minutes;
- perform hydrometer test with readings at 18, 40 s, 2, 5, 15, 30 min, 1, 4, 24 hours;
    1. insert the hydrometer directly after the shaking and start the timer
    2. leave the hydrometer in the tube for the first 3 readings (max 2 min)
    3. carefully take out the hydrometer (minimal disturbance), rinse with distilled water and place in the blank suspension to keep it at the desired temperature
    4. insert the hydrometer 30 s before each reading moment (with minimal disturbance)
    5. repeat step 3 and 4 until all readings have been done
- compute settling velocities $w_{s,i}$= h_i/t_i with hi= distance between fluid surface and middle of float at time t_i (based on calibration curve). Use the calibration sheet of the hydrometers to work out the results;
- Then together with the results of the sieve curve of the sand, make a full grain size curve of the sample.

5.5.2 Instruments used:

- Glass graduated cylinder (1 L)
- Mixing rod (perforated at the end)
- Calgon
- Distilled water
- 63 -μm sieve
- Hydrometer

5.6 Grain size analysis, < 63 μm

5.6.1 Procedure:

Via Settling test

- Prepare a sludge mix in a bucket with a high concentration (sand + sludge> 10000 mg / L) and determine the concentration by means of a filtering process (see filtering procedure);
    - dry sediment sample of about 100-300 gr on tray in oven (temperature of 150 °C); use larger sample mass for very sandy samples

- weigh dry sample of:
  - 30 g (mass Mtotal) when % sand is 0-30%;
  - 50 g (mass Mtotal) when % sand is 30-70%;
  - 150 g (mass M_{total}) when % sand is 70-100%;
- put dry sample in measuring glass with 125 ml-deflocculant + 400 ml distilled water; wait minimal 16 hours for complete deflocculation (use ultra-sonic vibration of 20 minutes in water bath if flocs are still present in suspension); The dispersing agent (deflocculant) is a mixture of sodium hexametaphosphate (S) and Natriumcarbonate (N), known as CALGON. We use the reference standard solution of 4.2% (35 g S+ 7 g N in 1 liter of distilled water).
- wash sample over 63-μm sieve using distilled water (with minimum distilled water, maximum 400 ml);
- wash sand fraction in glass; dry and weigh sample (M_{sand})
- put mud-residue into measuring glass and add distilled water until volume of 1 liter;
- mass mud fraction is M_{total}-M_{sand}; initial mud concentration is c=(M_{total}-M_{sand})/liter (range of 10 to 25 g/l)

- Optionally, the suspension used in the Hydrometer test can be used as a base concentration.
- The desired concentration for the settling test is 500 mg / L.
- If the concentration of the mix in the bucket is known, calculate the number of ml needed to create the desired concentration for the settling test to be performed. To prepare the desired concentration, use a small measuring cup (100 ml) and measuring cylinder (1L) to keep track of the amount of sludge mix. Then fill a bucket / measuring cup (2L) with the calculated amount of sludge mix and make up to 2 L with sea water.
- Fill the settling tube with the new concentration mix (2L).
- Record the initial height of the water limit in the pipe on the corresponding measurement form "Measurement form settling speed". Prepare 100 ml graduated cylinders. These measuring cylinders must be numbered from 1 to 9. Also prepare aluminum containers with filter papers in them. Number both and weigh the filter papers 5 times. Record the weight on the measurement form.
- Mix everything in the tube well with the stir bar (stick with pat flat at the end with holes) by moving up and down. Do that for exactly 1 minute. And make a note of the start time of the measurement once mixing is complete.
- After mixing, once the rod is out of the tube, sample 1 of approximately 30-50 ml can be taken in the small numbered graduated cylinders (100 ml) by opening the stopcock at the bottom of the tube. At the same time, the stopwatch must be turned on. (Hold the tube firmly, this requires two people). Record the new height of the water limit and the water volume of the measuring cylinders on the measurement form.
- Take all samples as in step 6. Follow the times on the measurement form (t = 0, 2, 5, 15, 30, 60, 240, 1440 minutes) at which samples must be taken and keep the time in the correct holes. The times can be extended
- After taking an x number of samples they can be filtered (see filtration procedure). Make sure that the correct samples in the measuring cylinders end up with the correct filter papers!
- Work out the results and together with the results of the sieve curve of the sand in, make a full grain size curve of the sample.

5.6.2 Instruments used:

- Settling tubes
- Graduated cylinders (100 ml)
- Mixing rod (perforated at the end)
- Filtration necessities

5.7 Determine sediment concentration by filtration

5.7.1 Procedure:

- Number and weigh the 63 µm sieves
    - Weigh 5 times to minimize weighing error
- Number nylon filters (with ballpoint pen) and weigh empty
    - Weigh 5 times to minimize weighing error
- Weigh the sample: bottle + lid filled water and sediment
    - Weigh 5 times to minimize weighing error
- Shake the bottle + lid well with water and sediment and pour into a 2 liter measuring cylinder
- Weigh empty bottle with lid
- Place pre-numbered filter paper in filter setup
- Carefully pour graduated cylinder in steps over 63-um sieve (fixed in the collection glass of the filtering unit) to separate sand fraction; rinse strainer and measuring cylinder with spray bottle (if necessary)
- Switch on the vacuum pump
- 63 µm sieve with sand + filter paper with sludge drying in oven (at 50 ° C)
- Weigh 63 µm sieve immediately after removal from oven (remove sand from sieve with a small brush and store in a jar; 1 jar for all sand samples)
- Weigh filter paper immediately after removal from oven
- Work out the results in a table, for determination of sand and silt concentration.

5.7.2 Instruments used:

- Filtration paper (Whatman, pore size 0.45 um)
- 63 µm sieves
- Filtration setup

5.8 Mineralogy

5.8.1 Procedure:

To be specified at a later stage by Wiertsema laboratory

5.8.2 Instruments used:

To be specified at a later stage by Wiertsema laboratory

5.9 Floc characterisation

5.9.1 Procedure:

Two instruments designed by A. Manning/ HR Wallingford will be used: an instrument for measuring the flocculation characteristics in the laboratory (LabSFLOC) and its field counterpart (INSSEV-LF). These instruments are described below.

The LabSFLOC – Laboratory Spectral Flocculation Characteristics – instrument (Manning et al., 2017), developed by Professor Andrew J Manning, is a laboratory derivation of the earlier in situ INSSEV instrument (Manning and Dyer, 2002) that enables floc properties to be measured in laboratory studies routinely using suspended particulate matter (SPM) concentrations of several 10’s g.l-1 (and often as high as 100-200 g.l-1 depending upon the suspension composition). LabSFLOC-2 (version 2) utilizes a low-intrusive, high-resolution, monochrome digital video camera to observe flocs as they settle in a 320 mm high settling column constructed of Perspex (square section of 100 x 100 mm).

The camera is fitted with a Sill TZM 1560 Telecentric lens to minimise any pixel distortion (pixel resolution ~5 µm). LabSFLOC utilises a homogeneous blue (470 nm) LED back-illumination system (located at the rear of the settling column), whereby floc images are manifested as silhouettes; i.e., particles appear to be dark on a light background. This reduces image smearing and renders the floc structure more visible. A floc sample is carefully extracted from its original environment (e.g., a jar, a flume, a water sampler, etc) and is immediately transferred to the column (filled with clear water of a similar salinity as the ambient conditions) using a modified pipette (Manning, 2006).
The LabSFLOC floc collection and sub-sampling protocols are both proven floc sampling techniques (see Manning, 2006; Manning et al., 2010a, b; Mehta et al., 2009), which permit minimal floc interference and flocs which are representative of the ambient population – especially in terms of floc size and settling velocity distributions. The floc sampling techniques also provide control volumes, which permit settling flux estimations (see later comments). The video camera, the centre of which is positioned 75 mm above the base of the column, views all particles in the centre of the column as they settle from within a predetermined sampling volume. All of the flocs viewed by the LabSFLOC video camera (within a specified optical control volume), for each sample, are measured both for floc size and settling velocity. Clear, grey-scale, 2-D optical images of the flocs are recorded by the video suite to a laptop. LabSFLOC-2 can measure floc sizes of 8 mm in diameter and settling velocities approaching 45 mm.s–1, providing the flexibility to measure both pure mud and mud–sand mixed sediment floc dynamics (Manning et al., 2010, 2013). By implementing a sequence of proven image-analysis algorithms (e.g. Manning, 2004), the individual floc porosity, fractal dimensions, floc dry mass and the mass settling flux distribution (e.g. Manning and Dyer, 2007; Soulsby et al., 2013; Manning et al., 2008) of a floc population can be computed. The calculated dry floc mass also can be accurately compared (i.e. mass-referenced and mass-balanced) with the measured suspended particulate matter concentration, thus providing an estimate of the efficiency and reliability of each sampling procedure (Manning et al., 2017). It follows that the data obtained from LabSFLOC is both qualitative and quantitative, and has been utilised in numerous published cohesive sedimentary research studies (e.g. Gratiot and Manning, 2007; Malarkey et al., 2015; Manning and Dyer, 1999; Manning et al., 2007; Mehta et al., 2014; Mietta et al., 2009; Spearman et al., 2020; Ye et al., 2020; Zhang et al., 2018).

The portability of the LabSFLOC instrument has led to the development of the INSSEV-LF: IN-Situ Settling Velocity instrument (see Manning et al., 2017). The INSSEV-LF permits floc samples to be collected in a field deployment scenario with a much greater easy and flexibility, but with an equally high standard of floc data quality, as the original INSSEV system. The LF (LabSFLOC) version of INSSEV is a hybrid system that combines two key components: (1), the low-intrusive LabSFLOC system and (2), an in situ estuarine floc sampling acquisition unit (to initially obtain the suspension sample). For the latter, a 2.2 l van Dorn horizontal sampling tube or Niskin tube with a 10–14 kg weight suspended from the underside of the tube have typically been used to collect a water sample at a nominal height above the estuary bed. For example Prof. Manning has deployed the INSSEV-LF configuration throughout San Francisco Bay and the Northern Californian River Delta (Manning and Schoellhamer, 2013) and in Upper Klamath Lake in Oregon, USA with the US Geological Survey and also Stanford University (2008-present); in the coastline north of Den Haag as part of STRAINS-II Megapex project with TU Delft and University of Washington (2015); and most recently in the Elbe Estuary as part of the Elbe-Dollard 2050 sustainability project with Deltares, Royal Haskoning and University of Maine USA (2018-19), and throughout the Port of Rotterdam assessing nautical depth associated with fluid mud from dredging activities with Deltares and Port of Rotterdam surveyors (2019-present).

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5.9.2 Instruments used:

The instruments are described in the previous section.

5.10 Atterberg limits test

5.10.1 Procedure:

To be specified at a later stage by Deltares/Wiertsema

5.10.2 Instruments used:

To be specified at a later stage by Deltares/Wiertsema

5.11 Remoulded shear test

5.11.1 Procedure:

To be specified at a later stage by Deltares

5.11.2 Instruments used:

To be specified at a later stage by Deltares

5.12 Flow-flume erosion test

5.12.1 Procedure:

Sample preparation

Start by preparing the sample as it has to settle for 24 hours before being tested.

- Stir the sample to a homogeneous composition
- Determine the density of the sample with a 71ml density spot.
- Use the pot scraper to fill the stainless steel sample container with the sludge mix. Make sure that it protrudes about 5cm above so that it can be leveled just before use.
- Place the stainless steel edge on the tray and tape it off.
- Put the stainless steel composition in a container and fill it carefully with water so as not to disturb the sludge surface. So also fill the stainless steel containers.
- Leave this for 24 hours to settle.

Preparation flume

- Before filling the flume, it must be completely clean. In addition to the inflow and outflow trough, do not forget to flush the transport pipe and drain to remove any algae or sludge.
- Fill the flume to 13 cm water depth in the flume with the tap at the outflow trough.
- Because each segment is equipped with a tap, the inflow and outflow troughs can be connected to each other to fill them simultaneously.
- Make sure the orange PVC ball valve is closed. You only open this to drain the water.
- Open the steel ball valves of the inflow and outflow trough, this will link both troughs together.
- Open the ball valve on the transport tube, it can also fill immediately to prevent any air bubbles in the system.
- Adjust the flume wall and bottom to the correct setting before the pump is started. Chances of damage are greater if they are not properly attached.
- Place the Vectrino or EMV centrally in the first part of the gutter using the appropriate bracket.

- The EMV measures at the exact height of the measuring head itself. Hang this at 40% of the water depth to measure the average flow rate
    - The Vectrino measures by means of an electromagnetic (this means that it measures 3 cm below the measuring head. So the measuring head must be placed 3 cm above 40% water depth to detect the average flow velocity.
- Place the OBS (AQUADOPP) just before the hatch near the outflow, attaching it to the wall with its suction cups.
    - Use the standard settings to set-up the programs on the computer. Always check if the program
        - Connects to the devices
        - Saves the recordings at the correct location
        - Saves both in binary and in ascii as a back-up
- Place the webcam such that the sample will be clearly visible, so a video of the flume tests can be taken.
- Flush the flume to remove any large air bubbles in the system.

Placement of sample

When the flume is ready and tested (no large air bubbles anymore), the sample can be placed in the flume.

- Lower the water level to just below the flume floor by turning on the orange PVC ball valve
- Remove the stainless steel edge from the stainless steel tray and place the tray in the flume.
- Smooth the sediment surface and make sure it is level with the bottom.
- Now fill the gutter to 13cm water depth. Do this slowly to avoid any soil agitation. It is important here that both tanks fill evenly and simultaneously to prevent flow. So check again whether the valves are set correctly. (Orange PVC ball valve closed, both ball valves of the inlet and outlet trough open)
- When the water is at the right level, the test can be started.

Flume test

- Start test by gradually increasing flow velocities in steps of 0.05 m/s per minute
- Determine critical velocities for gradual and mass erosion
- Determine erosion rate during mass erosion phase by measuring erosion volume and considering time over which erosion could take place
- Determine sand transport by emptying sand trap after each 0.05 m/s increase in velocity, if transport of sand is seen
- Measure wet density of remaining part
- Pump turbid water from the flume to settling tank
- Clean flow-flume with water vacuum cleaner

5.12.2 Instruments used:

- ADV (Vectrino) to measure velocities at mid-depth
- OBS to measure concentrations at mid-depth
- Camera to film erosion rates
- Peristaltic pump to empty sand trap

5.13 EROMES test

5.13.1 Procedure:

Sediment preparation

- Check if Eromes tray is watertight and not leaking
- Place a rubber mat in the tray

- Fill the tray with sediment with the required density
- Place the tray in a bucket with water such that the sediment is placed underwater
- Let the tray rest for approx. 12 - 24 hours before the test is executed

EROMES preparation

- Check calibration parameters EROMES;
  - If calibration curve is not known, first determine this relationship for the sediment.
- Increase rotation in steps of 10 with 20 seconds interval
- Place the Plexiglas tube in the sediment until the bottom of the tray, place the metal plate on top of the tube and tighten the screws so that the Plexiglas tube is forced against the bottom and is "watertight"
- Slide down the tin-plate cylinder onto the sediment
- Place the tube under the Eromes and lower the propellor so that the bottom of the propellor is located exactly 3 cm above the sediment
- Fill the tube very slowly with the verderflex pump with fresh water up to the marks on the cylinder. Fill the tube from a measuring cylinder to exactly know the volume of water in the EROMES cylinder (approx. 1,3 liter)
- Check if turbidity sensor has free space (is not directed on the tin-plate cylinder). If not, turn the cylinder to allow the sensor to have free sight
- Set the turbidity sensor at highest sensitivity & set to zero (in the clear water in the cylinder)
- Check if propellor is positioned exactly in the center of Eromes tube
- Remove any air bubbles under the sensor by using the special wiper

Start the test

- Write down the name of the test, type of sediment, date, etc. => fill in the EROMES test form
- Do the tests in steps of 10 for 20 seconds each step
- Describe what you see during the tests and write down the propellor speed

After the test

- Drain the cylinder slowly using a Verdeflex pump
- Take photo of the sediment bed
- Describe how the bed looks like

5.13.2 Instruments used:

- Eromes incl OBS
- Verderflex pump

5.14 Consolidation test

5.14.1 Procedure:

- Determine the wet and dry bulk density
  - Determine volume and weight of empty jar (V_1, M_1)
  - Fill 5 pots to the brim with sediment and determine the average weight (M_2)
  - Determine liquid bulk density: $\rho_{wet} = (M_2 - M_1) / V_1$
  - Determine dry bulk density using formula: $\rho_{dry} = (\rho_{wet} - \rho_w) / (1- \rho_w / \rho_s)$
  - Here is: ρ_w sea water density (~ 1022 kg / m3), ρ_s sediment density (~ 2650 kg / m^3)
- Prepare for each measuring tube (6 in total, volume V_2 = 2 L) a sediment suspension with separate concentrations of C (300, 200, 100, 50, 20 and 10 kg / m3).
- Calculate the amount of sediment needed to create the desired concentration for the settling test to be performed.
- In addition to the required sediment, fill each tube with water up to 2 L limit.

- Mix the sediment suspension with the mixer in the measuring tubes by moving the rod up and down until the sediment is homogeneously distributed over the water column.
- Start the measurement (can be done individually per tube) after the mixing rod has been removed. Read the height of the surface from the tape measure at time t = 0 and write it down on the ”Consolidation Measurement Form”. Also write down any comment in the box next to it.
- Regularly read the height of the separation surface between sediment and water on the tape measure and record the corresponding time on the measurement form.

5.14.2 Instruments used:

- Scientific scale
- Consolidation tubes

6 Database

6.1 Introduction

A database will be set up with relevant parameters on the erosion, settling, sedimentation and consolidation of sand-mud mixtures. The database will be filled with relevant information from the literature analysis, the laboratory tests and the field measurements.1210301-009

6.2 Parameters

A digital database in a suitable format will be set up which includes the metadata and measured sample properties. This will be done for the various tests as conducted for the different phases, as shown in the table below.

Test	**Description**
Sampling sites	Location of field site Sampling date Sampling depth Sampling conditions (weather, tide, flow) Info on water temperature, quality, salinity Sampling instruments Sampling attempts/errors Sampling storage Sampling persons Photographs Etc.
Sample handling / waste	Sampling storage Sampling transportation
Grain size (> 63µm)	Sieve curve per sample
Hydrometer (< 63µm)	Fall velocity per sample
Fall velocity (< 63µm)	Idem, including difference analysis
Mineralogy	Composition (external lab)
Flocculation (most clay-rich)	See description Andrew Manning (Section 5.9)
Density	Density
% organic	Organic content
Atterberg limits	Atterberg limits
Remoulded shear strength	Remoulded shear strength
Flow-flume/Wave-flow flume (short and long bed)	Overall flume configuration description Flow rates Water depths Critical bed shear stress for erosion Type of erosion (e.g. gradual/mass) Photographs (initial, during, final) Suspended sediment concentrations
Eromes	Critical bed shear stress for erosion
Consolidation	Consolidation parameters

The database will be updated each time additional data from the field and laboratory experiments becomes available, with proper version management.